Integrated assessment of adaptation to Climate change in Flevoland at the farm and regional level

Joost Wolf, Maryia Mandryk, Argyris Kanellopoulos,

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ABSTRACT

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A key objective of the AgriAdapt project is to assess climate change impacts on agriculture including adaptation at regional and farm type level in combination with market and technological changes. More specifically, the developed methodologies 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 to arable farming in Flevoland, the Netherlands as the key case. 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 in 2050 with different methods (i.e. Sensitivity analyses at farm level, and Data envelopment analysis), including the aggregation to the regional level . Results from the application of the different methodologies are presented.

Some of the many results from the project include:
a) A method to assess farm structural change at regional and farm level towards 2050 has been developed and applied. This analysis shows that historical trends, consistent scenario assumptions and stakeholder involvement can be used to derive plausible images of arable farms towards 2050. The farm images provide a proper basis for assessing the impacts of and adaptation to climate change in 2050 at a more detailed level.

b) A method for the calculation of yields, as a result of climate change, increased genetic potential of cultivars and closing yield gaps for the different scenarios in 2050 has been developed and applied. The calculated future yields of the main crop types in Flevoland are subject to a range of uncertain factors. Results reveal that assumptions on the increase in genetic yield potential are most important. Second, the effects of climate change and increased atmospheric CO_2 are also rather important. Finally, the effects of both adaptation and closure of the yield gap are smallest.

c) Sensitivity analyses for the main arable farm types in Flevoland show that the differences in gross margin per labour hour in future farming are mainly determined by first, the increases in input and product prices from 2005 to 2050 and second, the yield increase from 2005 to 2050.

d) Results from exploring farming systems in Flevoland using the data envelopment analysis show that the most important driving factors towards 2050 within the A1-W scenario with a globalized economy are the yield increase due to climate change, the expected price change and the degree of innovation in crop productivity. The effects of climate change are projected to have a positive economic effect on arable farming. However, a substantial increase in inputs for crop protection, fertilizers, and energy is also simulated. Increase of those inputs combined with a shift of production to other arable crops (mainly tulips and vegetables) can lead to additional environmental pressure per ha but not per ton of product.

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Contents

Summary

A key objective of the AgriAdapt project is the assessment of Climate change impacts on agriculture including adaptation at regional and farm type level in combination with changes in other drivers (e.g. markets). Different methodologies have been developed and applied to (a) to assess the 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) evaluate adaptation strategies at farm type and regional scale.

The methodologies have been applied to arable farming in Flevoland, the Netherlands as the key case study to demonstrate the approach. The methodologies cover the following main topics, as described in the following: (a) Integrated sustainability assessment and the linkage and integration of different methodologies, (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 the main arable farming systems in Flevoland and of arable farming in Flevoland as a whole with different methods (i.e. Sensitivity analysis at farm level, and Data envelopment analysis) for 2050.

Chapters 3-9 of the report present first, briefly the different methodologies and next, the results attained within the AgriAdapt project and an evaluation of these results. For more detailed information about the applied methodologies, see AgriAdapt report no. 1 with the applied methodologies.

Chapter 2 describes the integrated sustainability assessment as applied within AgriAdapt, showing how the different methodologies are linked and integrated. We have used different methods for different questions, to assess the impacts of different drivers (e.g. climate change, policies, market, technology), and the most effective adaptation strategies. Different methods complement each other, and together they provide a detailed picture of pathways to a climate robust agriculture in the future. Next, this report gives a description of the results from the different methodologies (from Chapter 3 onwards). The assessments have been done at two levels, crop level and farm (+ regional) level, and for mainly two levels of integrating the driving factors in 2050, i.e., either climate change effects alone (2050-CC-only) or changes in climate, agro-management, crop productivity, markets and policy environment combined (2050-CC-P-T) . Two SRES emission scenarios, A1FI and B2 (IPCC, 2001), and related KNMI climate change scenarios, W (or W+) and G (or G+), for the Netherlands have been used, resulting in e.g. the A1-W and B2-G scenarios. Stakeholders have been consulted to define specific questions to analyse.

We refer to Chapter 2 covering the integrated sustainability assessment, for a comprehensive overview of the results from the AgriAdapt project. Some of the many results from the project include:

a) A method to assess farm structural change at regional and farm level towards 2050 has been developed and applied. For this we used historical analysis (statistics based)

combined with hierarchical scenario analysis to project regional structural changes. We have developed transition rules to downscale the regional results to the farm type level. The analysis shows that historical trends, consistent scenario assumptions and stakeholder involvement can be used to derive plausible images of arable farms towards 2050. These future farm images provide a proper basis for detailed assessment of impacts of and adaptation to climate change. The scenarios we developed and the method to derive them can be re-used in other regions in the Netherlands or elsewhere in Europe.

b) A method for the calculation of yields for the different scenarios in 2050 has been developed and applied. The future yields of the main crop types in Flevoland are calculated in a straightforward way, but are dependent on several assumptions (e.g. increase in yield potential towards 2050) and uncertain data (e.g. weather data for 2050) and hence, are affected by uncertainty.

c) Sensitivity analyses for the main arable farm types in Flevoland and the different scenarios show that the differences in gross margin per labour hour in farming are mainly determined by first, the increase in product and input prices from 2005 to 2050 (and in particular, the degree that the product price increases are lower than the increases in costs) and second, the yield increase from 2005 to 2050. Results show that only for the 2050-A1-W-P-T scenario (i.e. A1-W scenario for 2050 combined with all other changes) with the highest yields and best management in 2050, the gross margins per labour hour, when expressed in euros of 2005, are higher than those in the Base year for all farm types.

d) Results from exploring farming systems in Flevoland and adaptation strategies to climate change using the data envelopment analysis, show that the most important driving factors towards 2050 (within the A1-W scenario with a globalized economy and strong climate change), are the yield increase due to climate change, the expected price change and the degree of technological innovation focused on crop productivity. The effects of climate change are projected to have a positive economic effect on arable farming. However, a substantial increase in inputs for crop protection, fertilizers, and energy is also simulated. Increase of those inputs combined with a shift of production to other arable crops (mainly tulips and vegetables), can lead to additional environmental pressure per ha. Nevertheless, the environmental pressure per ton of product is projected to decrease.

1 Introduction

A key objective of the AgriAdapt project is to assess climate change impacts on agriculture including adaptation at regional and farm type level in combination with market changes. More specifically, we have applied methodologies that 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 assessments are meant to 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 climate 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 climate change provide opportunities for agriculture?

Results from application of the different methodologies are described in this report. For each methodology its results are described in a separate chapter which covers the following:

- Short description of the methodology
- Results from application of the methodology
- Evaluation of the results

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

- Integrated sustainability assessment (Chapter 2), and the linkage and integration of different methodologies; this chapter also gives an overview of the main work in and results from the project
- Development of scenarios of farm structural change towards 2050 (Chapter 3)
- Calculation of crops yields for different scenarios in 2050 inclusive agro-climate calendars and analysis of the effects of extreme events (Chapters 4, 5, 6 and 7)
- Partial and fully integrated analysis of the main arable farming systems in Flevoland and of arable farming in Flevoland as a whole with different

methods (i.e. Sensitivity analysis at farm level, and Data envelopment analysis) for 2050 (Chapters 8 and 9).

2 Integrated sustainability assessment

M.K. van Ittersum, P. Reidsma & J. Wolf

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, 2006; Bohunovsky et al., 2011).

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 climate 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 climate change, but also on changes in technology, policy and markets. Drivers act at multiple scale with climate change impacting the farm level mainly through the crop level (assuming that sea-level rise can be controlled at higher hierarchical levels), while other drivers (such as markets and policies) act at regional to global level.

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 have been done at lower and higher levels for an integrated assessment.

2.2 Envisioning: scenarios and visions

In this project we have opted for two types of analysis of impacts of and adaptations to climate change in 2050:

1. Projecting climate change of 2050 on present arable farming systems in Flevoland, with their present layout, agro-management and productivity, markets and policies – 2050 climate change only analysis (‘***2050-CC-only***’).
2. Projecting climate change of 2050 on images of future arable farms in Flevoland, in alternative future scenarios (2050) of agro-management and productivity, markets and policy environment, which includes improved crop cultivars and management (i.e. improved Technology → T) and changes in Prices (i.e. P) – 2050 integrated analysis (‘***2050-CC-P-T***’).

Both were assessed against the Base year analysis. In the 2050 integrated scenario we aimed at assessing climate change in the context of technological, socio-economic (markets) and political changes towards 2050. This is relevant as climate change is only one of the drivers of agricultural systems in 2050; these other factors influence for instance the development of crop yields, prices and farm structure.

2.2.1 Base year analysis

A typology of farms was specified for Flevoland, based on the farm typology developed in the SEAMLES project, using the dimensions size, intensity, specialization and orientation of farms. For the Base year potential crop yields (as dependent on climate and CO_2 concentration) are for about year 2000, actual yields (from CBS) are for about year 2005, and most input data and costs for arable cropping are from KWIN (2009) and are averages for 2003-2007, all prices include VAT, and total variable costs include costs for contract work, taxes, energy, N, P and K fertilizers, and crop protection.

2.2.2 2050 climate change only analysis

In the 2050-CC-only scenario, climate change was assessed in the context of two contrasting SRES scenario, i.e. A1FI and B2. For the climate change in Flevoland, we used the weather data sets for present and 2050 conditions from KNMI for Lelystad, Netherlands: A1FI was associated to the W and W+ scenarios (+2°C) and B2 to the G and G+ (+1°C) scenarios of KNMI (Van den Hurk et al., 2006; see for more information http://www.knmi.nl/climatescenarios/knmi06/index.php). Future CO_2 concentrations are combined with these KNMI climate scenarios for 2050) and are derived from the SRES emission scenarios in the IPCC assessment report from 2001 (Scientific basis, Appendix II, Table II.2.1 with CO_2 abundances). See the link: http://www.grida.no/publications/other/ipcc_tar/ We have used the CO_2 concentrations from the ISAM model (Jain et al., 1994) for 2050 for first the high emission scenario A1FI (or called ***A1*** in the rest of this report) and second, the low emission scenario B2, being respectively 567 and 478 μmol CO2/mol, and for the baseyear, we have used 369 μmol CO2/mol. ***We have mainly applied two climate change scenarios, A1-W and B2-G, of which the scenario characteristics are indicated by, for example, 2050-A1-W-only (i.e. climate change only), 2050-A1-W-P-T (i.e. integrated analysis with price and technology effects included too), 2050-B2-G-only, etc.***

2.2.3 2050 integrated analysis

For the 2050 integrated analysis we used a combination of the socio-economic and emission scenarios A1FI and B2 and related climate change scenarios (see above). We made this operational through three analyses for these two scenarios:

1. An assessment of the relative influence of climate change on markets of agricultural commodities in 2050 (global, EU and national level analysis)

2. Drafting images of future farms in Flevoland for the year 2050 using the typology that was also used for the baseyear.
3. Making explicit estimations of technological change towards 2050, i.e. progress in genetic potentials of crops and yield gap closure.

In this way we were able to put climate change in the context of market (and policy) changes, changes in farm structure and technological progress.

Here we briefly present the methods and results for each of these three analyses.

Relative influence of climate change on markets in the EU

The effects of climate change on markets and prices of agricultural products have been calculated with the CAPRI model (Britz, 2005). CAPRI consists of two major modules. The supply module consists of independent aggregate non-linear programming models representing activities of all farmers at regional or farm type level captured by the Economic Accounts for Agriculture. The market module is a

Table 2.1 Description of CAPRI scenarios

	Base year [2004]	**B1 (Baseline) [2050]**	**B2 [2050]**	**A1_b1 [2050]**	**A1_b2 [2050]**	**A1_b3 [2050]**
Exogenous assumptions	Observed data (average 2003 - 2005) taken from EuroStat, FAO, OECD etc.	Inflation rate of 1.9% per year				
		constant exchange rates				
		Projection of GDP according to ???? Projection of population (growth) according to ?????	Derived from IMPACT scenarios (decreasing demand for agricultural products)	Derived from IMPACT scenarios (leading to increasing demand for agricultural products compared to B2)		
Commodity Prices	Observed prices (average 2003 - 2005)	Extrapolated from market outlooks (European Commisssion and IFPRI)	Simulation results			
Input Prices	Observed prices (average 2003 - 2005)	Extrapolated from market outlooks (constant in all simulations)				
Yield	Observed yields (average 2003 - 2005)	Trend projection combined with APES simulation (BCCR_BCM2_0/SRES B1 - less warming consistent across all European regions and seasons)	Apes siumlation (Pattern-scaled SRES B2 15-model ensemble mean)	Apes siumlation ·(SRES A1B 15-model ensemble mean)	Apes siumlation (MIROC3.2(hires)/SRES A1B more warming consistent across all European regions and seasons)	Apes siumlation (GISS_MODEL_E_H/SRES A1B - dry in MED and NEU)
Set-aside and quota policies	With obligatory set-aside and quota (milk and sugar)	Abolishing obligatory set-aside, expiry of milk quota, continuation of sugar quota				
Premium scheme	2003 CAP reform (decoupled + partially coupled payment)	2009 Health Check (decoupled payment, increased modulation)				
WTO trade policy	Tariffs and TRQ as in 2004	Tariffs and TRQ as in 2004		Reduction of tariffs and expansion of TRQ (sensitive products) as proposed by Falconer (2010)		

spatial, non-stochastic global multi-commodity model for about 40 primary and processed agricultural products, covering about 40 countries or country blocks in 27 trading blocks. Bi-lateral trade flows and attached prices are modelled based on the Armington assumptions. There are three types of scenario parameters applied to one CAPRI scenario in this study. The first type of parameters defines the regional crop yields derived from the crop growth simulations. The second type of parameters allude to the macroeconomic environment namely population and GDP growth. They were taken from older IMPACT simulation. Finally, also assumptions of climate effects on yields in the rest of the world had to be reflected. Unfortunately, there are not yet many studies assessing the effects of climate change on crop yields on a global level. We used a background note in the world development report by Müller et al. (2010). A summary of the CAPRI settings is given in Table 2.1 for the scenarios, for which the market and price changes towards 2050 have been established. Note that these price changes have been determined for more scenarios than subsequently used in the farm analyses (i.e. A1_b1 or A1 and B2). More information about this work can be found in the AgriAdapt report by Ewert et al. (2011).

Images of future farms in Flevoland

Images of future arable farms in Flevoland have been developed using a semi-quantitative method complemented with iterative feedback from stakeholders during two workshops in March 2010 and February 2011. These visions have been developed within two contrasting scenarios of development for the globe, Europe, The Netherlands and Flevoland. For this purpose, the two global SRES scenarios were 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 downscaling used trends in socio-economic developments as used in detailed scenarios that were developed quite recently for the future of rural Europe (Westhoek et al. 2006). We used the outcomes of the work of Riedijk et al. (2007) to assess future land use in Flevoland under future socio-economic and climate scenarios. For climate change towards 2050 we used the A1-W and B2-G scenarios, as described above.

Within these scenarios images of future farms have been developed using a combination of a quantitative analysis and stakeholder input and feedback (Chapter 3). This delivered possible future farms and their distribution for the two alternative scenarios for 2050. The farm typology of current farms (based on size, intensity, specialization and orientations of farms) was used as a basis. 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. 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.

In A1-W scenario the average farm size may increase from 95 to 118 NGE due to increase in crop productivity and shift to more profitable crops. Since area is a limited factor in Flevoland, and there have been increases in farm size in NGE, we observe further intensification. In specialization we assess a shift towards crops with high standard gross margin (flower bulbs and vegetables) and energy crops (these crops are part of diverse arable specialization). In terms of orientation there is projected to be a larger share of entrepreneurial farms (around 30% of total farm population). Increase in share of entrepreneurial, or multifunctional farming happens, since farmers seek alternative sources of income (e.g. recreation, processing and selling own products) due to changes in the agricultural policy paradigm (abolishment of payments and little alternative subsidies).

In B2-G scenario we assess a larger diversity in farming the landscape. We estimate that average farm size (economic and area) only slightly increases and remains close to the current level. No major changes are expected in the specialization of the farms either. Regarding orientation, a large share of nature conservation farms will be notable for the B2-G scenario (around 30% of the farms will do nature and landscape conservation). This comes when subsidies exceed gross margin of crops and the activity is more profitable, as the level of payment for social and environmental services will be increased in the B2-G scenario.

The most important farm type in the A1-W scenario is production oriented-very large-medium intensive-diverse mainly root crops. In the B2-G scenario it is entrepreneur oriented-large-medium intensive-diverse mainly root crops and specialized root crops.

Assessing technological change for 2050

We have assessed respectively, the genetic increase of the yield potential and the decrease in yield gap due to improved crop management. These two elements determine technological progress by 2050.

The increase in the genetic potential yield level in 2050 is a result of physiological, phenological and morphological characteristics of crops. 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 have been optimized for, in particular, grain crops during the last decades, and future genetic progress in yield of grain (and other main) crops will most likely be achieved by focusing on constraints to RUE, being indirectly influenced by sink strength (Reynolds et al., 2005). 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).

Based on these reviews, the increases in yield potential during the coming decades by genetic improvement can be derived and are estimated at 1% per year. This estimate corresponds well with the estimate as based on the historical yield trends to the future (Ewert et al., 2005; Reilly & Fuglie, 1998). 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 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. For the B2-G scenario (because of its more limited economic growth, more 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 and more environmental restrictions).

In Flevoland the yield gap between the potential yields and the actual yields in 2006-2008 is for the main crops small (maximally 25%), indicating optimal crop management at present. We assume that this yield gap of 10 to 25% for main crops can hardly 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. Hence, for the A1-W scenarios for 2050 the yield gap is set to 1 minus actual yield/potential yield, but maximally 0.2. For the B2-G scenario we assume that half of the difference between the actual yield gap and a gap of 0.2 can be filled towards 2050.

2.3 Experimenting at multiple scales and for two types of analysis

In the next phase, the experimenting phase of the project, the scenarios and images of future farms have been explored in terms of climate change assessment. We used 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 arable farming in Flevoland in 2050.

This experimenting has been done at two levels, crop level and farm level, and, as indicated, for two types of analyses (2050 climate change only; 2050 integrated analysis). For the 2050 climate change only, the Climate 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 Climate change impacts and identifying adaptation measures. In the 2050 integrated analysis Climate change impacts and adaptation measures are assessed 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 Climate change (time horizon 2050) impacts and adaptation strategies projected on the current (2010) arable farming systems in Flevoland? – 2050 climate change only
- What is the relative importance of Climate 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 integrated analysis.

2.3.1 Approach for and results of assessment Crop level

For calculating the yields of the main arable crops in Flevoland for different scenarios for 2050, we have considered the following factors affecting yield changes compared to the actual yields in the 2050 climate change only scenario: 1) increase in atmospheric CO_2, 2) change in climatic conditions; 3) changing effects of extreme conditions during crop cultivation (possibly before crop emergence and/or after crop maturity; see approach as described in Chapter 7). For the 2050 integrated analysis the following additional factors were considered: 4) genetic improvement of crop varieties, 5) decrease in yield gap due to improved crop management. In Fig. 2.1 the integration of this work is shown.

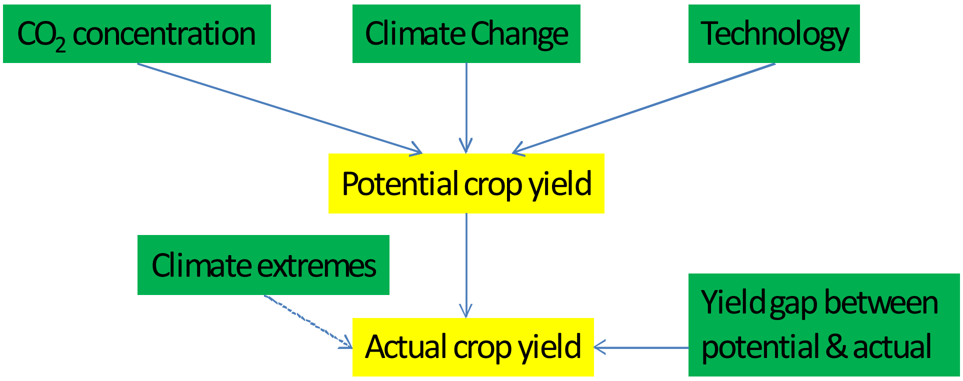


Fig. 2.1 Crop level assessment of the effects of CO_2 concentration, climate change, climate extremes and technology on crop yields

CO_2 and Climate change

The following initial questions at crop level were addressed by doing crop growth simulations with the WOFOST model:

- What is the impact of Climate change (incl. changes in atmospheric CO_2 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 Climate 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 Climate change?

The effectiveness of management adaptation to Climate change has been established by repeating the WOFOST 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).

Summarizing, simulation runs for the thirteen main crop types in Flevoland have been done for:

a) the current climate conditions for Lelystad, the Netherlands (369 µmol CO_2/mol),

b) the four KNMI scenarios for Lelystad with the high emission scenario A1FI (567 µmol CO_2/mol),

c) the four KNMI scenarios for Lelystad and the moderate emission scenario B2 (478 µmol CO_2/mol), and

d) the four KNMI scenarios with the high emission scenario A1FI plus management adaptation to Climate change.

The simulation runs 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).

Main conclusions are:

- Change in climate and increase in atmospheric CO2 in year 2050 result in yield increases for all crop types in Flevoland and all Climate change scenarios; for the G/G+ scenario the yield increase varied between for most crops between 5 and 15%; for sugar beet, rapeseed and onion the increases were up to 20%. In the W/W+ scenario effects varied between 2 and 18% for most crops, but for sugarbeet, rapeseed and onion effects yield increases were up to 25-30%.
- The four different climate change scenarios for 2050 from KNMI result in simulated yields for the different crop types that in general differ from highest to lowest yield for the scenarios in the following order: G → G+ → W → W+ ; this yield order can be explained from: G scenario has the coolest summer and the W+ scenario has the warmest summer, and the other scenarios have in-between changes.
- Increases in yields in 2050 compared to the current yields are mainly caused by the positive effect of the increase in atmospheric CO_2, whereas this effect is partly counteracted by the negative effect of temperature rise. Hence, the yield increases for the A1-W/W+ scenarios with a higher CO_2 concentration appear to be only slightly higher than those for the B2-G/G+ scenarios (Table 4.1).
- Management adaptation results in slightly to moderately higher (5-10%) yields for the main crop types in Flevoland.

Extreme events

Crop simulation models capture mainly gradual climate changes (i.e. changes in average conditions) and their effects on product quantity; only some adaptation options can be simulated. In practice, climatic extremes may have more impact than a gradual climate change. At the same time, many adaptation strategies to such extremes are available and for farmers these may be more relevant. Therefore, we assessesed 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 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?

Results from agro-climate calendar (ACC) analysis

The ACC assesses first the most important risks of extreme climate events and climate driven changes in pests and diseases on crop production and crop quality and next, the adaptation measures that prevent damage from the above risks. An important part of this method is the stakeholder interaction.

For Flevoland, we identified for the main crop types the crop and crop management specific vulnerable periods and climate factors. These climate factors are critical weather thresholds for crop damage that occur in specific periods in the year. The frequencies of occurrence of climate extremes (exceeding the threshold) have been derived first for the historic climate data records and next, for two climate change scenarios (van den Hurk et al. 2006) for Flevoland. Changes in frequency of extreme climate events for the climate change scenarios indicate the changes in growing conditions that may become critical for crop production and quality. As an example of the ACC analysis, results for seed poato are given below.

Current situation for Seed Potato - For the current production of seed potato, wet fields between October and March are problematic for plowing (Tables 2.2 and 2.3). This may lead to lower yields or increased costs if planting starts too late or under unfavorable conditions. A too dry soil between March and April can lead to planting delays. Moreover, the growth of the potato tubers can be reduced if moisture conditions are sub-optimal for the newly planted potatoes. Heat waves occur more regularly. The frequencies of sustained wet weather are high compared to other climate factors

Table 2.2 Frequency of occurrence of climate factors in Eelde as calculated by KNMI for the period 1976-2005 and indicative values for management costs and investments for seed potato

	Month												Manag costs (k€/ha) 2)	Investment (k€/ha) 3)
Climate factor 1)	J	F	M	A	M	J	J	A	S	O	N	D		
Wet field	13	5	5	0						5	8	9	nd	nd
High int. rain fall					0	0	0	2	1				0,4 – 0,5	7 - 8
Heat wave							2	6	0				1 - 2	15 - 25
Warm and wet							0	1	0				0,1 - 0,2	1 - 2
Sustained wet					5	8	7	5					5 - 6	80 - 90
Wet field								5	4	5			nd	nd
Warm winter	0	0	3									0	0,4 - 0,5	7 - 8

1) see Tables 6.2 and 6. 3 for further information
2) Indication of the maximal annual management costs to cope with the climate factor 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 to cope with the climate factor 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)

Situation 2040 for Seed Potato - It is expected that in 2040 there will be a notable increase in the frequency of warm winter months. Consequently, farms without adequate cold storage facilities will be negatively affected. As mentioned before, wet field conditions between August and October can become problematic when harvesting with heavy machinery.

Table 2.3 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 for seed potato

	Maand																								Manag costs (k€/ha) 2)	Investment (k€/ha) 3)
Climate factor 1)	J		F		M		A		M		J		J		A		S		O		N		D			
Wet Field	+1	+4	0	+1	0	0	0	0											0	-1	+1	0	+2	+3	nd	nd
High int. rainfall									0	0	0	0	0	0	0	-1	+1	+1							0,5 - 0,7	10 - 15
Heat wave													+2	+12	+7	+12	+1	+3							3 - 5	60 - 100
Warm and wet													+4	+6	+5	+6	+1	+2							1 - 2	20 - 35
Sustained wet									-2	-2	-2	-4	-2	-5	-4	-3									-	-
Wet field															-3	-3	0	-1	0	-1					nd	nd
Warm winter	0	+2	+1	+3	+3	+8																	+1	+1	1 - 3	20 - 60

1) see Tables 6.2 and 6.3 for further information
2) Indication of the maximal annual management costs to cope with the climate factor 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 to cope with the climate factor 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

According to Table 2.3 the frequencies of high intensity rainfall will not increase dramatically relative to the baseline frequencies presented in Table 2.2. However, it is expected that heat waves will occur more frequently: they range from an extra 1 to 7 events under the G+ scenario from June to August, and from 3 to 12 events under the warmer W+ scenario. Thus, increased occurrence of second-growth can be expected. The environmental conditions for the development of Pectobacterium carotovorum become more favorable in both the G+ and W+ scenarios. This may lead to increased yield losses. Interestingly, it may become easier to combat one of the current major hazards in potato production, late blight (Phytophthora infestans). Both under the G+ and W+ scenarios, the occurrence of sustained periods of humid weather will decrease. However, storage problems may occur because of higher winter temperatures, especially under the W+ scenario. High intensity rainfall (which can lead to rotting of tubers) may increase, but the frequency change is expected to be rather limited. Summarizing, changes in climate factors for seed potato under future scenario conditions appear to be partly positive and partly negative.

For the main crop types in Flevoland the ACC has supplied the risks of the impacts of unfavourable weather conditions on crop growth and yields for both current climate conditions and for different scenario climates for 2050. The resulting information about the frequency and the degree of yield losses due to extreme climate events has been used in the farm modeling with DEA (Section 2.3.2 and Chapter 9). Next, the adaptation measures that are able to prevent or limit yield losses due to extreme climate event with their effectiveness and their costs have been specified and have been used too in this farm modeling (see model run *Alter* in Table 2.7).

Quantifying the effects of extreme events based on historical data

The previous assessment of extreme events was based on literature, expert knowledge and stakeholder discussions. The main result was an overview of major climatic risks and relevant adaptation strategies, but quantifications were not accurate. Therefore, more data have been collected to investigate the impacts of climatic risks in more detail and more quantitatively.

We have identified the weather extremes that were responsible for the largest negative yield anomalies in ware potato and sugar beet. For ware potato in the province of Flevoland in the last 50 years the two most important weather extremes are: 1. a wet start of the season delays planting which in turn reduces yield; 2. a wet end of the season that inhibits harvesting operations. Quantitative meteorological definitions of these extremes were developed. Climate change scenarios indicated either no change or increased frequency of the extremes identified here. However, statements on changes in frequency are uncertain, due to lack of long (> 30 years) historical weather data and due to uncertainty in climate change projections in terms of rainfall. In climate change scenarios, the uncertainty in rainfall projections is much larger than the uncertainty in temperature projections.

In sugar beet, late sowing seems to be a major cause, though not the only cause, of low yields in specific years. A statistical negative relationship was found between total solar radiation in the 200 to 260 days prior to sowing and the actual sowing date, as well as between rainfall in the period between day 80 and 130 and the actual sowing date radiation. These relationships are not yet completely understood and need further study, but may indicate that an earlier sowing date is possible after a relatively dry winter and spring. Our data suggest that, if farmers do not change their rules for selecting their sowing date, a shift towards 1 to 5 days earlier sowing can be expected for 2050 compared to the Base year.

The method developed here, of identifying relevant weather extremes through a form of reverse engineering, in which we start with yield anomalies, weather data and descriptions of management and weather and derive quantitative definitions of extremes, is widely applicable provided that sufficient historical data are available. In our reconstruction of historical data we noted that since 1990, far less experimental data are available than before 1990 (with a notable exception for the case of data of the Dutch sugar beet institute IRS).

What is striking in our highly empirical analysis is that the main extremes are related to rainfall (and in case of sugar beet also probably indirectly to radiation) and not to temperature. There is large uncertainty in climate change scenarios of rainfall. It raises question whether at this stage, calls for adaptation to these extremes are necessary and possible. The outcomes of our research can help meteorological modellers to focus their research on those extremes that really matter for agriculture.

Yield gap closure and increase genetic potential

In practice, potential or water-limited yields are not achieved due to other limitations or reducing factors causing a yield gap. Furthermore, climate change is not the only factor that results in changes in crop yields. Therefore, we addressed the following questions for 2050:

- What is the combined impact of climate 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 climate change on actual yields?

We estimated the increases in yield potential and the decreases in yield gap towards 2050 for the different scenarios, as described in Section 2.2.3. Based on this information, the actual yields for the main crops in Flevoland for the different scenarios for 2050 have been calculated. These yield calculations have been done for current conditions and for future conditions, both with and without changes in yield gap and in yield level due to genetic improvement (Table 2.4).

Table 2.4 Actual yields (ton/ha air dry) for crop types in Flevoland as calculated for different scenarios for 2050[a] with and without changes in yield gap and yield potential towards 2050

Scenario	Current		2050, no genetic improvement, actual yield gap				2050, genetic improvement, yield gap for 2050			
Crop	Actual yield	Yield potential	G scen.	G+ scen.	W scen.	W+ scen	G scen.	G+ scen.	W scen.	W+ scen.
Winter wheat	9.19	12.32	10.16	9.76	10.63	9.76	11.58	11.12	14.82	13.60
Potato ware	54.14	70.97	58.71	56.46	64.99	60.01	66.15	63.62	88.60	81.81
Sugar beet	73.39	84.56	87.55	87.67	97.46	97.88	96.30	96.44	126.70	127.25
Onion	62.75	68.13	75.48	71.57	88.85	82.16	83.03	78.73	115.51	106.80

[a] The potential yield calculations are based on crop modeling with WOFOST for weather conditions and CO_2 concentrations around year 2000 (current) and 2050; the crop management is adapted to Climate change for the W and W+ scenarios only

For example, for the A1-W/W+ scenarios with a strong decrease in yield gap and a strong increase in yield potential the yields in 2050 for all crop types become higher to much higher than the current yield potential due to mainly the strongly improved varieties and crop management (Table 2.4).

Main conclusions of this analysis are:

- The proposed method for the calculation of actual yields for the different scenarios in 2050 is straightforward.
- Calculated actual yields for scenarios in 2050 are depending on several assumptions (e.g. increase in yield potential towards 2050) and uncertain data (e.g. weather data for 2050) and hence, have a range of uncertainty; however, there appears to be no solid alternative solution.
- A main factor that determines the actual yields in 2050, is the degree that the yield potential of different crop types may increase towards 2050 through genetic improvement; we derived a relationship between this increase in yield potential (+30% and +10%) and respectively, the A1-W and the B2-G scenarios, which relationship is rather uncertain.

Table 2.5 shows for some crops the relative contributions from climate change, increase in yield potential and decrease of the yield gap to total changes in productivity towards the year 2050. The table shows that assumptions on the increase in genetic yield potential are most important. Second, the effects of climate change and increased atmospheric CO_2 are also rather important. Finally, the effects of both adaptation and closure of the yield gap are smallest.

Table 2.5 Relative contributions of different factors to yield changes for the A1-W and B2-G scenarios towards 2050

Crop	Actual yield in 2000-2009 (t fresh/ha)	Effect of climate change (%)	Effect of climate change + adaptation [1] (%)	Effect of increase in genetic potential (%)	Effect of yield gap closure (%)	Overall increase in actual yield 2050 vs. 2000-2009

A1-W scenario						
Winter wheat	9.19	+10.7	+15.7	+30.0	+7.2	+61.2
Potato ware	54.14	+10.9	+20.0	+30.0	+4.8	+63.7
Sugar beet	73.39	+30.8	+32.8	+30.0	0.0	+72.6
Onion	62.75	+26.0	+41.6	+30.0	0.0	+84.1
B2-G scenario						
Winter wheat	9.19	+10.5	-	+10.0	+3.6	+26.0
Potato ware	54.14	+8.4	-	+10.0	+2.4	+22.2
Sugar beet	73.39	+19.3	-	+10.0	0.0	+31.2
Onion	62.75	+20.3	-	+10.0	0.0	+32.3

[1] No management adaptation has been applied for the B2-G scenario

2.3.2 Approach for integrated assessment at farm and regional level

At farm level we have employed two methods:

1. Sensitivity analysis at farm level using fixed cropping patterns to assess relative importance of different drivers of change towards 2050 at farm and regional level;
2. Data Envelopment Analysis (DEA) to assess adaptation options for the climate change only and integrated analyses for a range of farms.

The fixed cropping pattern method is a straightforward sensitivity analysis that estimates the relative influence of climate change, technological development, policy and market changes and farm structural change on farmer's income. It projects these changes on the current farm structure.

In the analysis using Data Envelopment Analysis (DEA), we assess adaptations at the whole farm level. Often bio-economic 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 indicate 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, in which behavioural assumptions can be made to identify optimal strategies of farmers. DEA is thus a substitute for the '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.

Sensitivity analysis at farm and regional level

Economic results have been assessed for arable farming in Flevoland. The calculations have been done assuming fixed (but being different per scenario) cropping patterns and not applying any optimization of the cropping pattern. The fixed cropping patterns for the Base year and 2050 are based on the farm structural change work by Mandryk et al. (2011; see above and Chapter 3). The calculations have been done first for the main arable farm types in Flevoland in the Baseyear. Second, the calculations have been repeated for the same farm types in Flevoland with the same cropping patterns, farm area, labour use per crop type, product prices, and costs but with yields calculated for the A1-W scenario for 2050 with management adaptation and for the B2-G scenario for 2050 (i.e., climate change only analysis, thus: 2050-A1-W-only and 2050-B2-G-only scenarios). Third, the calculations have been repeated for the same farm types in Flevoland with the same farm area and labour use per crop type, but with cropping patterns (see Table 8.1), product **P**rices, costs and yields for respectively the A1-W and B2-G scenarios for 2050 (see Table 8.2 for more information), called 2050-A1-W-P and 2050-B2-G-P. Fourth, the calculations have finally been done for the same farm types in Flevoland with the same farm area and labour use per crop type, but with cropping patterns, product prices, costs, and yields for respectively the A1-W and the B2-G scenarios for 2050, and also with further yield increases due to **T**echnological (i.e. both crop genetic and management) improvements, called 2050-A1-W-P-T and 2050-B2-G-P-T scenarios.

Summarizing, the analyses have been done in three steps compared to the Base year, with first, only the climate change and increased CO_2 effect on yields included, second, the changes in product prices, costs and cropping patterns towards 2050 also included and finally, the effects of crop genetic and management improvements on crop yields in 2050 included, too. The analysis was done for five main farm types in Flevoland, and for explicit assumptions about the changes towards 2050 in product prices, costs, cropping pattern and yield increases from crop genetic and management improvements towards 2050.

The economic results for the different farm types in Flevoland and for the Base year 2005 and the different scenarios are summarized in Table 2.6. Farm types C and D with half of the farm area used for seed potato production, result in the Base year in much higher values for the gross margin per labour hour than those for farm types A and B. This difference between the farm types can be explained from the high economic values of seed potato in combination with the cropping pattern per farm type in the Base year. Effects of climate change and increased atmospheric CO_2 on the gross margin per labour hour are clearly positive. The 2050-A1-W-only scenario with some management adaptation gives 30% to 50% higher yields and thus gross production compared to those in the Base year, which results in 50% to 90% higher total gross margin and gross margin per labour hour (Table 2.6). The 2050-B2-G-only scenario gives 15% to 35% higher yields and thus gross production compared to those in the Base year, which results in 25% to 60% higher total gross margin and thus gross margin per labour hour.

Table 2.6 Summary of the Economic results (i.e. Gross margin per labour hour, in euros of 2005) for farm types in Flevoland and for arable farming in Flevoland as a whole for the Base year and for the different scenarios. Note that compared to the Base year the following changes are applied in the scenarios: a) ***Scen. 2050-A1-W-only***: effect of climate change and increased CO_2 on yields, b) ***Scen. 2050-A1-W-P***: idem point **a** plus changes in product prices, costs and cropping patterns for the scenario in 2050 (A1-W or B2-G), and c) ***Scen. 2050-A1-W-P-T***: idem point **b** plus further yield increase from technology(i.e. both crop genetic and management) improvements

Farm type[1] Scenario	A	B	C	D	E	Reg[2]
Gross margin in euro-2005 / labour hour [3]						
Base year 2005	28.2	28.2	61.5	61.4		56.2
Scen. 2050-A1-W-only	54.3	54.3	90.5	90.5		84.7
Scen. 2050-B2-G-only	45.4	45.4	76.3	76.3		71.4
Scen. 2050-A1-W-P	38.1		55.4	55.5	62.2	48.9
Scen. 2050-B2-G-P	18.3	18.3	38.7	38.7		34.2
Scen. 2050-A1-W-P-T	62.8		89.0	89.0	99.2	79.2
Scen. 2050-B2-G-P-T	24.7	24.7	48.8	48.8		43.5

[1] Information about the five farm types is given in Table 8.1
[2] Regional average for Flevoland; based on area fractions for the five farm types (Mandryk et al., 2011)
[3] Based on cost trend of +45% in total from 2005 to 2050; crop yields for A1-W scenarios assume management adaptation to climate change but those for B2-G scenarios do not (see Table 5.2)

If in addition to the effects of climate change and increased atmospheric CO_2 we also include the changes in product prices, costs and cropping patterns from 2005 towards 2050, the gross margins per labour hour, as expressed in euros of 2005 (Table 2.6), strongly decrease for both scenarios and all farm types (e.g. by minus one third for scenario 2050-A1-W-P compared to scenario 2050-A1-W-only). These strong decreases in gross margin can be explained from the stronger increases in costs over time than the increases in product prices. Finally, if we also assume that further yield increases are possible by way of crop genetic and management improvements, the changes in gross margin per labour hour for the 2050-A1-W-P-T scenario are nil to slightly positive compared to the scenario 2050-A1-W-only (Table 2.6). This shows that only for the 2050-A1-W-P-T scenario with the highest yields and best management in 2050, the gross margins per labour hour, when expressed in euros of 2005, are higher than those in the Base year for all farm types (Table 2.6). For the 2050-B2-G-P-T scenario, however, the gross margins per labour hour are still lower than those in the Base year for all farm types, which is mainly caused by its more limited yield increases. This indicates the need for both improved crop cultivars and management to increase the gross margin per labour hour.

For arable farming in Flevoland as a whole, the changes in the economic results for the different scenarios have also been established. These mean values for the gross margin per labour hour in arable farming in Flevoland (Table 2.6) have been derived from the values for the five different farm types, using the area fractions for the different farm types as weighing factors. The differences in gross margin per labour hour between the Base year and the six scenarios for the average arable farm in Flevoland appear to be roughly similar to those for the individual farm types (Table 2.6).

The outcomes for the different scenarios (Table 2.6) show that the differences in gross margin per labour hour are mainly determined by first, the increase in product prices from 2005 to 2050 (and in particular, the degree that these price increases are lower than the cost trend) and second, the yield increase from 2005 to 2050. Figure 2.2 shows that, for example, the gross margin per labour hour on farm type C in the Base year of 61.5 euro/hour (Table 2.6) can be attained in year 2050, when the yields increase to 140% compared to the Base year and the product prices increase to 120% (in euros of 2050). The 2050-A1-W-P scenario results on farm type C in a gross margin per labour hour of 55.4 euro-2005/hour (Table 2.6), which corresponds with an increase in yield to 130% and in price to 120% (in Figure 2.2). The 2050-A1-W-P-T scenario results on farm type C in a gross margin per labour hour of 89.0 euro-2005/hour (Table 2.6), which corresponds with an increase in yield to 182% (due to further crop genetic and management improvements) and in price to 120% in Figure 2.2.

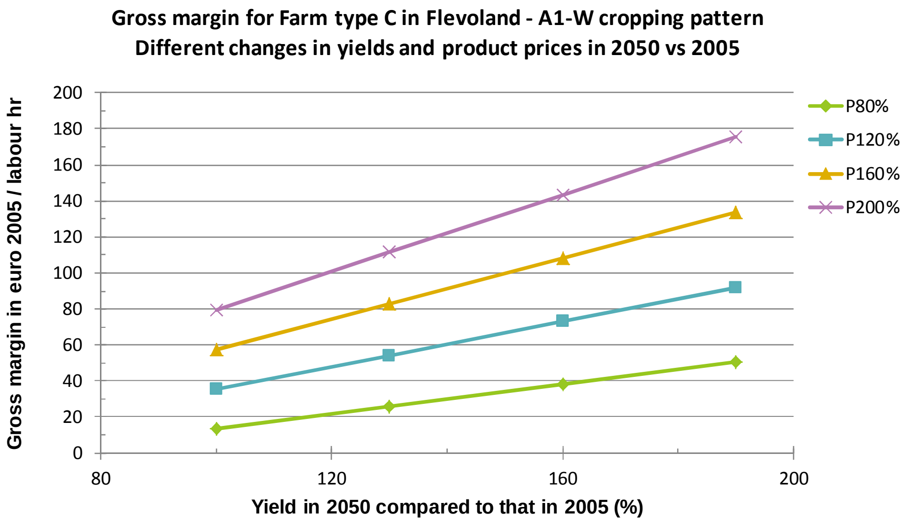


Figure 2.2 Gross margin per labour hour (expressed in euro for 2005) on farm type C in Flevoland, the Netherlands for different values for respectively, the future product prices (expressed in euros of 2050) and the relative yields in 2050 (as dependent on the assumed

yield increases due to climate change and increased CO_2 and crop genetic and management improvements); cropping pattern of A1-W scenario is applied

Exploring arable farming systems and adaptation strategies to climate change using Data Envelopment Analysis (DEA)

The effects of the A1-W scenario were evaluated in arable farms in Flevoland. Individual farm data (i.e. inputs, outputs and farm resources) of 85 individual representative farms from FADN were used. The base year scenario was calculated by averaging FADN data of years 2000-2006. The DEA procedure was used to specify the technical relationships between important inputs and outputs. Inputs used in the DEA procedure were: capital (€), crop protection (€), fertilizer (€), energy use (€), labour (distinguishing between hired and family labour in hours), other inputs (€). The outputs used were: potatoes, onions, sugar beet, wheat (tons), other arable output (€) total livestock output (€) and other outputs (€). Technical efficient farms (best farm practices) were identified and formed the DEA frontier, which was assumed to be the current production function. A farm is characterized as "best" farm practice when at a certain input level, there is no linear combination of the inputs and outputs of the other existing farms that results in lower input level without increasing the level of another input or decreasing the level of an output.

Expected yield and input (i.e. fertilizers) changes due to climate change scenario A1-W were calculated for year 2050 without (i.e. 2050-A1-W-only scenario) and with technological change (i.e. 2050-A1-W-T scenario), whereas the price change towards 2050 was applied in some model runs (from *Price* run below) for both scenarios. The calculated inputs and outputs of future activities were used to identify the new input-output relationships for the A1-W scenario using DEA.

Ten model runs have been performed for the two scenarios. In the first model run (*Profit*), it is assumed that farmers are gross margin maximizers. The available farm resources are allocated to the best current production possibilities and optimum farm plans are calculated. In the second model run (*Calibr*), FSSIM is calibrated to base year observed input and output levels. The difference between the gross margins of this model run with the gross margin of the previous one represents the costs that farmers are willing to take for maintaining their own current production strategy that satisfies their multiple objectives. In the third model run (*B2050*), the expected yield change due to climate change, without accounting for the effect of extreme events, is evaluated using the calibrated FSSIM model. In the fourth model run (*Extreme*), the effect of the increased occurrence of extreme events (i.e. prolonged wet conditions during spring and dry conditions during spring and summer) are taken into account. In the fifth model run (*Alter.*), alternative adaptation measures are offered. In the sixth model run (*Price*), the future price changes, simulated with CAPRI, are used. Finally, in model runs 7 to 10 (*Scaling*), it is allowed to increase labour, capital, other inputs, livestock outputs and other outputs. In model run 7, we allow for 20% more hired labour. In model run 8, on top of model run 7, we allow for 20% more capital. In model run 9, on top of model run 8 we allow for 20% more other inputs and in model run 10, on top of model run 9 we allow for 20% more livestock output and other outputs. It is important to notice that specifications of model run 4 to 10 are additive.

Results from all FSSIM model runs for arable farming in Flevoland as a whole are presented in Table 2.7. Detailed results for different farm types in Flevoland are also given (but not shown here). The simulated inputs and outputs in the *Calibr* model run represent the current situation, since the PMP based calibration procedure guarantees exact reproduction of historical input-output levels. Comparing the gross margins achieved in the Profit model run with the gross margin that is currently achieved (i.e. *Calibr* model run), it can be concluded that in all farm types, farmers sacrifice a substantial part of their profit for maintaining their current production activity. In the *Profit* model run, the production of main cash crops like potatoes, onions and other arable output (i.e. mainly tulips, bulbs and field scale vegetables) increase. This is achieved by increasing areas but also by intensifying production (selecting systems with higher yields). The shift of production to cash crops and higher yields causes an increase in inputs of fuels (energy), fertilizers and crop protection (Table 2.7).

In the *B2050* model run, in the 2050-A1-W-only (without technological change) scenario the increased expected yields cause a substantial increase of gross margins (compared to the current situation in the *Calibr* model run) (Table 2.7). Compared to the current situation, inputs of fertilizers, energy and crop protection increase. In the *B2050* model run of the 2050-A1-W-T scenario, where technological change is assumed and improved varieties (in terms of yields) were offered to the model, similar but more dramatic changes are observed (Table 2.7). Areas of onions and potatoes decrease compared to 2050-A1-W-only scenario. The consequence is that the inputs of fertilizer increase substantially. Another interesting result is that in *B2050* model run of 2050-A1-W-T scenario, the fraction of hired labour increases substantially compared to the fraction of hired labour in the *B2050* model run of the 2050-A1-W-only scenario (Table 2.7). This is related to the large increase of other arable output in the 2050-A1-W-T scenario and the seasonality of labour involved in growing crops like tulips and field scale vegetables.

The effect of the increased occurrence of extreme events in the *Extr* model run is minor in both scenarios (Table 2.7). The average yields of main crops decrease which causes a marginal decrease of gross margins. No major adaptation or changes in production orientation (crop rotation, inputs etc.) occurred. In the *Alter* model run, a number of adaptation options are offered. In the 2050-A1-W-only scenario only the gross margin of large farms benefit marginally (compared to the *Extr* model run) (not shown). The main reason for this is that activities, which require investment decisions and involves additional maintenance costs, become profitable only at larger scales of production. At smaller scales, the beneficial effects of alternative activities level out with additional costs related to maintenance of machinery, energy and labour. In the 2050-A1-W-only scenario, the adoption of alternative activities is the highest in the large farms. Alternative activities with no or low investments are mainly selected. In the 2050-A1-W-T scenario, the adoption of alternative activities is minor and lower than the adoption in the 2050-A1-W-only scenario.

Accounting for the expected price changes as those have been calculated by CAPRI, in the *Price* model run, results in a substantial decrease of gross margin in the 2050-A1-W-only scenario (Table 2.7). Areas of potatoes, onions and sugar beet decrease. Production swifts further, from main arable products to other arable outputs (i.e. tulips and vegetables). Given the 2050 prices, and without any technological change it becomes less profitable to grow the current cash crops. In the 2050-A1-W-T scenario, the effects of price change are smaller than in 2050-A1-W-only scenario because of the higher yields (due to technological improvement) of main crops.

In model runs 7 to 10, the consequences of expanding in terms of hired labour, capital, other inputs, other outputs and livestock outputs were investigated. In all farms in both evaluated scenarios, capital availability is the most important factor for increasing adoption of alternative activities (compared to the *Price* model run) (Table 2.7). Additional capital is invested in adapting or purchasing machinery that increase sowing density.

Results from the evaluated scenarios (i.e. A1-W scenarios assuming a globalized economy and strong climate change context) show that the most important driving factors towards 2050 are the yield increase due to climate change, the expected price change and the degree of technological innovation that focus on crop productivity. The effects of climate change (i.e. increase of temperature and atmospheric CO_2 concentration) are projected to have a positive economic effect on arable farming. However, a substantial increase of inputs of crop protection, fertilizers, and energy is also expected. Increase of those inputs combined with a swift of production to other arable crops (mainly tulips and vegetables) can lead to additional environmental pressure per ha. Nevertheless, the environmental pressure per ton of product is projected to decrease.

Effective policy decisions that target at promoting production of currently grown crops should promote research and development projects to make new highly productive varieties available. However, it appears that lack of new more productive varieties as in the 2050-A1-W-only scenario, results in higher adoption rate (compared to the 2050-A1-W-T scenario) of alternative activities (being highest at the large farms) with improved management practices (e.g. investing in precision agriculture systems or increasing top soil organic matter content). It appears that making new more-productive varieties available competes with promoting the use of existing technologies that focus on improving resource use efficiencies. From the results of the analysis, it was shown that accessibility to capital can increase the adoption rate of the tested adaptation strategies.

Table 2.7 Simulated input-output levels, areas and yields of an average farm in Flevoland for two scenarios for 2050

			Scenario 2050-A1-W-only without technological change								Scenario 2050-A1-W-T with technological change							
							Scaling								Scaling			
	Profit	Calibr	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10
Capital (1000 €)	213	335	270	266	266	222	223	229	230	232	242	242	242	227	227	235	239	243
Crop protect. (1000 €)	21	15	17	16	16	14	14	14	15	15	15	15	15	16	16	16	17	17
Energy (1000 €)	19	13	18	18	18	18	19	19	21	21	21	21	21	22	23	23	23	24
Fertilizers (1000 €)	7	7	10	9	9	7	7	7	8	8	13	12	12	11	11	12	12	12
Family labour (hrs)	2512	2854	2382	2373	2361	2160	2175	2191	2154	2178	2010	1999	1999	1978	1985	2004	1942	1960
Hired labour (hrs)	1285	1776	1423	1416	1475	1489	1602	1672	1650	1653	1608	1611	1611	1605	1733	1778	1871	1875
Area (ha)	46	49	47	46	47	40	40	40	40	40	44	43	43	43	42	43	42	43
Other input (1000 €)	104	149	127	127	126	113	114	115	120	121	134	133	133	130	131	132	144	146
Gross margin (1000 €)	284	146	275	263	267	134	135	138	141	143	333	326	326	346	351	354	367	373
Livestock output (1000 €)	0	29	11	11	11	10	10	10	10	10	11	11	11	4	4	4	4	4
Other output (1000 €)	17	32	21	21	21	20	20	21	20	21	19	19	19	18	18	18	18	19
Onions (tons)	591	412	544	441	468	325	321	325	336	342	550	454	458	453	444	463	475	476
Potatoes (tons)	896	547	648	632	642	523	528	537	545	548	741	721	727	776	780	791	742	753
Sugar beet (tons)	457	467	814	803	811	636	635	653	638	630	849	836	838	888	884	904	850	858
Wheat (tons)	29	49	62	67	66	72	71	72	66	66	85	87	87	109	108	108	99	100
Oth. arable output (1000 €)	79	53	105	109	104	129	134	135	149	149	269	274	272	280	289	289	331	334
Areas																		
Onions (ha)	12	11	11	10	10	7	7	7	8	8	9	8	8	8	8	8	8	8
Potatoes (ha)	16	12	12	12	12	10	10	10	10	10	10	10	10	11	11	11	10	11
Sugar beet (ha)	9	7	9	9	9	7	7	7	7	7	7	7	7	7	7	7	7	7
Wheat (ha)	3	6	7	7	7	8	7	8	7	7	6	7	7	8	8	8	7	7
Other crops (ha)	6	13	9	9	9	8	8	8	8	9	11	11	11	8	8	8	9	9
Yields																		
Onions (tons/ha)	48	37	52	44	46	44	44	45	45	45	63	55	55	55	55	56	57	57
Potatoes (tons/ha)	57	44	55	54	55	51	51	52	52	52	72	70	71	71	71	71	71	71
Sugar beet (tons/ha)	49	70	91	92	92	94	93	94	93	94	119	119	119	122	122	122	122	123
Wheat (tons/ha)	9	8	9	9	9	9	10	10	9	10	13	13	13	14	14	14	14	14

2.4 Learning: integrating and iterating knowledge

The last phase in the project includes learning, evaluation and monitoring. During the experimenting phase, internal evaluation has taken place continuously, as different methods give answers to different questions, and interactions help to improve assessments. Outputs have been evaluated with stakeholders: do the modelling results reflect what will likely happen in reality? This may potentially provide the basis for a next integrated sustainability analysis (ISA) cycle, leading to a reframing of the shared problem perception (e.g., climate 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 may be further refined based on the crop and farm level simulations. In another report from the AgriAdapt project (Schaap et al., 2011) we focus on this last phase of ISA. Here we present an example only for the development of images of future farms.

In the development of images of future farms in Flevoland (Section 2.2.3) we additionally used information from stakeholders (farmers, representatives of water boards, local policy makers). Stakeholder workshops have been organized in the study area in March 2010 and February 2011. During the interactive sessions the participants shared their visions on adaptation strategies to climate, market and policy changes for arable farming in Flevoland in the future (i.e. 2050) for the two contrasting socio-economic and climate scenarios (i.e. A1-W and B2-G). The participants were asked to write down the most important adaptation strategies to market, policy and climate change. Adaptation strategies could be from the categories market opportunities, farm size, technology, crop choice, or additional ones defined by the farmers themselves. Stakeholders were also asked to rank the strategies. The results of the exercise were discussed in a round table panel afterwards, which provided us with quantitative and qualitative farm characteristics for the 2050-A1-W and 2050-B2-G scenarios.

For the 2050-A1-W scenario the most important farm type based on the utilized arable area, is expected to be „production oriented-very large-medium intensive-specializing in diverse arable crops (mainly root crops)". In our quantitative analysis such a farm is a large scale, capital intensive holding with the average farm size of 130 ha. Farmers, however, would expect this farm to be larger by 2050, i.e. 150-180 ha. This can be achieved through a considerable share of rented land in the total amount of utilized agricultural area (up to 75%). The farm will operate in a close collaboration with neighbouring farms in terms of management operations and (partial) processing of the products. Technical advances on such farm are the attributes of precision agriculture, which contribute to high labour efficiency and productivity. The farm produces mostly seed and ware potato. Stakeholders expect Flevoland to guarantee its position in export of seed potato by maintaining the high quality of the product. Sugar beet cultivation might diminish strongly due to the high competition on the global sugar market. As a substitute for sugar beet in a bio-based economy scenario, local stakeholders mentioned energy crops. 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 highly technically efficient on this farm. 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 (ware and seed potato, vegetables) and innovative technology. Enlargement of a farm size through land rental schemes and cooperation with other farmers can provide benefits of economy of scale.

A typical farm in the 2050-B2-G scenario is expected to be "entrepreneur-oriented-large-medium intensive-diverse mainly root crops and specialized crops". According to the stakeholders, this farm type will mostly produce biologically. Projected farm size is 61 ha, whereas farmers would expect it to increase up to 80-120 ha. The output intensity is kept to the current level through strict environmental legislation, aimed at limiting growth potential of agriculture. The share of rented land varies between 50 and 75 %. Collaboration between neighbours is strongly supported by regional development policy. Technological progress is focused on environmentally friendly production means and development of biological crop varieties. The balance between consumer demand and production supply is regionally based. A farm becomes a part of a local market chain (retail, direct sells from a farm, local supermarkets). Traditional crops dominate the arable farm specialization: consumption potato, seed potato, winter wheat, and sugar beet. In the 2050-B2-G scenario this farm type is expected to adjust to the regional/local market situation and consumer behaviour, being oriented at sustainably produced local products.

In general, the images of the future farms as seen by the stakeholders, are supported by results from projections based on historical analyses (see Chapter 3). The main mismatches between the farmers expectations and quantitative projections are found in the estimation of future farm areas.

3 Scenarios of farm structural change towards 2050

M. Mandryk

3.1 Introduction

Globally, climate change became an important issue during the last decades. In many regions in the world one can already observe effects of the changes and variations in climatic conditions on crop productivity, farmers' income and land use (Berry et al., 2006; Bindi and Olesen, 2010; Bradshaw et al., 2004; Olesen and Bindi, 2002; Reidsma et al., 2009). Also for the future of agriculture in a temperate zone such as The Netherlands the potential importance of climate change cannot be ignored, especially regarding effects of weather extremes (Bresser, 2005; Peltonen-Sainio et al., 2010; Schaap et al., 2011; van Dorland, 2008). However, changes in agricultural policy setting, market responses and technological development were shown to be at least equally important drivers (Hermans et al., 2010). Due to the impact of these drivers, farms in The Netherlands have been changing considerably since World War II (Meerburg et al., 2009). Those changes affected not only the numbers of farms, 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).

Impacts of future climate change are usually projected on current farms and cropping systems (Easterling et al., 2007). Since the impacts of climate change will be relatively minor in the short term, assessments must be performed for a long time horizon (2050 in present study), when climate change will likely have larger impacts. At the same time assessments of impacts and adaptation strategies have focused primarily on food production (Easterling and Apps, 2005; Easterling et al., 2007), while it is expected that in The Netherlands and Europe as a whole, more multifunctional landscapes will evolve. Effective adaptation strategies thus need to consider additional economic, social and environmental objectives, associated with multifunctionality of agriculture. Therefore, one has to take into account that the farms in the future are not the same as the current ones: they will evolve through structural changes. The aim of this study is to derive images of future farms in a region, under different plausible future scenarios for demographic, economic and political drivers. These images then form a proper context to assess impact of and adaptation to climate change.

The most common method to study farm structural change is using econometric models, as shown in the overview by Zimmermann et al. (2009), or agent-based models as applied by Piorr et al. (2009). When dealing with a long time horizon, these models cannot be used. A long time horizon brings many uncertainties in how future farm development will unfold in the context of multiple drivers of change acting at different levels. We used a scenario approach to capture uncertainty in future changes of drivers. Hierarchical scenario development to arrive at scenarios at regional level has been performed in many studies (Abildtrup et al., 2006; Audsley et al., 2006; Dockerty et al., 2006; Rounsevell et al., 2003; Vandermeulen et al., 2009). These studies, however, focused on modeling spatial distribution of agricultural land use at regional and the EU scale under global environmental (climate change) and EU policy drivers and did not consider farm structural changes induced by these drivers. Reidsma et al. (2006) made an attempt to project changes in intensity of farm types in order to assess changes in agricultural biodiversity, but this study lacked other farm structural characteristics besides intensity. Possible short to medium term farm structural changes as a result of adaptation to policy drivers were investigated by Piorr et al. (2009). The study used agent-based and Linear Programming models to assess responses to changes in the Common Agricultural Policy of the European Union at the regional and farm level. It was concluded that different farm types develop different strategies of adaptation to the changing policy context. Climate change was not included in the scenarios.

Development of hierarchically consistent scenarios of farm structural change at farm and regional level defined by plausible directions of change in climate and socio-economic developments has not been performed previously. We need these scenarios to assess adaptation strategies to climate change in the long term. The aim of this study is to derive images of future farms in a region, under different plausible future scenarios for demographic, economic and political drivers. These images then form a proper context to assess impact of and adaptation to climate change.

The province of Flevoland in 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 towards 2050. Ultimately, these scenarios and the method to derive them can be re-used in other regions in the Netherlands or elsewhere in Europe.

3.2 Short description of the methodology

The procedure to derive the images of future farms in 2050 includes several steps (Fig. 3.1). In the first step we identify and classify current farm types and their distribution using a farm typology. In the second step, a historical analysis was performed to assess the impact of a range of important drivers (technology, policy, market and climate change) on the farm structure. The outcome of this step is the relative contribution of each driver to the changes in each of the farm structural dimensions (orientation, size, intensity, specialization). In the last step, socio-economic and climate scenarios were downscaled to the regional and farm level to explore effects of the drivers and the resulting changes in farm dimensions and characteristics towards 2050 and to develop images of future farms. We first obtained the results on structural change at regional level and then downscaled them to a farm level using transition rules per scenario on shifts between farm types.

Data sources used in the analysis (including farm typology) are described in detail in Chapter 3 of the AgriADAPT project report no.1 about Methodologies.

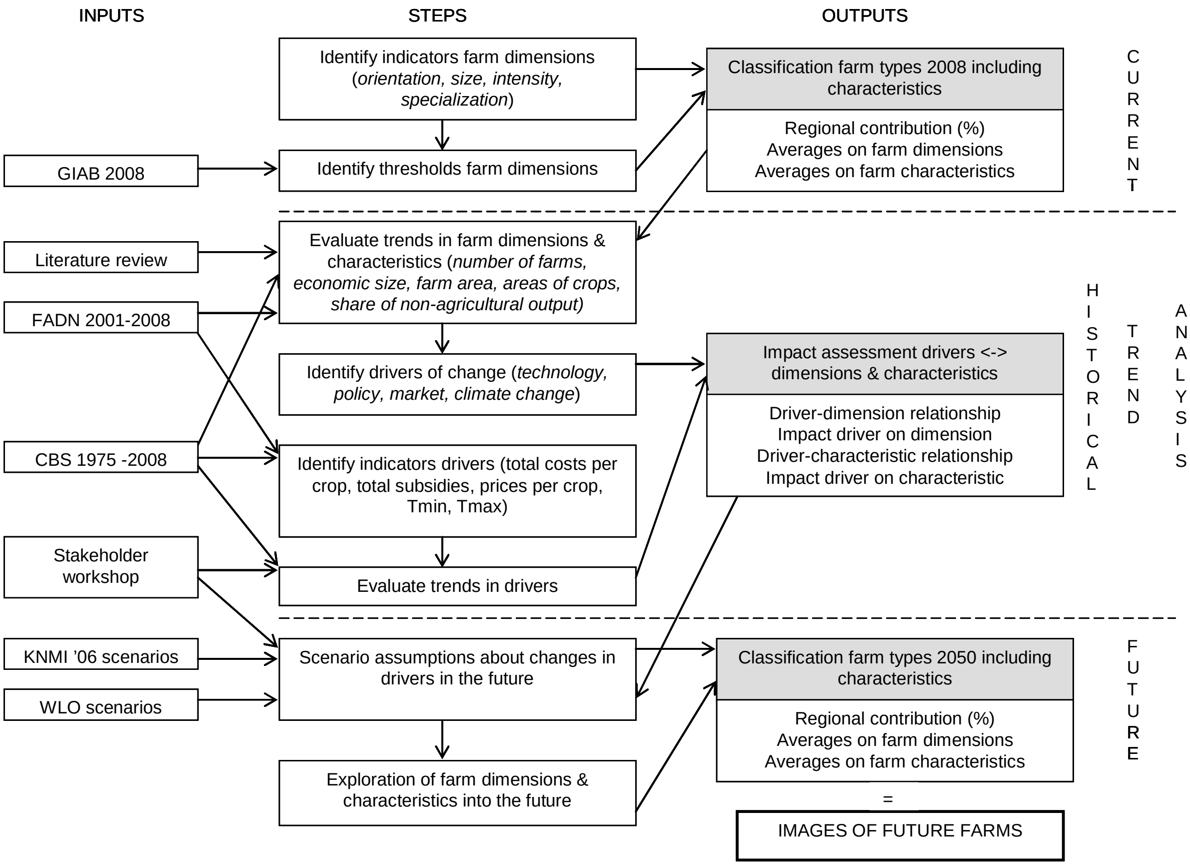


Figure 3.1. Overview of methodological approach to derive images of future farms

Historical trend analysis

In our research we considered four major drivers for farm structural change in the future. Literature review and historical data analysis showed that since World War II farms in Flevoland were changing due to technological progress, policy intervention and markets' developments (Koomen et al., 2005; Meerburg et al., 2009; van Bruchem and Silvis, 2008). In the future the impact of climate change is expected to be significant. Therefore, for further investigation we chose as drivers technology, policy, market, and climate change.

We first performed trend analyses for all typology dimensions (orientation, economic size, intensity, and specialization) to observe the dynamics in structural change and formulate the hypotheses on the contribution of each driver to the change in each dimension. The analysis was based on regional farm data (CBS, FADN) for the period 1986-2008, i.e. from the year that Flevoland was registered as a separate province of the Netherlands. Changes in values of each of the dimensions over time were assessed through selected indicators. For size we used farm economic size (NGE); for intensity: farm economic size (NGE) per unit of area (ha); for specialization: area of root crops, flower bulbs, and vegetables (ha); and for orientation: share of non-agricultural output (% from total economic output). We also considered additional indicators such as total number of farms, farm size in ha, number and types of non-agricultural activities on a farm. The drivers were also assigned indicators to study the impact of each driver on farm structural change. The indicators were selected on the basis of similar studies that were investigating impacts of certain drivers on farm level responses (Reidsma et al., 2010). For technology we used variable input costs for cultivating 1 ha of consumption potato (€/ha) and winter wheat (€/ha); for policy: total subsidies (€/ha); for market: prices for ware potato (€/100 kg) and winter wheat (€/100kg); for climate: minimum and maximum annual temperature (˚C).

Subsequently, the relation between each driver and dimension was investigated. For this we used a literature review on the contribution of each driver to the change in each dimension (Smit, 2004; van Bruchem and Silvis, 2008), statistical analyses (correlation and (multiple) regression) using regional level and farm level data (CBS and FADN). Next, we also verified and discussed the findings with stakeholders. In some cases, the relationships between a driver and a dimension strongly evidenced by the literature, were not supported by results of statistical analyses.

Drivers at regional level

Per scenario, we analyzed possible developments in drivers impacting structural change. We used the same indicators for drivers as in the historical trend analysis. Applying scenario assumptions on changes in technology, policy, market and climate (Table 3.1) we projected the impact of two scenarios on drivers. We used general scenario assumptions on development in drivers for A1 and B2 SRES storylines (Nakicenovic and Swart, 2000) and specified these with assumptions from literature regarding changes in particular indicators per driver.

Table 3.1 Assumptions on development of drivers per scenario

Driver	Indicators	A1-W scenario	B2-G scenario	Source
Technology	Total costs	Continuation of historical trend or towards +50% of historical trend	Lower increase in continuation of historical trend	Ewert et al. (2005)
Policy	Subsidies	No crop subsidies and price support	Subsidies for environmental and social services	European Commission (2010)
Market	Price wheat	+68 % increase	-11% decrease	Ewert et al. (2010)
	Price potato	+15% increase	+5% increase	
Climate change	Temperature	+2 °C increase	+1 °C increase	KNMI scenario's (van der Hurk et al. 2007)

Developments in technology will be of a different nature in the two scenarios. While in A1-W technological progress will be related to further increase in crop productivity accompanied with necessary intensification of production, in B2-G the focus will be on clean and energy saving technology, which does not necessarily lead to higher production intensity. When we relate this to production costs, we expect a larger increase in costs in A1-W compared to B2-G. The Common Agricultural Policy (CAP) is assumed to develop differently in A1-W and B2-G. In A1-W we assume adoption of Option 3 proposed by the European Commission in November 2010, which implies abolishment of direct payments and introduction of small payments for environmental public goods. In B2-G we see the CAP to be similar to Option 1: maintaining levels of payments for social and environmental services. Future market developments are assessed through changes in prices for agricultural commodities using the CAPRI model. The simulated scenarios comprise shocks on the supply site (yield changes) as well as on the demand site (population and GDP) (Ewert et al., 2011). While in A1-W there will be considerable increase in prices for wheat and ware potato, in B2-G the prices will slightly increase (case of potato) or decrease (case of wheat). Regarding climate change, we consider impacts of temperature only, thus not including changes in air circulations. As explained before, A1-W has a higher temperature increase than B2-G.

Dimensions at regional level

Since structural change at regional level results from dynamics in values of each typology dimensions over time due to influence of driving forces, in this methodological step we aim to obtain future values for each of the typology dimensions. The outcomes from the historical analysis and the development of drivers per scenario show which drivers are important for changes in farm type dimensions in the future. Consequently, the drivers that will have a strong influence

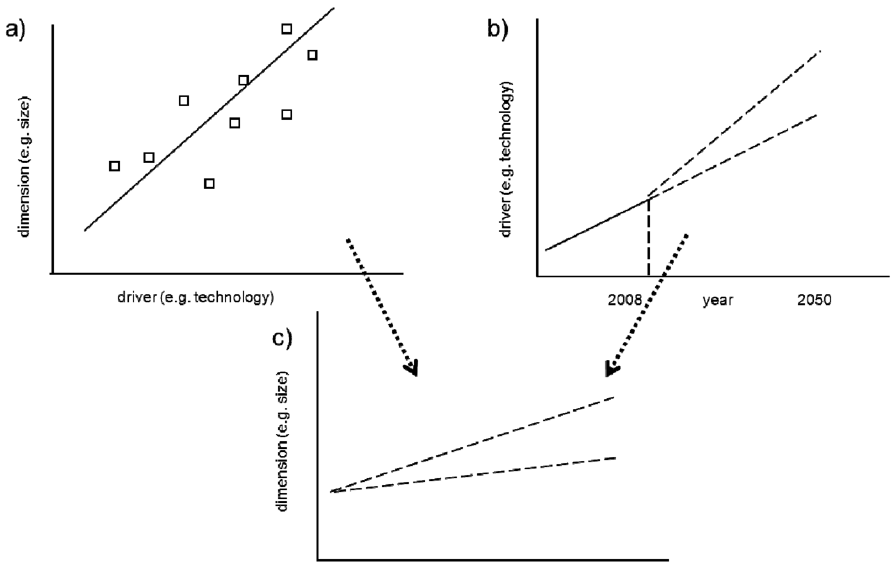


Figure 3.2 Schematic representation of statistical procedure to derive the future farm size based on historical trend analysis

on a dimension in the future are used to derive future regional values for the particular dimension. The steps in the analysis are presented in Figure 3. For example, in the A1-W scenario farm size is expected to change due to technology and markets (see section Results and Table 3.3). We start from deriving future farm size in NGE determined by the technology driver. From historical analysis we obtained the statistical relationship between the technology driver and the dimension of size (Figure 3.2a). Then we extrapolated the autonomous trend of the indicator for technology (input costs for cultivating 1 ha of consumption potato (€/ha) and winter wheat (€/ha)) towards 2050 based on the historical analysis at regional level (Figure 3.2b). Next, we used scenario assumptions for A1-W suggesting increase in input costs and generated future values of costs for a possible range of increase (100-150% continuation of historical trend; see Figure 3.2b). Then we derived the corresponding farm size in NGE (Figure 3.2c) from a possible range of future changes in the technology driver. We did it by taking the : average value from autonomous trend in input costs (100% continuation of historical trend) and 150% continuation of historical trend in input costs. We replicated the procedure for the market driver scenario assumptions on changes in prices for wheat and consumption potato. However, in from our historical data analysis the relationship between wheat and potato price with farm size was not significant. Therefore, the future farm size in the A1-W scenario in 2050 we derived from only the technology driver. We then verified the value against projections and visions for the farm size in A1-W coming from literature and stakeholder consultations. The procedure was repeated for B2-G.

Dimensions at farm level

Structural change at farm level results from change in weights of different farm types defined by the farm typology. Therefore, next to deriving the future values for farm structural dimensions at regional level, we downscaled these to farm type level. Having the current classification of all farms in Flevoland (the distribution of farms in farm types within utilized agricultural area and their percentage in the total farm population) we proceeded with future scenarios. The outcomes from the historical driver-dimension analysis provided information on trends in change of total number of farms, average parameters values for farm size, farm area, area of different crops, and change in orientation for the A1-W and B2-G scenarios (see previous paragraph). From Riedijk et al. (2007) we took the total projected utilized arable area for Flevoland and scenario assumptions on development in arable farming in the Netherlands under the two combined socio-economic and climate scenarios towards 2040. We extrapolated these towards 2050.

We assumed the thresholds for typology dimensions to remain at current level. For NGE this implies that the unit is regularly updated, so that thresholds represent levels related to the viability of farms. Using the total number of farms, average farm size and the total available utilized arable area in 2008 and in 2050 we can arrive atderive future distribution of farm types in the two scenarios. We developed transition rules at farm type level per scenario which are based on the historical analysis of impacts of drivers on structural change and scenario assumptions on development in arable farming.

In the A1-W scenario to stay viable a farmer can follow one of the following options: 1) increase area (from buying the land from a neighbour who stopped), 2) change specialization (towards more profitable crops), 3) diversify (increase share non-agricultural output). Otherwise a farm stops. Some of these options lead directly to structural changes between typology dimensions (i.e. diversification leads to change in orientation, change in crops leads to change in specialization), while other structural changes occur indirectly, according to the definition of the dimensions used in this study. For example, farm size increases as a result of changes in farm area and types of crops in rotation, whereas intensity increases as a result of change in farm size and/or area. The percentage of farms following each of the four options indicated above comes from the percentage of change in a dimension at the regional level. This is another important transition rule (the modeling choice made in this study). For example, if an average farm size increases with 25%, it means that 25% of farms shift to a larger farm type (medium to large, large to extra large). Change in specialization is possible across different groups of arable crops (specialized root/tuber, diverse mainly root, diverse arable). We assume no transition from flower bulb and vegetable types to arable, only arable to flower bulbs and vegetables is possible.

The results from historical analysis on future development in most important drivers and their impact on farm structural change in the B2-G scenario indicate that In this scenario the farms do not necessarily have to enlarge or intensify to stay viable. The most important structural change here is increase of share of nature conservation and entrepreneur farms (each of the farm types will occupy approximately 30% of total utilized arable area by 2050). This assumption is arguable, but we make it on the basis of literature review, both scientific articles and policy documents (e.g. Jongeneel et al. (2008), European Commission (2010)). The percentage of farmers quitting farming is also lower in this scenario.

3.3 Results from application of the methodology

Driver – dimension relationship

Changes in farm type dimensions were attributed to technological progress, as well as policy and market developments. Through the indicator assigned to each driver and structural dimension the historical impact of each driver on structural change was assessed.

As an outcome of the historical trend analysis we obtained the historical relationships between a driver and a dimension (Table 3.2). We used them to project the future impact of each driver on the structural dimension per scenario.

Table 3.2 Contribution of drivers to farm structural change

dimension (indic.) / driver (indicator)	Orientation (share of non-agricultural output)	Farm size (NGE)	Intensity (NGE/ha)	Specialization (area root crops, flowers, and vegetables)
Technology (input intensity)	0	++	0	++
Policy (subsidies)	++	0	0	+
Market (prices)	+	++	+	++
Climate change (T)	0	0	0	+

0 no significant impact on structural change
+ impact on structural change
++ strong impact on structural change

Regarding orientation, policy incentives largely stimulated adoption of non-agricultural activities. The impact from market was indirect: the farmers looked for alternative sources of income due to decrease in prices for major crops over time. Farm size was influenced by technology and market. Increase in crop productivity was mainly caused by technological advances (input intensity, efficient machinery, new crop varieties with higher yields and pest/disease resistance, new management techniques). The output prices define to a large extent farm gross income and therefore they influence farm economic size. While prices for major crops in Flevoland decreased over time, farmers took advantage of economy of scales to increase farm size and compensate for low prices. Intensity was not influenced by the drivers directly. Although productivity increased, and also the types of crops became more intensive, farm area also increased, and the NGE unit is adapted over time to reflect developments. As to specialization, specific crop subsidies or quotas influenced crop choice on farms. Crops with high gross margins like root- and tuber crops, vegetables and flower bulbs increased their share in a typical rotation in Flevoland.

So far, in Flevoland there is no strong evidence of climate change impact on crop choice or any of the other dimensions of the farm typology. However, Olesen and Bindi (2002) and Reidsma et al. (2007) observed that elsewhere in Europe there is impact of climate change through spatial variability in yields and crop choice. Thus we assume a future relationship between climate change and specialization.

Applying the scenario assumptions on changes in technology, policy, markets, and climate (presented earlier in Table 3.1) we projected the impact of drivers per dimension in two scenarios (Table 3.3).

Table 3.3 Impact of drivers on farm structural change in future scenarios

		driver (indicator) \ dimension (indic.)	Orientation (share of non-agricultural output)	Farm size (NGE)	Intensity (NGE/ha)	Specialization (area root crops, flowers, and vegetables)
			A1-W scenario			
Change in drivers	++	Technology (input intensity)	0	++	0	++
	++	Policy (subsidies)	++	0	0	+
	++	Market (prices)	+	++	+	++
	++	Climate change (T)	0	0	0	+
			B2-G scenario			
Change in drivers	+	Technology (input intensity)	0	+	0	+
	+	Policy (subsidies)	++	0	0	+
	+	Market (prices)	+	+	+	+
	+	Climate change (T)	0	0	0	+

Significant differences in types of impact (next to size of impact) of drivers on structural dimensions between scenarios are observed for the impacts of the technology driver. In B2-G scenario the technology changes will be in the direction of energy-saving and environmentally friendly, which will have less influence on farm structure than in A1-W scenario. For orientation, policy is the major driver that has a different focus per scenario with respect to stimuli for adoption of particular non-agricultural activities on the farm. For example, in B2-G scenario policy will largely stimulate alternative functions that agriculture can provide to the society, especially nature conservation. The smaller influence of drivers in B2-G scenario compared to A1-W scenario suggests that farm structural change in B2-G scenario will be less significant than in A1-W scenario.

Regional farm structural change

The regional level results on farm structural change in two scenarios are presented in Table 3.4. In A1-W scenario the average farm size will increase from 95 to 118 NGE due to increase in crop productivity, and shift to more profitable crops and an average farm area increase. Since area is a limited factor in the province, and there have been increases in farm size in NGE, we observe further intensification. In specialization there is a shift towards crops with high standard gross margin (flower bulbs and vegetables) and energy crops (these crops are part of diverse arable specialization). In terms of orientation there is projected to be a larger share of entrepreneurial farms (around 15% of total farm population). Increase in share of entrepreneurial, or multifunctional farming happens, since farmers seek alternative sources of income (e.g. recreation, processing and selling own products) due to changes in the agricultural policy paradigm (abolishment of payments and little alternative subsidies).

Table 3.4 Farm structural characteristics at regional level

Structural characteristics	2008	A1-W scenario	B2-G scenario
Arable UAA, ha	78118[1]	67785[2]	72149
Arable UAA under arable farms, ha	50775	40921	38280
% arable UAA under arable farms	64.5	60.4	53.0
Average size, NGE	95	118	102
Average area, ha	56	70	61
Average intensity, NGE/ha	1.7	1.7	1.7
Average area root/tuber crops, ha	29230	15397	24297
Average area vegetables, ha	6231	10527	7596
Average area flower bulbs, ha	2868	6529	2268

In B2-G scenario there is a larger diversity in farming the landscape. We estimate that average farm size (economic and area) only slightly increases and remains close to the current level. No major changes are expected in the specialization of the farms either. Regarding orientation, a large share of nature conservation farms will be notable for the B2-G scenario (around 30% of the farms will do nature and landscape conservation). This comes when subsidies exceed gross margin of crops and the activity is more profitable, as the level of payment for social and environmental services will be increased in B2-G scenario.

Farm level structural change

Using the example of 'production oriented-medium size-medium intensive-diverse mainly root crops and specialized root crops' farm type, we demonstrate the application of rules that have been developed to translate the regional level results to changes in the distribution of farm types in A1-W scenario (Figure 3.3). From the results of historical trend analysis we know that medium size production oriented farms will disappear, as the only options for them in A1-W scenario are either size enlargement or quitting. The other options (i.e. change in intensity, specialization or orientation) do not apply for medium size farms in A1-W scenario. According to the results at regional level (Table 3.1), there will be 25% enlargement for both area and economic size for arable farms in Flevoland. This implies that 25% of farm population from the farm type medium will move to large and 75% of farms from this farm type will quit. This percentage comes from subtraction from a total farm population (100%) the percentage of farms undergoing structural change (25% for size enlargement). This is the result of application of the transition rules we developed (see methodology section Dimensions at farm level, where we indicate

[1] CBS, 2009

[2] Riedijk et al., 2007

that percentage of change in dimension at regional level will correspond directly to percentage of farms from certain farm type shifting to another farm type. Note, that the high percentage of quitting farms is typical for medium sized farms, as the total decrease in number of farms is 45 % (Table 3.4).

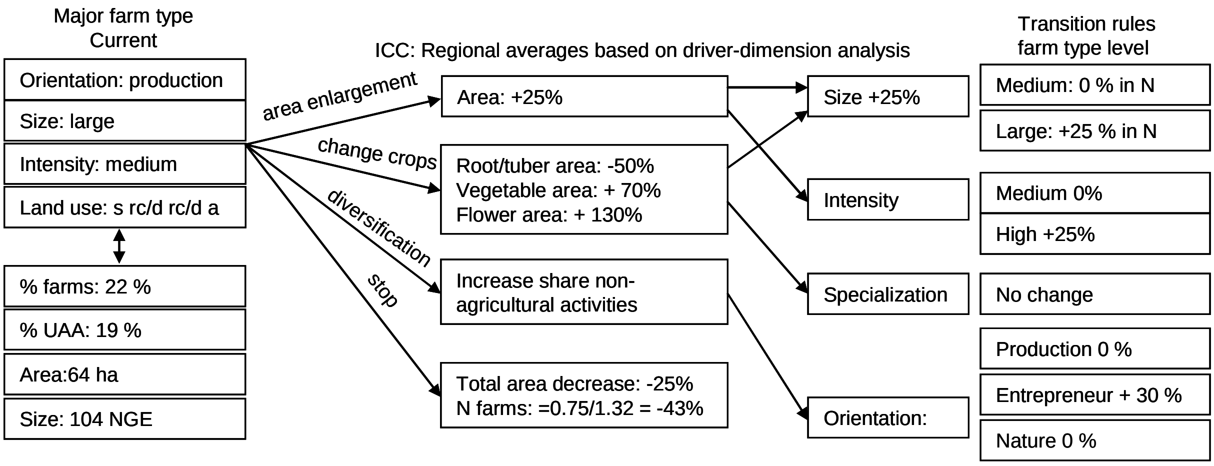


Figure 3.3 Transition rules for a production-oriented-medium size-medium intensity-diverse mainly root crops, diverse arable, specialized root crops farm type in the A1-W scenario

For other farm types there could be other options available (e.g. also change in orientation), depending on the current farm type. For example, 30% of farms from the farm type 'production oriented-very large-medium intensive-diverse mainly root crops' will change to entrepreneur farms.

The most important farm type in A1-W scenario is production oriented-very large-medium intensive-diverse mainly root crops. In B2-G scenario it is entrepreneur oriented-large-medium intensive-diverse mainly root crops and specialized root crops (Table 3.5).

3.4 Evaluation of the results

We presented a method to assess farm structural change at regional and farm level towards 2050, which was not previously performed for such a long time horizon. We used historical analysis (statistics based) combined with hierarchical scenario analysis to project regional structural changes. We developed transition rules to downscale the regional results to the farm type level. The analysis shows that historical trends, consistent scenario assumptions and stakeholder involvement can be used to derive plausible images of arable farms towards 2050. These future farm images provide a proper basis for assessment of impacts of and adaptation to climate change. The scenarios we developed and the method to derive them can be re-used in other regions in the Netherlands or elsewhere in Europe.

A limitation of the method is that it relies on availability of good historical data on farm structure. For some dimensions, such as orientation, this was lacking in our case. Regarding the number of farms implementing multifunctional activities (including nature conservation) and the total economic output from these activities the data is available for the last 10 years only. Besides, these data were not complete and consistent. This is mostly attributed to the procedure the data have been collected: there are different data sources and different definitions of multifunctional activities (Roest et al., 2010). We could not simply extrapolate the percentage of output from multifunctional activities and number of farms implementing different activities towards 2050. Therefore, we made assumptions based on literature review (both scientific articles, and policy documents) regarding transition of farms from production oriented towards entrepreneur and nature conservation types per scenario.

The indicator choice might not have been optimal in this study. Ewert et al. (2005) proposed to model technology through the gap between actual and potential yield. We used variable input costs as a reflection of technological progress, which is an arguable indicator, but was chosen based on data availability. We also chose to work with one indicator per driver to assess the impact of each driver on farm structural change and to assess the impacts of scenario assumptions on a driver. Yet, scenarios are too complex and cannot be reflected by just one indicator per driver.

The transition rules we developed to downscale the regional results to the farm type level are in some cases still arbitrary. For example, we state that in A1-W there will be no medium size farms. We based this assumption on the results of historical trend analysis which shows that medium size production oriented farms disappear, as the only options for them in A1-W are either size enlargement or quitting. Large farms have proven to be more efficient and their share is increasing (see also Figure 4). Small farms can still remain in Flevoland, as these are mainly part-time enterprises, where the farmer is not dependent on farming as a major source of income.

Our results are reflecting the application of a positive rather than a normative approach, i.e. projections are based on what can be expected, not on what is aimed for or desirable from a normative point of view. Grounded in historical data analysis they give predictions on possible developments in drivers and in farm structural characteristics influenced by the drivers. Selected drivers impacting farm structural change in the present study are downscaled from global and European level. The stakeholders (farmers, representatives of farmers organizations and water board) agreed on the translation of the global change scenarios to the regional application, but often projected more drastic changes than can be expected based on the historical data analysis. This comes from the fact that the vision of farmers also reflects how they would like to see their own future; stakeholder views are more normative. The challenge of this study was to combine quantitative statistical projections with qualitative information coming from scenarios to arrive at robust scenarios of farm structural change. We showed what will possibly happen to the farming landscape in Flevoland in 2050 under external changes in two contrasting scenarios. Waldhardt et al. (2010) used one well-elaborated normative scenario to demonstrate to policy makers and land users the design of alternative multifunctional future landscape. For our study it would be interesting to show what future farm structural change implies for agricultural policies and farmer adaptation strategies and what extra needs to be done to achieve normative goals of the stakeholders.

This study provides a context and important insights for climate change adaptations at farm level and regional level. We distinguish here the difference between structural change at farm and regional level: at a regional level farm structural change is an adaptation strategy to policy, market, technology and climate change by itself, while at a farm level it is setting the context for adaptation strategies to climate change. Reidsma et al. (2010) showed that farm level responses are crucial for adaptation to climate change. Therefore, images of future farms are important. The majority of performed studies on impacts of and adaptation to climate change are either focusing on changes in sowing dates and cultivars in the current farming setting (e.g. (Easterling, 1996; Kaiser et al., 1993), and/or assess economic implications in that current setting (Prato et al., 2010). Our study provides a setting for assessment of adaptation strategies to future climate change in a broader context of other important changes and allows to account for alternative functions of agriculture to society in the future. It allows to assess impacts of climate change relative to other factors.

Table 3.5 Farm level results on farm structural change in two scenarios

n	Orien-tation	Size	Inten-sity	Specialization	2008	A1-W scenario	B2-G scenario	size, NGE	size, ha	int, NGE/ha
						% arable UAA				
1	production	small	med	diverse arable (50%)/specialized: root crops(50%)	0.5	0.4	0.4	11	9	1.1
2				specialized: vegetables	0.0	0.0	0.1	13	9	1.4
3		medium	high	diverse: mainly root crops (60%)/specialized: root crops(40%)	2.4	0.0	0.5	50	22	2.3
4				specialized: flower bulbs	0.1	0.0	0.0	41	6	7.3
5			med	diverse: mainly root crops(60%)/diverse arable (20%)/specialized: root crops(20%)	9.7	0.0	2.1	46	29	1.6
6				specialized: vegetables	0.4	0.0	0.6	41	25	1.7
7		large	high	specialized: flower	0.2	0.6	0.2	111	16	7.0
8				diverse: mainly root crops (65%)/specialized: root crops(35%)	5.2	5.4	1.1	104	44	2.4
9			med	specialized: vegetables	0.0	1.0	0.0	100	65	1.5
10				diverse: mainly root crops	19.3	6.1	4.3	104	64	1.6
11		very large	high	specialized: flower	4.0	10.4	3.4	589	61	9.7
12				diverse: mainly root crops(50%)/specialized: root crops(50%)	6.6	8.2	3.6	254	108	2.4
13			med	diverse: mainly root crops	8.7	17.7	4.7	224	130	1.7
14	entrepreneur	medium	high	diverse: mainly root crops (60%)/specialized: root crops(40%)	0.0	0.0	0.8	50	22	2.3
15			med	diverse: mainly root crops	1.4	0.0	5.0	55	36	1.5
16		large	high	diverse: mainly root crops(65%)/specialized: root crops(35%)	0.0	2.3	0.0	104	44	2.4
17			med	diverse: mainly root crops	4.1	6.6	9.7	99	61	1.6
18	nature	medium	high	diverse: mainly root crops(60%)/specialized: root crops(40%)	0	0.0	0.8	50	22	2.3
19			med	diverse: mainly root crops(60%)/diverse arable (20%)/specialized: root crops(20%)	0	0.0	3.1	46	29	1.6
20		large	high	diverse: mainly root crops	0.1	0.0	1.4	97	37	2.6
21			med	diverse: mainly root crops	0.6	1.8	6.2	105	61	1.7
22		very large	high	diverse: mainly root crops	0.8	0.0	2.6	334	132	2.5
23			med	diverse: mainly root crops	0.4	0.0	2.5	199	114	1.7

4 Potential yields for scenarios in 2050 for Flevoland

J. Wolf

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 Climate 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 taken into account. For more information about the applied methodology, see AgriAdapt report no. 1 with the applied methodologies.

4.2 Short description of the methodology

Simulation runs with WOFOST (http://www.wofost.wur.nl/UK/) have been done for the main crops in Flevoland and current weather conditions (period 1992-2008). These runs have been carried out for the current crop varieties and current sowing dates and next, the runs have been repeated for four KNMI climate scenarios 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, and is deep.

Atmospheric CO_2 concentrations that are used as inputs for the WOFOST growth simulations and are combined with the four KNMI climate scenarios for 2050 (i.e. G, G+, W and W+ scenarios from Van den Hurk *et 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 CO_2 abundances). See the link: http://www.grida.no/publications/other/ipcc_tar/. We used the CO_2 concentrations from the ISAM model (Jain et al. , 1994) for 2050 for first, the high emission scenario A1FI and second, the low emission scenario B2, being respectively 567 and 478 μmol CO_2/mol, and for the current situation around year 2000, we use 369 μmol CO_2/mol. The CO_2 concentration from the A1FI scenario might correspond best with the W and W+ scenarios of KNMI and the CO_2 concentration from the B2 scenario with the G and G+ scenarios, but initially we have done simulation runs for all (4* 2) combinations.

The effectiveness of management adaptation to climate 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).

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,

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 climate change.

The simulation 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. The runs 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).

Increase in atmospheric CO_2 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 CO_2 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 range of uncertainty in the generated future weather data.

4.3 Results from application of the methodology

From the simulation runs of crop growth under potential conditions the mean and SD of the following outcomes as simulated over 17 years for Lelystad, Flevoland, are available and also the outcomes per year are available as Excel files on request:

1) Dates of sowing, emergence, flowering (or tuber initiation), and maturity

2) Growth durations

3) Weights at harvest of total roots, leaves, stems, grains /tubers/ bulbs, and total above-ground biomass

4) Maximum leaf area index and harvest index

5) Transpiration coefficient

6) Total gross assimilation and total maintenance respiration
7) Total soil evaporation and total crop transpiration.

From the simulation runs of crop growth under water limited conditions the mean and SD of the following outcomes as simulated over 17 years, and also the outcomes per year are available as Excel files on request:

1) Dates of sowing and emergence, and the growth duration
2) Weights at harvest of total leaves, stems, grains /tubers/ bulbs, and total above-ground biomass
3) Maximum leaf area index and harvest index
4) Transpiration coefficient
5) Components of the water balance during the simulated period, such as cumulative rainfall, change in soil water in maximally rooted zone, cumulative crop transpiration and soil evaporation, and total water losses by downward flow and by surface runoff
6) Fractions of yield and total above ground biomass compared to the yield and total biomass under potential conditions.

Assuming that for regions with high groundwater levels and deep alluvial soils as Flevoland, the water supply will generally not be limiting for growth of the main crops during the summers and that some valuable crops with a limited rooting depth as onion and potato will be irrigated, we will use the simulated potential yields to calculate actual yields in Flevoland in Chapter 5. Hence, we focus in the following on the yield results of the crop growth simulations under potential conditions, as given in Table 4.1. For the reasons described in Section 4.2, we combine the high emission scenario A1FI with the W and W+ scenarios of KNMI, resulting in the A1-W and A1-W+ scenarios, and the low emission scenario B2 with the G and G+ scenarios of KNMI, resulting in B2-G and B2-G+ scenarios.

Results for ***winter wheat*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 6-11% and 3-11% due to mainly the positive effect of CO_2 increase which is larger than the negative effect of temperature rise (being strongest for the W+ scenario and smallest for the G scenario), (b) additional yield increases of 3-4% for the A1-W/W+ scenarios by management adaptation due to the longer growth period.

Results for ***spring wheat*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 11-14% and 9-18% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 6-8% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***spring barley*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 11-14% and 10-18% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 7-9% for the A1-

W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***potato ware*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 4-8% and 2-11% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 8% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier planting date.

Table 4.1 Mean of crop yields (in ton dry matter per ha) for potential conditions as simulated with the WOFOST model for current weather conditions (period 1992-2008; **Base**) in Lelystad, Flevoland and for future weather conditions (also 17 years) around year 2050, and the dry matter fractions in air dry yields. The calculations for future conditions have been done for the four KNMI Climate change scenarios for 2050 (**G, G+, W, and W+**), first, the W and W+ scenarios being combined with a high CO_2 concentration of 567 μmol CO_2/mol from the ISAM model for 2050 for the high emission scenario A1FI (**A1-W, A1-W+**), second, the same high emission scenario but with management adaptation (**A1-W-Ad, A1-W+-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, the G and G+ scenarios being combined with a lower CO_2 concentration of of 478 μmol CO_2/mol from the ISAM model for 2050 for the low emission scenario B2 (**B2-G, B2-G+**)

Crop	Base	B2-G	B2-G+	A1-W	A1-W+	A1-W-Ad	A1-W+-Ad	DM fr. in yield
Winter wheat	10.35	11.44	10.99	11.46	10.63	11.97	10.99	0.84
Spring wheat	9.07	10.36	10.04	10.68	9.86	11.34	10.68	0.84
Spring barley	8.68	9.91	9.63	10.22	9.51	10.94	10.34	0.84
Potato ware	15.61	16.93	16.28	17.31	15.96	18.74	17.31	0.22
Potato seed	11.02	12.12	11.69	12.32	11.33	13.66	12.60	0.22
Sugar beet	16.91	20.17	20.20	22.11	21.75	22.46	22.56	0.20
Maize fodder	22.47	24.57	24.22	24.25	23.17	26.30	25.22	0.33
Maize grain	10.01	11.38	11.24	11.34	10.84	11.78	11.32	0.87
Winter rapeseed	4.72	5.71	5.53	6.01	5.58	6.66	6.19	0.91
Sunflower	3.83	4.24	4.15	4.48	4.26	4.63	4.41	0.94
Peas	5.86	6.51	6.35	6.74	6.39	7.34	6.99	0.87
Onion	13.63	16.39	15.54	17.17	15.56	19.29	17.84	0.20
Tulip	6.76	7.840	7.53	8.17	7.48	8.88	8.15	0.20

Results for ***potato seed*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 6-10% and 3-12% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 11% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier planting date.

Results for ***sugar beet*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 19% and 29-31% due to the positive effect of CO_2 increase and the longer growth period, (b) additional yield increases of 2-4% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***maize fodder*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 8-9% and 3-8% due to mainly the positive effect of temperature rise, (b) additional yield increases of 8-9% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***maize grain*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 12-14% and 8-13% due to mainly the positive effect of temperature rise, (b) additional yield increases of 4% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***winter rapeseed*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 17-21% and 18-27% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 11% for the A1-W/W+ scenarios by management adaptation due to the longer growth period.

Results for ***sunflower*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 9-11% and 11-17% due to the positive effects of CO_2 increase and temperature rise, (b) additional yield increases of 3-4% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***peas*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 8-11% and 9-15% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 9% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***onion*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 14-20% and 14-26% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 12-15% for the A1-W/W+ scenarios by management adaptation due to the longer growth period and the earlier sowing date.

Results for ***tulip*** compared to the current situation: (a) yield increases for the B2-G/G+ and A1-W/W+ scenarios by resp. 11-16% and 11-21% due to mainly the positive effect of CO_2 increase, (b) additional yield increases of 9% for the A1-W/W+ scenarios by management adaptation due to the longer growth period.

4.4 Evaluation of the results

Effects of climate change and increase in atmospheric CO_2 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 (Chapter 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 is almost optimal and the yield levels are high in Flevoland (i.e. actual yields of the main crop types are almost 80% of the simulated yields under potential conditions, see Table 5.1), this assumption is justified.

Changes in climate and increases in atmospheric CO_2 towards year 2050 for the four scenarios result in simulated yield increases for all crop types in Flevoland. These yield increases for 2050 are mainly caused by the increase in atmospheric CO_2, being higher for the A1 emission scenario than for the B2 scenario. The four different Climate 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 → G+ → W → 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 the other scenarios have in-between changes.

The positive CO_2 effect on yield is partly counteracted by the negative effect of temperature rise due to the shortened growth duration. Hence, the yield increases for the A1-W/W+ scenarios appear often to be only slightly higher than those for the B2-G/G+ scenarios (Table 4.1),. This is due to the fact that the A1-W/W+ scenarios have both a higher atmospheric CO_2 concentration and a stronger temperature rise than the B2-G/G+ scenarios, with both effects compensating each other.

The simulated yield changes due to Climate 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 Climate 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 growth simulations practically optimal management is assumed and that the effects of most options to optimize the crop management (e.g. improved nutrient application and crop protection methods, change in soil tillage and in timing of field operations, and/or use of more disease-resistant crop varieties) cannot be studied in these growth simulations. The applied management adaptations result here for all crop types in Flevoland in slightly to moderately higher yields under potential growing conditions. The reason that the effects of management adaptations are often 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 Climate change and limits the positive effects of management adaptation on yields.

Main conclusions are:

- Change in climate and increase in atmospheric CO_2 in year 2050 result in yield increases for all crop types in Flevoland and all Climate change scenarios.

- The four different Climate change scenarios for 2050 from KNMI result in simulated yields for the different crop types that in general differ from highest to lowest yield for the scenarios in following order: G → G+ → W → W+ ; this yield order can be explained from: G scenario has the coolest summer and the W+ scenario has the warmest summer, and the other scenarios have in-between changes.

- Increases in yields in 2050 compared to the current yields are mainly caused by the positive effect of the increase in atmospheric CO_2, whereas this effect is partly counteracted by the negative effect of temperature rise. Hence, the yield increases for the A1-W/W+ scenarios with a higher CO_2 concentration appear to be only slightly higher than those for the B2-G/G+ scenarios (Table 4.1).

- Management adaptation results in slightly to moderately higher yields for the main crop types in Flevoland.

5 Actual yields for scenarios in 2050 for Flevoland

J. Wolf

5.1 Introduction

Actual yield levels of the main crop types in Flevoland in 2050 are required for the farm level analyses (Chapters 8 and 9) for the 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 CO_2, 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.

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 CO_2 and changes in climatic conditions on the actual yields in 2050 can be taken into account. For more information about the applied methodologies, see Chapter 5 of the AgriAdapt project report no. 1 about Methodologies.

5.2 Short description of the methodology

First, we have 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. 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 have been optimized for, in particular, grain crops during the last decades, and future genetic progress in yield of grain (and other main) crops will most likely be achieved by focusing on constraints to RUE, being indirectly influenced by sink strength (Reynolds et al., 2005). 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) describes six potential routes of increasing RUE by improving photosynthetic efficiency, ranging from altered canopy architecture to improved regeneration of the acceptor molecule for CO_2. He states that collectively, these changes could improve RUE and, therefore, yield potential by maximally 50%.

Based on these reviews, the increases in yield potential during the coming decades by genetic improvement can be derived and are estimated at 1% per year. This estimate corresponds well with the estimate as based on the historical yield trends to the future (Ewert et al., 2005; Reilly & Fuglie, 1998). 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+ scenarios (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. For the B2-G/G+ scenarios (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 and more environmental restrictions).

In Flevoland the yield gap between the potential yields and the actual yields in 2006-2008 is for the main crops small (maximally 25%), indicating optimal crop management at present. We assume that this yield gap of 10 to 25% for main crops (Table 5.1) can practically not been 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, spring barley and winter rapeseed, the yield gap appears to be somewhat higher, however, their cropping areas are limited and hence, this is of less importance.

Hence, for the A1-W/W+ scenarios for 2050 the yield gap is set to 1 minus actual yield/potential yield, but maximally 0.2. For the B2-G/G+ scenario we assume that half of the difference between the actual yield gap and a gap of 0.2 can be filled towards 2050.

Table 5.1 Comparison of actual yields (ton/ha air dry) for main crop types in Flevoland with the mean potential yields as modeled with WOFOST, dry mater percentage in air dry yield, and one minus the yield gap fraction (i.e., actual yield / potential yield)

	Actual yield (air dry)[a] 2000-2009[a]	Mean potential yield (air dry)[b]	DM % in yield	One - Yield gap, gap[c]
Winter wheat	9.19	12.32	84	0.746 , m
Spring wheat	6.92	10.80	84	0.641, l
Spring barley	6.74	10.33	84	0.652, l
Potato ware	54.14	70.97	0.22	0.763, m
Potato seed	37.98	50.10	0.22	0.758, m
Sugar beet	73.39	84.56	0.20	0.868, s
Maize fodder	53.20	68.10	0.33	0.781, m
Maize grain	12.25	11.51	0.87	1.064, n
Winter rapeseed	3.18	5.19	0.91	0.613, l
Sunflower	No yield data	4.07	0.94	0.7, as gap set to 0.3
Peas	4.72	6.74	0.87	0.700, m
Onion	62.75	68.13	0.20	0.921, s
Tulip	No yield data	33.82	0.20	0.7, as gap set to 0.3

[a] Derived from CBS (http://statline.cbs.nl/statweb/) for period 2000-2009
[b] Based on crop modeling with WOFOST model for weather data from Lelystad for period 1992-2008
[c] Yield gap in 2000-2009 is nil, small, moderate or large, as indicated by n, s, m and l

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), 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 Climate change and increase in atmospheric CO_2 (note that for 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 some valuable crops as onion and potato with a limited rooting depth will be irrigated and hence, simulated yields for potential growing conditions 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 (see above), d) yield gap for 2050 (GAP50), being equal to the minimum of either the yield gap set for 2050 (GAP50s, as described above) or the actual yield gap (GAPc) at present per crop type (GAPc = 1 – (AYc / PYc)), e) effects of extreme events during crop growth (however, not the effects before and after the growth period on tillage, sowing and harvesting, see Chapters 6 and 7) are included in the current yield gap and hence, are not included separately in these yield calculations for 2050.

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). For GAP50s, see the next paragraphs. We present here two calculation examples for two scenarios, i.e. first the high emission A1-W scenario with the strongest temperature increase and second, the low emission B2-G scenario, with atmospheric CO_2 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 (e.g., 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 9190 kg/ha (Table 5.1), a current (around year 2000) simulated potential yield of 12320 kg (air dry)/ha, a DM content in air dry wheat grain yield of 0.84, a genetic yield improvement factor of 0.30, and a simulated potential yield for the W-scenario in 2050 inclusive management adaptation of 11967 kg DM/ha, the actual wheat yield (air dry) becomes in 2050: 1.30 * (11967/0.84) * Maximum (either 9190/12320 or 0.8; i.e., actual value versus maximal value for one minus yield gap) = 14820 kg/ha

For the B2-G scenario for 2050 using the current yield (air dry) for winter wheat of 9190 kg/ha, a current (around year 2000) simulated potential yield of 12320 kg (air dry)/ha, a DM content in air dry wheat grain yield of 0.84, a genetic yield improvement factor of 0.10, 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 9190/12320 or 1 – GAP50s) = 11578 kg/ha. Note that GAP50s is equal to 0.227, being halfway between a gap of 0.20 and the current yield gap.

5.3 Results from application of the methodology

The actual yields for the main crop types in Flevoland have been calculated for the different scenarios for 2050 (Table 5.2). The ratios between the actual yield and the potential yield from the simulation are used to calculate the current yield gaps, which are partly used (see above) to calculate the yield gaps in 2050. The yields have been calculated for future conditions (i.e., for climate change scenarios with increased atmospheric CO_2, as done in Chapter 4) , and both with and without changes in yield gap and yield potential due to genetic improvement (Table 5.2).

Table 5.2 Actual yields (ton/ha air dry) for the main crop types in Flevoland as calculated for different scenarios for 2050[a] with and without changes in yield gap and yield potential towards 2050

Scenario	Current[b]		2050, no genetic improvement, actual yield gap				2050, genetic improvement & yield gap for 2050			
Crop	Actual yield	Yield potential	G scen.	G+ scen.	W scen.	W+ scen	G scen.	G+ scen.	W scen.	W+ scen.
Winter wheat	9.19	12.32	10.16	9.76	10.63	9.76	11.58	11.12	14.82	13.60
Spring wheat	6.92	10.80	7.90	7.66	8.65	8.15	9.77	9.47	14.04	13.22
Spring barley	6.74	10.33	7.70	7.48	8.50	8.03	9.43	9.16	13.55	12.80
Potato ware	54.14	70.97	58.71	56.46	64.99	60.01	66.15	63.62	88.60	81.81
Potato seed	37.98	50.10	41.77	40.26	47.06	43.42	47.22	45.52	64.56	59.57
Sugar beet	73.39	84.56	87.55	87.67	97.46	97.88	96.30	96.44	126.70	127.25
Maize fodder	53.20	68.10	58.16	57.34	62.25	59.70	64.74	63.84	82.87	79.48
Maize grain	12.25	11.51	13.92	13.75	14.41	13.84	15.32	15.13	18.74	18.00
Winter rape seed	3.18	5.19	3.85	3.73	4.49	4.17	4.88	4.72	7.61	7.07
Sunflo-wer	No data[c]	4.07	3.16	3.09	3.44	3.29	3.72	3.65	5.12	4.88
Peas	4.72	6.74	5.24	5.11	5.91	5.62	6.17	6.02	8.77	8.35
Onion	62.75	68.13	75.48	71.57	88.85	82.16	83.03	78.73	115.51	106.80
Tulip	No data[c]	33.82	27.43	26.35	31.06	28.54	32.33	31.05	46.15	42.40

[a] The potential yield calculations are based on crop modeling with WOFOST for weather conditions and CO_2 concentrations around year 2000 (current) and 2050; the crop management is adapted to climate change for the W and W+ scenarios only; for more information about the potential yield calculation see Chapter 4 and Table 4.1, and about these actual yield calculations, see the text

[b] For information about the current yields, see Table 5.1

[c] Current yield gap is set to 0.3, thus 1 – gap = 0.70

The calculated yields for 2050 if there is no change in yield gap and yield potential from year 2000 towards 2050, are higher than the current yields due to mainly the increase in atmospheric CO_2, but generally lower than the current yield potential due to the yield gap (Table 5.2). Exceptions are sugar beet, onion and grain maize which have in 2050 higher yields than the current yield potential. This can for sugar beet and onion be explained from the strong yield increase due to both the increase in atmospheric CO_2 and the increased duration of the growth period. For grain maize the strong yield increase can be explained from the rise in temperature that becomes more favourable for maize growth.

The calculated yields for 2050 if the yield gap can be reduced and the yield potential increases by genetic improvement, are much higher for the B2-G/G+ scenarios than the current yields due to the increase in atmospheric CO_2 and the improved variety and management, but are often lower than the current yield potential due to the yield gap (Table 5.2). Exceptions are again sugar beet, onion and grain maize which have in 2050 higher yields than the current yield potential, as explained in the previous paragraph. For the A1-W/W+ scenarios with a stronger decrease in yield gap and a stronger increase in yield potential the yields in 2050 for all crop types become higher to much higher (Table 5.2) than the current yield potential due to mainly the strongly improved varieties and crop management.

5.4 Evaluation of the results

The method for the calculation of actual yields for the different scenarios in 2050 can simply be applied and 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 calculation results presented in Sections 5.2 and 5.3, we can assume that the effects of climate change and increase in atmospheric CO_2 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. 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).

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 simulated yield potential and/or in the current yield gap (Table 5.2). Changes in these effects towards 2050 might result in changes in the yield gap, however, such changes in yield gap are difficult to quantify and are not treated here. Hence, the effects of extreme climate events that cannot be covered by these calculations (e.g. climate effects outside of the crop growth period that influence crop emergence or harvesting), are quantified in Chapters 6 and 7 and their results (i.e. changes in frequency towards 2050 of extreme events with their effects on yields, see Table 9.2) are applied in the farm calculations in Section 9.

Main conclusions are:

- Method for the calculation of actual yields for the different scenarios in 2050 is straightforward.
- Calculated actual yields for scenarios in 2050 are dependent on several assumptions (e.g. increase in yield potential towards 2050) and uncertain data (e.g. weather data for 2050) and hence, have a range of uncertainty; however, there appears to be no solid alternative solution.
- A main factor that determines the actual yields in 2050, is the degree that the yield potential of different crop types may increase towards 2050 through genetic improvement; we derived a relationship between this increase in yield potential towards 2050 (+30% and +10%) and respectively, the A1-W emission scenario with rapid economic growth, strong increase in food demand and globalization and second, the B2-G scenario with less economic growth and increase in food demand combined with trade blocks and more environmental taxes; however, this relationship is rather uncertain.

6 Agro-climate calendars and Adaptation measures

B. Schaap

6.1 Introduction

In Flevoland agriculture is a major driver of the local economy (Hermans and Verhagen, 2008; Hermans, Geijzendorffer et al., 2010).Climate change is an additional risk for agriculture and hence to the economic development of the region. Therefore, in 2005 policy makers and other local stakeholders initiated a study in the Northern Netherlands including Flevoland to assess whether agriculture in the region can maintain its strong position given the expected impacts of climate change on the major crops. Policy makers are interested to see which local adaption policies are needed to maintain a strong agricultural sector in the region. Local policy makers, who partly funded this study, were together with farmers and the agricultural sector involved in the research process.

Decisions by farmers are often based on risks related to market forces and policy decisions (Smit and Skinner 2002; Howden, Soussana et al. 2007). Climate change is not yet included in most decision making processes of farmers in the Netherlands, which may lead to sub-optimal decisions by farmers that can result in economic losses or missed opportunities. These opportunities are important, as climate impacts are not always negative. In fact, climate change may also have positive effects and provide opportunities (Adams, Fleming et al., 1995; Olesen and Bindi, 2002; Chloupek, Hrstkova et al., 2004; Alcamo, Moreno et al., 2007). For example, climate change may allow production of new vegetables or fruits such as grapes in areas, where this was previously not possible (Jones, White et al., 2005).

Crop growth models are a commonly used tool to assess the effects of elevated CO_2 levels and climate change on agricultural yields (e.g. (Adams, 1986; Rosenzweig, Phillips et al., 1996; Downing, Barrow et al., 2000; Reilly, 2002; Reilly, Tubiello et al., 2003; Parry, Rosenzweig et al., 2004; Porter and Semenov, 2005; Wolfe, Ziska et al., 2008; see also Chapter 5 of this report). The results from these studies show positive and negative impacts on yields. For northern latitudes, most of the modeling studies show a positive combined effect of elevated CO_2 levels and increased temperatures (Adams, Fleming et al., 1995) and some report a slightly negative effect (Parry, Rosenzweig et al., 2004). Others point out that higher temperatures could also lead to lower wheat yields because of a shorter grain filling stage and a shorter growing season (Wolf and van Diepen, 1995; Eitzinger, Formayer et al., 2008). When also including technological development as a yield-determining factor, the relative change is mostly positive (Ewert, Rodriguez et al., 2002).

These model studies provide valuable insight in the effects of biological processes influenced by temperature and CO_2 increase. Unfortunately they often do not include all factors that determine actual crop yields (Wolfe et al., 2008; Tubiello et al., 2007). This makes it difficult to translate results from modeling studies into actual changes in regional productivity (Ewert et al., 2002; Tubiello et al., 2007). Often, yield determining factors such as pests and diseases and extreme events are not modeled, whereas these factors could be more important than the changes of CO_2 levels and temperature (Porter and Semenov, 2005; Cobon et al., 2009; Rosenzweig et al., 2002; Tubiello et al., 2007).

Some authors (Vereijken and Hermans, 2010; Hermans et al., 2010) addressed the combined impact of climate change and changing market conditions on agriculture in Europe. A comparable study has been done on future agriculture in the northern part of the Netherlands(see Section 6.1), also including Flevoland. See Figure 6.1 for a map of the Netherland with the province Flevoland. The results from these studies indicate that gradual changes are not expected to lead to a disruption of the agricultural sector. The relative strong position of agriculture in this region is the combined result of a favorable biophysical and institutional environment. This is, however, not a guarantee for the future position of the region as an important producer and exporter of agricultural products. Extreme events and pests and diseases can potentially have a strong impact on the yield and quality of high value crops (Olesen and Grevsen 1993; Jones, White et al. 2005; Maracchi, Sirotenko et al. 2005) and can threaten the relative strong position of this predominantly agricultural area (Hermans et al. 2010) as markets may not accept a decline of product quality (e.g. spread of pests and diseases).

Figure 6.1 Map of the study region Flevoland

As agriculture is of importance to the local economy of the northern Netherlands, and because this sector will be impacted by climate change, a risk assessment of climate factors can help to identify opportunities and threats to crop production. By combining information (climate sensitivity of crops, occurrence of climate factors, farm management) from various sources we assess the risk of Climate change on agriculture in the northern part of the Netherlands. To complement other crop impact studies we will not assess mean warming and the rise of CO_2 levels, but we rather focus on extreme events including the emergence and abundance of pests and diseases. Furthermore this study does not only include potential yield losses, but also loss of product quality. The aim of the risk assessment is to inform stakeholders (e.g. farmers and policy makers) about the direction and order of magnitude of change of climate factors and to give an overview of the most important threats and opportunities. Farmers can use this overview to develop farm-level management responses, or adaptation measures (e.g. the use of better adapted crop varieties) and policy makers can use the overview as a basis for regional adaptation strategies (e.g. regional water management strategies).

A total of 15 cropping and 2 animal production systems have been studied (Schaap et al., 2009 and De Wit et al., 2009). For the cropping systems an Agro Climate Calendar (ACC) has been developed (Schaap, Blom-Zandstra et al., 2009). The 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 Agri-Adapt project, such as the farm modelling in Chapter 9. The integration of the applications of the different methods is discussed in Chapter 2.

6.2 Description of the method

This applied method identifies:

1. the most important risks of extreme climate events and climate driven changes in pests and diseases on crop production and crop quality and
2. adaptation measures that prevent damage from the above risks.

An important part of the method is the stakeholder interaction. Farmers and other sector representatives as well as policymakers have been part of the research process. In Figure 6.2 an overview is given of this process, in which workshops have been used to share the developed knowledge and to receive feedback from stakeholders on risks and impacts (Chapter 7 and this Chapter), on farm typologies and scenarios for Flevoland (Chapter 3), and on valid adaptation measures for Flevoland (this Chapter and Chapter 9).

In workshop I, feedback has been given by the stakeholders on the risks of climate factors for arable farming in Flevoland as explained in Section 6.2.1.

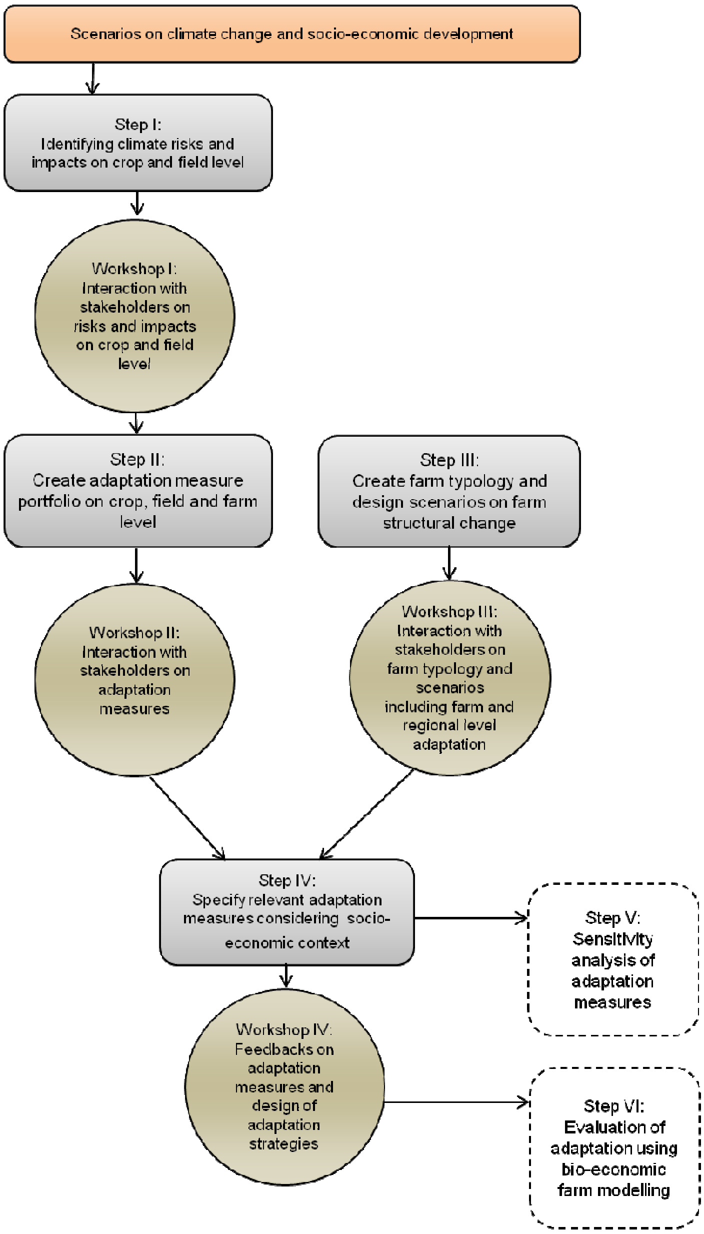


Figure 6.2 Process diagram for the methodology. Central are the workshops where scientific knowledge and practical implications are shared amongst researchers and stakeholders . Figure is taken from the report 'Adapting agriculture in 2050 in Flevoland; perspectives from stakeholders' (Schaap et al., 2011b)

We have used multiple climate thresholds for a selection of the most important crops of the selected region. The vulnerability of crops has been analyzed for two distinct periods: 1976 – 2005 (further referred to as 1990) and 2026 – 2055 (further referred to as 2040). A total number of 15 crops has been analyzed, but information about two crops is presented here. To illustrate the method, we selected the most important crop for the region in terms of value, seed potato, and the most common crop in terms of area, which is winter wheat (Table 6.1).

The second focus point is related to adaptation measures. After the risks and potential impacts have been discussed with stakeholders from the region, adaptation measures are proposed that can prevent damage to crop production. We took a broad range of adaptation measures from literature and from practice and compiled an extensive list. The adaptation measures are then discussed with stakeholders from the region.

6.2.1 Agro Climate Calendar

In order to identify the specific impacts of extreme weather events on arable farming systems in the northern region of the Netherlands, we have looked at the frequency of these extreme events, the potential development of pests and diseases and the effects of extreme events on the quality of the agricultural products.

To assess the possible impacts of extreme weather events on crop production we have identified five different steps. In the first step, relevant crops were selected based on their economic importance and spatial claim in the region (Table 6.1).

In the second step, we collected location-specific weather and climate information.

In the third step, we identified crop- and crop management-specific vulnerable periods and climate factors. These climate factors are critical weather thresholds for crop damage that occur in specific periods in the year. This was done by combining information from peer reviewed and "gray" literature, results from model studies and expert judgment.

In the fourth step, changes in the frequency of occurrence of the climate extremes based on the historic data records for 1990 (1976 – 2005) and for the predicted future climate 2040 (2026-2055) for two climate change scenarios (van den Hurk et al. 2006), are determined for a representative meteorological station in the selected region. Note that the 2040 time horizon is lightly different than the 2050 time horizon used for modeling with WOFOST (Chapter 4). A 30 year period is commonly used to describe and define the climate.

In the fifth and final step the climate factors and changes in frequency of extreme events are confronted with each other, resulting in a change in the impact of climate factors on crop production and quality levels (Figure 6.3). The resulting Agro Climate Calendar (ACC) gives insight in the changes that are critical for crop production and quality. This information is used in the next part of the study (Tables 6.9 and 6.10 and next Chapter 9), in which crop and farm level adaptation options are defined and prioritized.

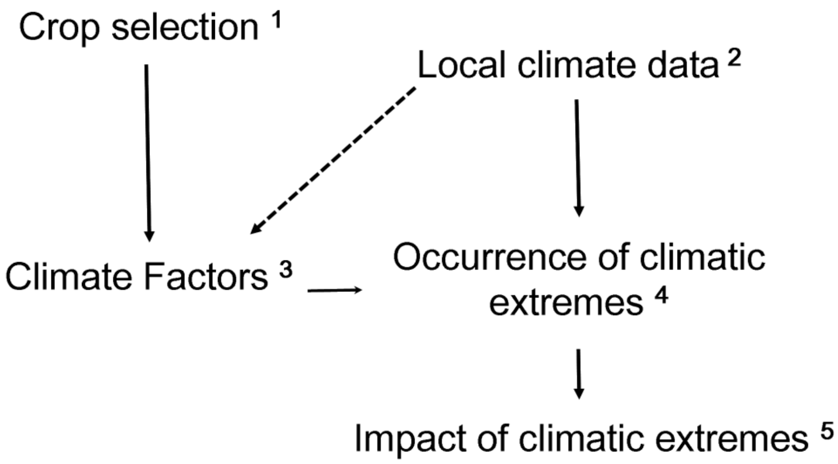


Figure 6.3 Diagram of the steps used in the Agro Climate Calendar

Step one - Crop selection

The fifteen most important crops in the region were selected on basis of four criteria: area occupied, economic importance according to the European Size Unit (ESU) for size of production, type of product (food, fodder, ornamental, or energy source) and sector (arable, livestock, horticulture). The area occupied, extent, and economic importance are taken from the Geographical Information System for Agricultural Businesses (GIAB) dataset (Naeff 2006).

The crop list contains the following traditional crops: potato (three types of potato; seed, consumption, and starch), grass, wheat, sugar beet, carrot, lily, rapeseed, cherry and onion. The list was extended with crops that might have economic potential in the region under future climate conditions. Selected crops are sunflower, grape and artichoke. The selection of these crops was based on their importance in regions with current climatic conditions that are expected in the northern part of the Netherlands in the future, such as northern France (Kattenberg 2008). Additionally, also a biofuel crop was selected: common reed. Local stakeholders were consulted in order to give their expert judgment on the list of selected crops.

To illustrate the methodology we present the results for two of the 15 selected crops: seed potato, the most important crop in terms of value, and winter wheat, the most common crop measured in terms of area (Table 6.1). When describing the results, we follow the sequence of farming events, starting from field preparations until crop storage.

Step two - Local climate data

To assess the changes in extreme events from the reference period 1990 to 2040, we used historical data records from the Royal Netherlands Meteorological Institute (KNMI) from weather station Eelde and the KNMI'06 scenarios (van den Hurk et al. 2006).

The KNMI'06 scenarios were obtained by downscaling a range of Global Circulation Model (GCM) simulations and Regional Climate Models (RCMs), and by transforming historic weather into future weather conditions, as described by van den Hurk et al. (2006). It is problematic that not all RCMs indicate the change in the prevailing winds (circulation change), that will affect future rainfall patterns. Therefore, next to temperature rise, the KNMI'06 scenarios make use of an additional driving factor: the index of circulation (Figure 6.4). The plus sign in Figure 6.3 indicates that there is a change of circulation and thus an altered rainfall pattern. In such a scenario, the temporal distribution of rainfall will be different from the current situation (i.e. same amount of rainfall in summer periods but less evenly spread). The scaling procedure produces predicted weather towards 2100 with a daily time scale for weather station Eelde.

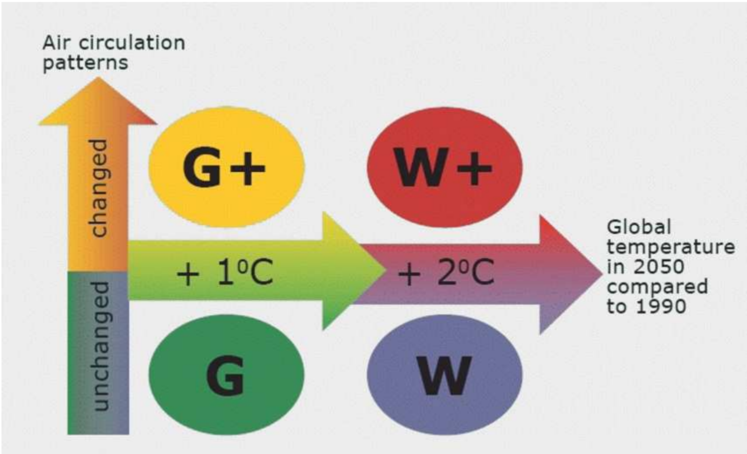


Figure 6.4 The KNMI'06 scenarios of the Royal Dutch Meteorological Society (adapted from: van den Hurk et al., 2006)

For this study we selected two contrasting climate scenarios from the KNMI'06 scenarios for the 2040 time horizon, the G+ and the W+ scenario. The G+ scenario is comparable to the B1 and B2 scenarios used in IPCC SRES (Parry et al. 2004), whereas the W+ scenario corresponds to the SRES A1 and A2 scenarios. The weather and climate data are the basic input for step four.

Step three - climate factors

Each crop has a specific development sequence and requires a series of management activities during its development. Standard management practice in agriculture starts with soil tillage and field preparation and ends with harvest and storage. Weather is an important driver of crop development and determines the timing and effectiveness of management activities. The ACC follows this sequence of events and lists climate factors that have a potential direct or indirect negative effect (in terms of damage) on crop production and quality.

For example, tuber bulking and maturation of potatoes are critical phases that can be negatively affected by extreme wet or dry conditions. Extreme wet conditions can also hamper seeding or harvest activities. Moreover, the occurrence and abundance of pests and diseases are strongly linked to climate factors such as warm and wet conditions or prolonged wet periods. Specific crop factors and potential impacts are based on expert judgment, literature, and crop models as presented in Tables 6.2 and 6.3.

Step four - Occurrence of climatic extremes

The weather and climate information collected in step two is used to calculate the changes in frequency of each climate factor on a monthly basis. We have calculated these changes in frequency by first determining the current frequencies of each climate factor for the reference climate of 1990 and next, determining the future frequencies for the climate projections for 2040 for the two contrasting scenarios (G+ and W+).

Step five - Impact of climatic extremes

In this step the possible impacts and damage levels related to the changes in occurrence of the climate factors are determined. The 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. This information can then be used as a basis for field and farm level adaptation strategies. Sector sessions are being held to validate the degree of impact that these climate factors have on current farms with local stakeholders. The current standard gross margin of the crop is taken as the potential economic loss for each climate factor. (basic assumptions for this calculation are given in De Wit et al., 2009, annex 3).

Per crop type it is also indicated which positive effects climate change might have. 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.

6.2.2 Selecting 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 6.10). These adaptation measures are taken from literature and current expert knowledge on 'state of the art' farm management. 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.

6.3 Results

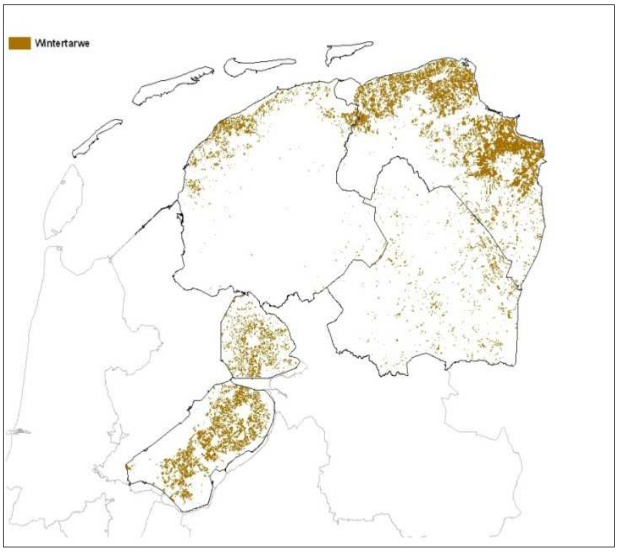
6.3.1 General

Examples for the results on risks and impact for crop production is given mainly for seed potato and winter wheat and to a lesser extent for sugar beet, see Table 6.1. The same information is available for the other main crops in the Netherlands too. For example, Table 6.10 gives information about the adaptation measures for the main arable crops grown in Flevoland, such as seed potato, winter wheat, sugar beet, onion, carrot and lily.

Table 6.1 Important arable crops for Northern Netherlands measured by area (ha) and the Economic Size Unit (ESU) per hectare; 1 ESU represents a standard gross margin of about €1200, source: European Commission, 2010

Crop	Area (x1000 ha)	ESU / ha	Total ESU (x10^6)
Seed potato	13.4	4310	57.7
Winter wheat	36.5	1180	43.1
Sugar beet	24.3	2460	60.0

Seed potato is the smallest crop measured in area for the region (Figures 6.6) but it has a high value and in the rotation it is the dominant crop because it generates the highest share of revenue (Table 6.1). Seed potatoes from the Netherland are exported and used for planting in many parts of the world (Africa, Middle East etc.). Wheat is the main grain crop in the world, but in the region (Figure 6.5) it is mainly grown to support the rotation of potato-sugar beet-grains. Seed potatoes are planted in planting beds in spring (around April) and are harvested in summer. Most of the wheat in the Netherlands is grown for fodder in the meat industry. 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.



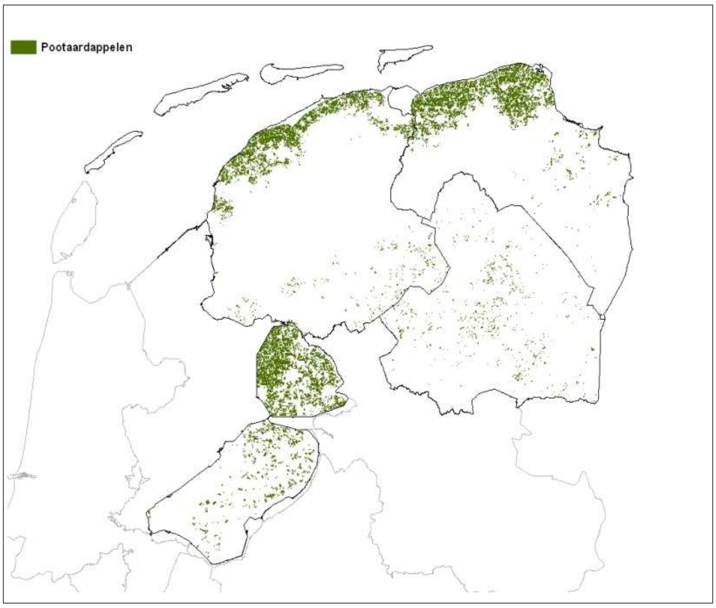
Area in 2008[Error! Bookmark not defined.]

- Northern-Netherlands: 54.504 ha
- Groningen: 31.646 ha
- Friesland: 7.186 ha
- Drenthe: 2.326 ha
- Flevoland: 13.346 ha

Crop characteristics

- Sowing: Sept. – Febr.
- Harvest: Aug.- Sept.
- Cultivation in rotations

Figure 6.5 Areas with winter wheat cultivation in the Northern part of the Netherlands and some characteristics



Areaal in 2008[Error! Bookmark not defined.]

- Northern-Netherlands: 23.661 ha
- Groningen: 8.178 ha
- Friesland: 6.531 ha
- Drenthe: 961 ha
- Flevoland: 7.991 ha

Crop characteristics:

- Planting: March - April
- Harvest: Juli – Sept.
- Planting on ridges
- Indicatieve yield[Error! Bookmark not defined.]:
  - Tubers: 33.000 kg/ha
  - Price:€0,20 per kg
  - Revenues: €6.600 per ha

Figure 6.6 Areas with seed potato cultivation in the Northern part of the Netherlands and some characteristics

6.3.2 Climate factors, impact on crop and damage

In Tables 6.2 and 6.3 the climate factors are described as follows: on a monthly basis, as a meteorological event, with farm management, as impact on the crop, and finally as the % of the weight of the economic loss of such a climate factor.

The monthly basis shows when the crop is potentially exposed to the climate factor. For example, wet conditions may result in larger yield losses due to disease infestation and/or due to a delay in harvesting in winter wheat. The main climate factors for winter wheat and seed potato, their effects on crop growth and yields, and the yield losses are given in respectively, Tables 6.2 and 6.3.

Table 6.2 Agro Climate Calendar that gives climate factors, their meteorological description, the type of farm management if applicable, the impact on the winter wheat crop, the vulnerable period, and the estimated range of crop losses (in % market value). See also Schaap, Blom-Zandstra et al., 2011

Climate factor	Vulnerable period	Meteorological description	Farm management	Impact on crop	Weight of economic loss (%)	Reference
Wet field	Oct – Dec	Period of 21 days of more than 0.5mm rainfall on 75% of the days	Ploughing and preparation of sowing bed	Delayed planting date	-	(Darwinkel 1997)
Frost-thaw	Nov – Mar	Period of minimal three days of repeated frost and thawing (night T < -1°C and day T > 1°C) after period of strong frost (Min. T < -10°C), incl. a 2 day transition period to thawing	-	Root damage	10 - 50	(Timmer 2008)
Drought	Jun - Aug	At least 40 days with less than 10mm rainfall	-	Lower grain yield	10 - 50	(Timmer 2008)
Sustained wet	Apr – May	At least 21 days with more than 0.5 mm precipitation on 75 % of the days	-	Yield decrease by Leaf blotch *Septoria tritici*	25 - 75	(Timmer 2008)
Sustained humid	May – Jul	At least 21 days with more than 0.5 mm precipitation on 75 % of the days	-	Yield decrease by Seedling blight *Fusarium spp., Septoria nodorum*, reduced product quality (mycotoxins)	25 - 75	(Darwinkel 1997)
Wind and rain surges	May - Aug	Precipitation of 45 mm or more in one day	Harvest	Lodging, inability to harvest	unknown	(Timmer 2008)
Sustained wet	Jul – Sep	Period of 21 days of more than 0.5mm rainfall on 75% of the days	Harvest	Inability to harvest	10 - 75	(Timmer 2008)

Table 6.3 Agro Climate Calendar that gives climate factors, their meteorological description, the type of farm management if applicable, the impact on the seed potato crop, the vulnerable period, and the estimated range of crop losses expressed (in % market value). See also Schaap, Blom-Zandstra et al., 2011

Climate factor	Vulnerable period	Meteorological description	Farm management	Impact on crop	Estimated range of crop losses (%)	Reference
Wet field	Oct - Apr	Period of 21 days of more than 0.5mm rainfall on 75% of the days	Ploughing and preparation of planting bed	Delayed planting date	-	(Bus, van Loon et al. 2003)
High intensity rainfall	May – Sep	Daily precipitation of at least 45 mm or at least 60 mm in three days	-	Rotting of the tubers	25-75	(Haverkort 2008)
Heat wave	Jul – Sep	Heat wave (at least 3 days with more than 30°C in a period of at least five days above 25°C)	-	Second-growth	25-75	(Jackson 1999; Haverkort and Verhagen 2008; Haverkort 2008)
Warm and wet	Jul - Sep	At least 14 consecutive days with a maximum temperature above 20°C and for 50% of the days at least 0.5 mm precipitation	-	*Pectobacterium* (previously Erwinia) *carotovorum* causes soft rot and black leg	10-50	(Haverkort and Verhagen 2008; Haverkort 2008; Czajkowski, Grabe et al. 2009)
Sustained wet weather	Jun – Sep	A period of at least 21 days with more than 0.5 mm precipitation on 75 % of the days	Spraying	Not possible to spray against *Phytophthora infestans*	50-100	(Zwankhuizen and Zadoks 2002; Haverkort 2008)
Wet field	Aug - Oct	Period of 21 days of more than 0.5mm rainfall on 75% of the days	Harvest	Damage to tubers	N.A.	(Bus, van Loon et al. 2003)
Warm winter	Dec – Mar	Period of at least 14 days with a maximum temperature above 10°C	Storage	More rotting of tubers and early sprouting in March	25-75	(Bus, van Loon et al. 2003; Haverkort and Verhagen 2008)

6.3.3 Shifting frequencies for climate factors for Winter Wheat and Seed Potato

Current situation for Winter Wheat

In Table 6.4 it is indicated per climate factor how often the factor occurs per month in a period of 30 years for winter wheat. Under the current climatic conditions (around year 1990) permanent moist weather in the period 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 for winter wheat in Eelde measured by KNMI in the period 1976-2005 and indicative values for management costs and investments for winter wheat (see adaptation measures in Table 6.10 for more detail)

	Month												Manag.costs (k€/ha) [2]	Investment (k€/ha) [3]
Climate factor [1]	J	F	M	A	M	J	J	A	S	O	N	D		
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
[2] Indication of the maximal annual management costs to cope with the climate factor 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 to cope with the climate factor 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

Situation 2040 for Winter Wheat

Prolonged drought slightly increases over the period 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 for winter wheat 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 6.10 for more detail)

	Month																								Manag.costs (k€/ha) [2]	Investment (k€/ha) [3]
Climate factor [1]	J		F		M		A		M		J		J		A		S		O		N		D			
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

1) see Tables 6.2 and 6.3 for further information
2) Indication of the maximal annual management costs to cope with the climate factor 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 to cope with the climate factor 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

The sowing of winter wheat can sometimes be problematic if the previous crop is late (e.g. after mid-October) and when the period between October and early December is wet. Wet periods in October to December do occur regularly, but fortunately farmers can sow spring wheat in the next year instead of winter wheat. At present, frost and thawing does not occur often, but according to Table 6.5 it will occur more in the future and may cause a potential yield loss of 10-50% for individual fields. Drought (40 days with less than 10 mm rain) is not a frequent phenomenon and it seems that it will not occur significantly more under a G+ scenario or W+ scenario. Sustained periods of wet and humid weather do not seem to increase, and in August even a modest decrease in the W+ scenario can be identified. Consequently, the conditions for the development of leaf blotch (Septoria tritici) and Fusarium are not more favorable: Fusarium might even decrease in August. Wind and rain surges are not likely to change significantly. Harvesting may prove difficult because of the occurrence of wet periods from July to September.

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)

Current situation for Seed Potato

Currently, wet fields between October and March are problematic for plowing (Tables 6.6 and 6.7). This may lead to lower yields or increased costs if planting starts too late or under unfavorable conditions. A too dry soil between March and April can lead to delays in planting. Moreover, the growth of the potato tubers can be reduced, if moisture conditions are sub-optimal for the newly planted potatoes. Intense rainfall during the growing season is not very common in the northern part of the Netherlands; it only occurred twice in August and once in September during the reference period 1976-2005. Heat waves occur more regularly. The frequencies of sustained wet weather are high compared to other climate factors

Table 6.6 Frequency of occurrence of climate factors for seed potato in Eelde as calculated by KNMI for the period 1976-2005 and indicative values for management costs and investments for seed potato, (see adaptation measures in Table 6.10 for more detail).

	Month	Manag	Investment

Climate factor [1]	J	F	M	A	M	J	J	A	S	O	N	D	costs (k€/ha) [2]	(k€/ha) [3]
Wet field	13	5	5	0						5	8	9	nd	nd
High int. rain fall					0	0	0	2	1				0,4 – 0,5	7 - 8
Heat wave							2	6	0				1 - 2	15 - 25
Warm and wet							0	1	0				0,1 - 0,2	1 - 2
Sustained wet					5	8	7	5					5 - 6	80 - 90
Wet field								5	4	5			nd	nd
Warm winter	0	0	3									0	0,4 - 0,5	7 - 8

[1] see Tables 6.2 and 6.3 for further information
[2] Indication of the maximal annual management costs to cope with the climate factor 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 to cope with the climate factor 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)

Situation 2040 for Seed Potato

It is expected that in 2040 there will be a notable increase in the frequency of warm winter months. Consequently, farms without adequate cold storage facilities will be negatively affected. As mentioned before, wet field conditions between August and October can become problematic when harvesting with heavy machinery.

Table 6.7 Change in the frequency of the occurrence of climate factors for seed potato 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 for seed potato (see adaptation measures in Table 6.10 for more detail).

	Maand																								Manag costs (k€/ha) [2]	Investment (k€/ha) [3]
Climate factor [1]	J		F		M		A		M		J		J		A		S		O		N		D			
Wet Field	+1	+4	0	+1	0	0	0	0											0	-1	+1	0	+2	+3	nd	nd
High int. rainfall									0	0	0	0	0	0	0	-1	+1	+1							0,5 - 0,7	10 - 15
Heat wave													+2	+12	+7	+12	+1	+3							3 - 5	60 - 100
Warm and wet													+4	+6	+5	+6	+1	+2							1 - 2	20 - 35
Sustained wet									-2	-2	-2	-4	-2	-5	-4	-3									-	-
Wet field															-3	-3	0	-1	0	-1					nd	nd
Warm winter	0	+2	+1	+3	+3	+8																	+1	+1	1 - 3	20 - 60

[1] *see Tables 6.2 and 6 3 for further information*
[2] *Indication of the maximal annual management costs* to cope with the climate factor *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* to cope with the climate factor *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

According to Table 6.7 the frequencies of high intensity rainfall will not increase dramatically relative to the baseline frequencies presented in Table 6.6. However, it is expected that heat waves will occur more frequently; they range from an extra 1 to 7 events under the G+ scenario from June to August, and from 3 to 12 events under the warmer W+ scenario. Thus, increased occurrence of second-growth can be expected. The environmental conditions for the development of Pectobacterium carotovorum become more favorable in both the G+ and W+ scenarios. This may lead to increased yield losses. Interestingly, it may become easier to battle one of the current major hazards in potato production, late blight (Phytophthora infestans). The period when fungicides against late blight need to be applied will become drier, which reduces spraying difficulties. Both under the G+ and W+ scenarios, the occurrence of sustained periods of humid weather will decrease. However, storage problems may occur because of higher winter temperatures, especially under the W+ scenario. High intensity rainfall (which can lead to rotting of tubers) may increase, but the frequency change is expected to be rather limited.

Summarizing, most of the climate factors for seed potato do seem to be problematic, although for some factors the increase of the frequency is not big. The climate factor that will have a lower frequency is sustained wet and this might indicate fewer problems with *Phytophthora infestans*.

6.3.4 Selecting adaptation measures

In Tables 6.8 and 6.9 the possible adaptation measures to prevent or limit damage due to climate change for 2050 are given for respectively, winter wheat and seed potato.

Table 6.8 Adaptation measures for the most risky climate factors in 2050 for winter wheat (see adaptation measures in Table 6.10 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 resistant crop variety	Sector	-	1.000 - 10.000 [2)]
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 [2)] costs cannot be expressed per hectare			

We focus here on winter wheat. 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 under dry conditions too. 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.

Table 6.9 Adaptation measures for the most risky climate factors in 2050 for seed potato (see adaptation measures in Table 6.10 for more detail)

	Level	**Indicative Costs**	
High intensity rainfall – Rotting of tubers (May - Sept.)		Annually (k€/ha)	Investment (k€/ha)
Increase permeability of sub soil [1)]	Farm	0,2 - 1	-
Increase ability for surface drainage [1)]	Crop/Farm	0,1 - 0,2	-
Intensify drainage	Farm	0,1 - 0,2	0,5 - 2,5
Develop variety that can cope with water stress	Sector	-	1.000 - 10.000[2)]
Heat wave – Second-growth (July - Sept.)			
Plant in wider ridges	Crop/Farm	0	>50
Plant and harvest earlier	Crop/Farm	-	-
Cooling by drip irrigation	Crop/Farm	1	-
Optimal planting distance and optimal nutrient management for good crop cover	Crop	0 – 0,5	-
Develop a heat resistant variety	Sector	-	1.000 - 10.000[2)]
Warm and wet – Bacterial disease Erwinia (Juli - Sept.)			
Develop resistant variety	Sector	-	1.000 - 10.000[2)]
Organic control	Sector	nb	nb
Optimise nutrient management (healthy plant is less vulnerable)	Crop/Farm	0 - 0,5	-
Warm winter – difficulties with storage due to sprouting (Dec. - March.)			
Air conditioning	Crop/Farm	0,1 - 0,2	3
Sprouting control	Crop/Farm	0,1 - 0,2	-
Develop a new variety without sprouting problems	Sector	-	1.000 - 10.000[2)]

Remarks:
[1)] for possible measures see De Wit et al. (2009), annex 4
[2)] costs cannot be expressed per hectare

More detail about the climate factors that are considered as risks, and the required adaptation measures are given in Table 6.10 for winter wheat and also for seed potato, sugar beet, onion, carrot and lily. 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.

Table 6.10 Climate factors of importance (with extreme events), impact on crop production, potential economic loss in euro/ha, damage profile, the adaptation measures and their effectiveness, variable costs and capital input (from De Wit, Swart et al. (2009) and expert judgement)

Crop	Climate factor	Impact	Potential economic loss €/Ha	Potential damage profile	Adaptation measure	Scale	Effectiveness	Variable costs (€)	Capital input (€)
Seed potato	**Field is too wet for planting (traffic-ability)**	**Late emergence**	**4800**	**10 - 30 %**	More organic matter in top soil for better soil structure	Field	Low	200	
					GPS steering to prevent damage to soil structure	Field/Farm	High	100	20000
					Automatic inflation correction	Farm	Medium	100	20000
	Warm winter	**Storage problems**	**4800**	**25-75 %**	Air conditioning	Farm	High	200	3000 (per ha)
					Sprouting control (chemicals)	Crop	Medium	200	

Crop	Climate factor	Impact	Potential economic loss €/Ha	Potential damage profile	Adaptation measure	Scale	Effectiveness	Variable costs (€)	Capital input (€)
Winter wheat	**Long dry period**	**Yield decrease**	**800**	**10-15 %**	More organic matter in top soil	Farm	Low	200	300
					Develop drought resistant variety	Sector	High		10000
	Wet field	**Delayed planting date**		**10%**	Re-sowing	Field	Medium/High	100	

Crop	Climate factor	Impact	Potential economic loss €/Ha	Potential damage profile	Adaptation measure	Scale	Effectiveness	Variable costs (€)	Capital input (€)
Sugar Beet	**Long dry period**	**No emergence**	**2275**	**20-35%**	NA	NA	NA	NA	NA
	Warm winter	**Loss of sugar content**		**10-25%**	Forced ventilation of storage heap	Farm	High	200	6000
					Optimise sowing distance with GPS	Field/Farm	Medium/Low	1000	15000
					Shorten storage time	Sector/Farm	High	-	1- 10 Million

Onion	**Long dry period in spring**	**Crop failure**	**6600**	**0 - 100 %**	Irrigation	Farm	High	500	25000
					Re-sowing	Field	Medium	500	500
					Higher sow density	Field	Low	500	500
	Warm and wet - Fungi	**Quality decrease**		**50-60 %**	Crop protection (chemical)	Field	High	1000	50000
					UV crop protection	Farm	High	650	30000
	Long dry period in summer	**Decreased growth**		**30-40 %**	Irrigation	Farm	High	500	25000
					More organic matter in top soil	Field	Low	300	
	Soil is inundated	**Harvest not possible**							

Carrot	**Dry growing season**	**Delayed emergence**	**6800**	**30-40%**	Irrigation	Farm	High	500	25000
					Drip irrigation	Farm/Field	High	1000	
					Re-sowing	Field	Medium	300	
	High intensity rainfall	**Rotting**		**10-50 %**	More organic matter in top soil for better soil structure	Field	Low	200	300
					GPS steering to prevent damage to soil structure	Field/Farm	High	100	20000
					Automatic inflation correction	Farm	Medium	100	20000
					Intensified drainage	Farm	Medium/High	200	1500

Lily	**High intensity rainfall**	**Rotting of tubers**			Increase the infiltration rate soil (same as more organic matter in top soil)	Farm	Low/medium	500	500
					Increase sub surface flow	Field	Medium		200
					Intensified drainage	Farm	High		2500

Other negative effects of climate change on winter wheat - 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 (a) biocide application and (b) later sowing date. An early natural attack by e.g. beetles and spiders may prevent that the 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 effects of climate change - Permanent wet weather will occur in the future less often, which might lead to improved traffic-ability 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 of less important. It is possible that (yellow) rust and barley-yellowing diseases may become a larger problem with climate change and require more attention (e.g. more biocide application and/or development of resistant varieties).

6.4 Discussion

6.4.1 Risks and impact on crop production

For the main crops in Flevoland, the ACC gives the risks of 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 has been determined for the current climate in Flevoland. Next, for the different KNMI future climate scenarios (van den Hurk, Klein Tank et al. 2006) the changes in these frequencies per crop type have been determined. Some threats, however, are not described in the dataset, because the relationship between specific weather conditions and their impacts is insufficiently clear and/or too complex. This holds mainly for some indirect consequences from climate change on pests and diseases. Apart for some limitations, the method appears to give a good overview of the most important changes of extreme events and the associated impacts on the crop.

In a next step we have translated the frequency of unfavourable weather conditions during sensitive periods per crop type and the change in their frequencies per crop type for a climate change scenario for 2050 into a relative yield reduction per crop type for that scenario. This allows to correct both future mean yields and yield variations for scenario weather conditions. Furthermore, costs and benefits of adaptation strategies have been quantified for the farm modelling, in order to assess whether farmers are likely to adopt these strategies (as done in Chapter 9) or not. However, see the remarks in the next paragraph. A strong point of the method is that the calendar approach is able to present data on extremes on a monthly basis and that it is easily presented to and discussed with stakeholders. The feedback from stakeholder (mainly from the sector) has been crucial for the quality of the regional dataset of risks and impacts for arable crops in Flevoland.

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 ACC (see Table 6.10) 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 climate 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 frequent under different scenarios of climate change in the future and the required adaptation measures, e) model simulations of crop growth and yields for future scenario climates generally assume optimal crop management and sufficient management adaptation under a changing climate, because in the long term technological development cannot be separated from adaptation; this means that in model simulation 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. This information complements the yield calculations, as it indicates which adaptation is required to prevent damage from certain 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.

6.4.2 Selection and adoption of Adaptation measures

The list of climate risks and adaptation measures in Table 6.10 has initially been compiled with the best available knowledge from literature and expert judgement. In the workshops held with farmers in the region these adaptation measures have been specified and some proposed measures have been 'weeded out', because they were regarded as too impractical, too expensive or not substantial at all. This resulted in a list of adaptation measures to climate change risks and impacts of extreme events for arable cropping, that contains elaborate information and is rooted in the farming region.

To also explicitly address the adoption and impact of adaptation measures, we have perform an additional assessment for 2010, by assuming that the climate conditions of 2050 are reflected by an extreme (current) 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 one (i.e. impacts of climatic risks) 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 on farm management. Furthermore, climatic extremes do not give an average yield reduction, but only a reduction in the years in which they occur. One option is to use the average of the estimated damage range (see Table 6.10 and Chapter 9) and another option is to improve the yield reduction with new knowledge based on empirical data (from 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 9) the possible adoption of the adaptation measures and their impacts can be assessed. The data from Table 6.10 are used as input in the farm model (Table 9.2).

Sensitivity analyses (see step V of Figure 6.2) can be performed to investigate whether the adoption of the adaptation measures is sensitive to estimates on the damage of climatic risks, the costs and benefits of adaptation measures, and/or the frequencies of climatic risks from climate change scenarios.

7 Effects of extreme events on crop management, yields and yield quality

P.A.J. van Oort and B. Timmermans

7.1 Introduction

For two crops (potato and sugar beet) we have studied in detail how historical yields were affected by weather extremes. These two crops were chosen because they are economically important in Dutch farming and because much data are available on these crops. We have compiled time series of historical yields from annual reports of experimental farms in the Netherlands.

In the resulting time series we have searched for years with large negative yield anomalies, i.e. the yield in such years being more than 20% lower than expected, based on the long term trend. As we will show, many of these large negative yield anomalies are caused by adverse weather conditions. From descriptions of management and weather in the annual reports, we could derive qualitative definitions of weather extremes, largely responsible for the yield anomalies, for example “wet spring delaying planting”. Next, we derived quantitative definitions of weather extremes. Finally, we derived a threshold planting date, beyond which adverse effects on yield may be expected and a planting rule, which predicts planting date as a function of weather in the preceding days. Having identified the key weather extremes and translated them into quantitative definitions, we studied whether their frequency in the future would increase.

Below, we present data, methods and results for potato (Section 7.2), for sugar beet (Section 7.3) and conclusions (Section 7.4).

7.2 Extremes in potato

7.2.1 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 coarse 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. We will quantify their effect on loss of production and quantify the past and future frequency of these extremes.

7.2.2 Short description of the methodology

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,
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 www.knmi.nl and downscaled scenarios of Climate 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.

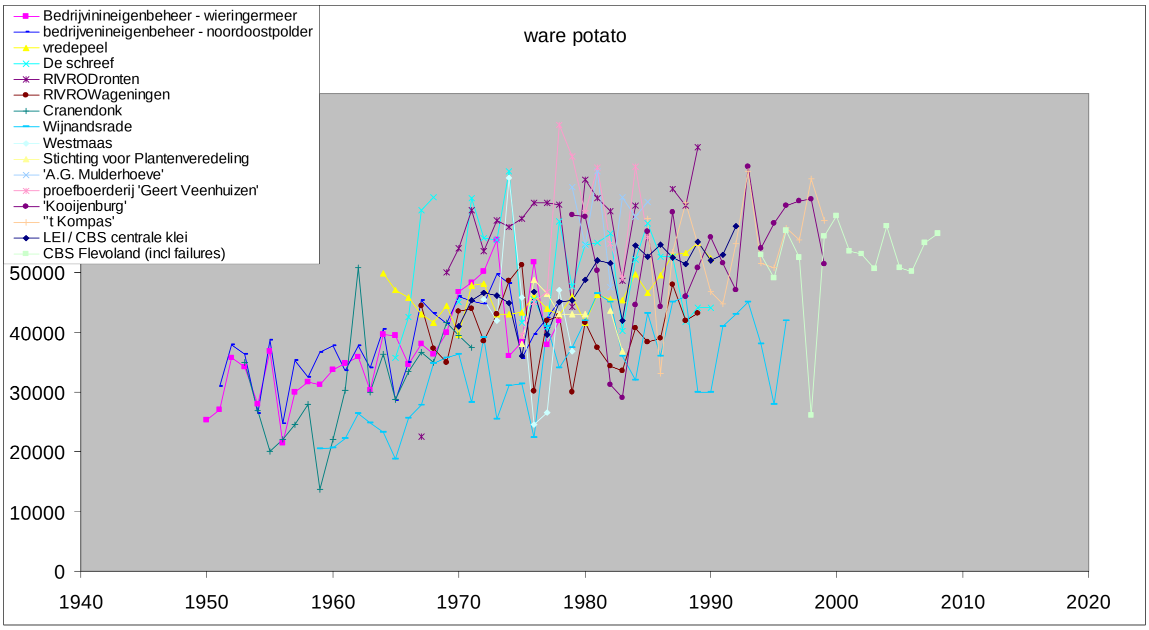


Figure 7.1 Time series of ware potato yields (kg/ha) for various experimental farms and national datasets

7.2.3 Results from application of the methodology

Over the past 50 years, the most important weather extremes affecting ware potato production have been a continuously wet spring which delayed planting (years 1956, 1965, 1975, 1979, 1983) and a continuously wet end of the growing season which may hinder harvesting (1998 whole country, 1974 west part of the country). Figure 7.2 shows that these two extremes can explain all major yield anomalies in the past 50 years for the province of Flevoland.

We define the extreme "wet start" through a threshold date for late planting and a rule for predicting the potato planting date. Potato planting date is best predicted with the following rule:

$$DOY_{plant} = 76.7+0.388*rainsum_{75\text{-}125}$$

where $rainsum_{75\text{-}125}$ is the sum of rainfall from day 75 to 125 (16 March to 5 May). We found that when planted later than day 120, large negative effects on yields may be expected (-30 to -40% when planted around day 150-160). It is difficult to say how large this effect on yields is, as this effect also depends on subsequent summer and autumn weather and as such late plantings are very rare (thus there are few data). From the equation above, we can derive that late planting occurs when $rainsum_{75\text{-}125} > 110$ mm.

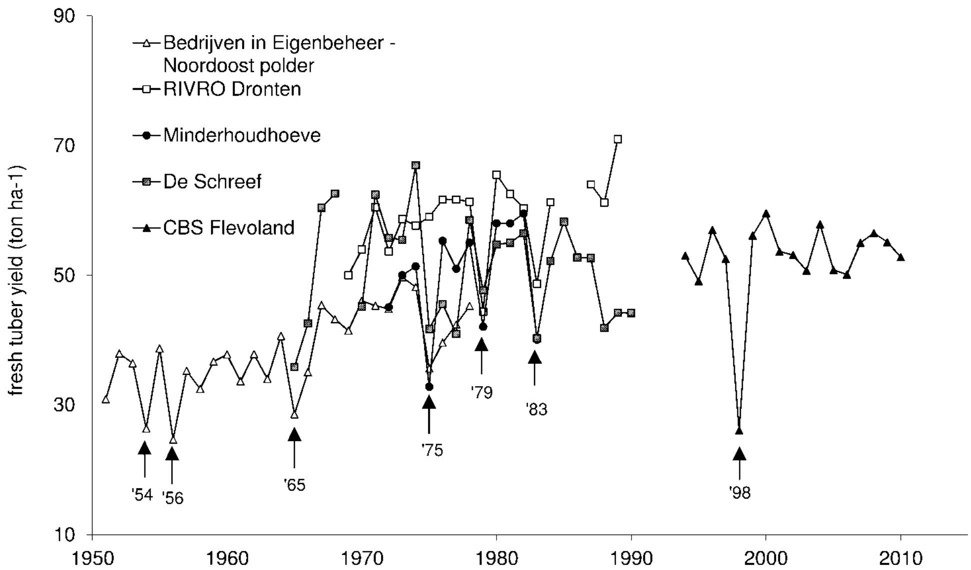


Figure 7.2 Time series of ware potato yields (kg/ha), with arrows for years with large negative yield anomalies

We define the extreme "wet end" through a threshold date for autumn rain and a linear equation for estimating the percentage of land not harvested as a function of autumn rain. The threshold and equation were derived by iteratively changing the start and end date of the period, over which the rain sum is calculated. Table 7.1 shows the thresholds and equations that gave the most accurate results. 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. Note that thresholds and the equations for % of the land not harvested differ between regions, probably due to differences in soil.

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

Region	% not harvested	Threshold (mm rain in 20 aug-4 nov)
Zeeland + Noord-Brabant (ca 40 % of total ware potato area on clay)	0.86*(rainsum-280)	280
Flevoland + Zuid-Holland (ca 42 % of total ware pot area on clay)	0.4*(rainsum-300)	300
Limburg + Noord-Brabant (64 % of total ware potato area on sand/peat)	0.21*(rainsum-280)	280

The year 1998 was a dramatic year for Dutch ware potato production (Figure 7.3), for the whole of the country. Written reports indicate that 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.

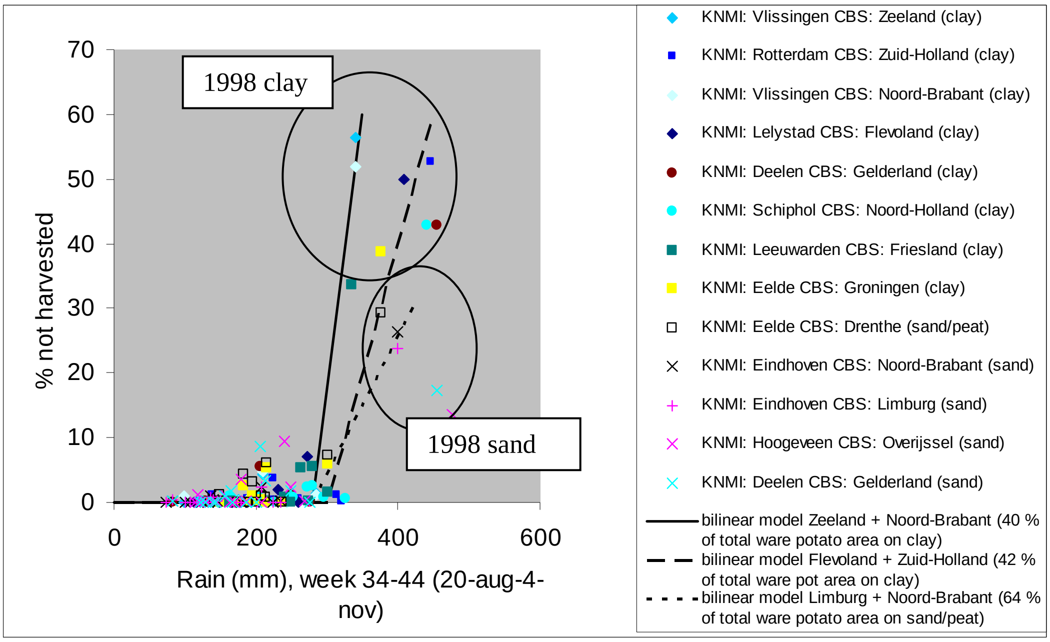


Figure 7.3 Harvesting problems associated with extreme rainfall, with on the X-axis the sum of rainfall over the period August 20 to November 4

7.2.4 Climate Change Scenarios

Using the definitions of weather extremes in the previous section, we calculated whether these would change in the future, by comparing frequencies calculated for KNMI climate change scenarios with frequencies calculated for historical weather data. Table 7.2 shows return intervals; for example, a return interval of 6 means that a certain threshold is exceeded on average once in 6 years. If the return interval changes to 4, this means that the frequency increases.

Table 7.2 Return interval of ***wet start*** of the season based on the rain sum planting rule for three historical weather data sets and for the four climate change scenarios

threshold (doy) ->		120	140
		Return interval (years)	
historical	1960-2009	5	25
	1960-1989	4	15
	1976-2005	6	30
Scenarios[a] 2050	G	4	30
	G+	4	30
	W	4	10
	W+	4	30

[a] Scenarios:
G = +1 °C (2050 rel. to 1990), weak change in atmospheric circulation
G+ = +1 °C (2050 rel. to 1990), strong change in atmospheric circulation
W = +2 °C (2050 rel. to 1990), weak change in atmospheric circulation
W+ = +2 °C (2050 rel. to 1990), strong change in atmospheric circulation

Table 7.2 shows frequencies for two thresholds: day 120 (start of negative yield effects) and day 140 (large negative effect. This shows that the frequency is expected to increase relative to the period 1960-2009 and relative to the period 1976-2005. Also one can see that the period 1960-1989 has a high frequency of the "wet start" extreme.

In a similar manner we calculated changes in the frequency of the "wet end" extreme. Table 7.3 shows the return interval of having more than 300 mm rain (threshold) and of having more than 350 mm rain (severe harvesting problems). This shows that the frequency of this extreme (>350 mm) is expected to remain unchanged or increase in the future.

Table 7.3 Return interval of ***wet end*** of the season for the four Climate change scenarios in comparison with those for the historical weather data set 1976-2005

	1976 - 2005		Future return interval (F350)			
Weather station	F300	F350	G	G+	W	W+
Valkenburg (Z.-Holland)	8	30	30	30	15	30
De Kooy (N.-Holland)	8	30	10	15	8	30

Schiphol (N. -Holland)	15	30	15	30	15	30
De Bilt (Utrecht)	15	30	30	30	30	30
Soesterberg (Utrecht)	30	30	30	30	30	30
Leeuwarden (Friesland)	15	>30	30	30	15	30
Eelde Groningen)	15	30	30	30	30	30
Twenthe (Overijssel)	30	30	30	30	30	30
Vlissingen (Zeeland, Westen part of N.-Brabant)	30	>30	30	30	30	30
Rotterdam (Z.-Holland)	10	30	10	15	10	30
Volkel (Noord-Brabant)	30	30	30	30	30	30
Maastricht (Limburg)	30	>30	30	>30	30	>30
Average	20	30	25	27	23	30

To test the sensitivity to the chosen historical period, we also compared frequency changes relative to the period 1974-2003. These results are given in Table 7.4, which results show that the frequency of this extreme increases less than that in Table 7.3. This sensitivity analysis shows that the resulting change in frequency is strongly dependent on the choice of the historical period, with which we compare. Also, it should be noted that in climate change scenarios the uncertainty in rainfall projections is much larger than the uncertainty in temperature projections.

Table 7.4 Return interval of wet end of the season for the four Climate change scenarios in comparison with those for the historical weather data set 1974-2003

	1974 - 2003		Future return interval (F350)			
Weather station	F300	F350	G	G+	W	W+
Valkenburg (Z.-Holland)	8	15	30	30	15	30
De Kooy (N.-Holland)	6	15	10	15	8	30
Schiphol (N. -Holland)	30	30	15	30	15	30
De Bilt (Utrecht)	15	30	30	30	30	30
Soesterberg (Utrecht)	30	30	30	30	30	30
Leeuwarden (Friesland)	30	>30	30	30	15	30
Eelde Groningen)	15	30	30	30	30	30
Twenthe (Overijssel)	30	30	30	30	30	30
Vlissingen (Zeeland, Westen part of N.-Brabant)	15	30	30	30	30	30
Rotterdam (Z.-Holland)	8	15	10	15	10	30
Volkel (Noord-Brabant)	30	30	30	30	30	30
Maastricht (Limburg)	30	>30	30	>30	30	>30

Average	21	26	25	27	23	30

7.3 Extremes in sugarbeet

7.3.1 Introduction

The relation between yield anomalies and weather extremes is less clear in sugarbeet than in potato. However, there is also a strong indication that large yield anomalies in sugarbeet are due to late sowing (1966, 1975, 1983, 1985, 1994, 1998, 2001). As above for potato, we try to derive a rule for calculating the date that sugarbeet farmers do their sowing. And from this, we have made projections on whether climate change may result in a shift in sowing dates or not.

7.3.2 Short description of the methodology

The methodology presented here is still under development. Here we present the current status of our research at the time of publication of this report, which work is to be continued.

The Dutch sugarbeet institute divides the Netherlands in a number of regions. For each region it records since 1996 every year how much of the sowing is done in every week. We aim to reproduce the weekly percentage sown in all 15 years and in four regions: 1 (ZV, Zeeuws Vlaanderen), 5 (Flevo, Oost- en Zuid Flevoland), 6 (NOP, Noordoostpolder) and 7 (NK, Noordelijke klei). Other regions appeared to be too large to relate to a single weather station and hence, this would complicate analyses too much. We used weather data of the Royal Dutch Meteorological Institute (KNMI), from stations 319 (Westdorpe) in region ZV, 269 (Lelystad, Flevo), 273 (Marknesse, NOP) and 277 (Lauwersoog, NK).

We simulate for each region and for each year the daily percentage of sowing. We aggregate these daily to weekly percentages and compared them with observed weekly percentages. The percentage sown was calculated as:

$$SIMSOW_{r,y,doy} = earliest * suitable * percentsown$$

where $SIMSOW_{r,y,doy}$ is the percentage sown in year y on day doy in region r ; *earliest* and *suitable* are binaries indicating whether or not day *doy* is suitable for sowing and *percentsown* is the percentage sown in case of a suitable day. Variable *earliest* is 0 for any day before the earliest possible sowing day and 1 after that day. Therefore, we need a method to estimate the earliest possible sowing day. Variable *suitable* is 1 if in the preceding x days rainfall was not more than y mm (or average temperature in the preceding x days was no less than y °C). *Percentsown* is a parameter. All parameters are estimated, by systematically testing a wide range of parameter values and retaining the most accurate model.

7.3.3 Results from application of the methodology

We found that there is large variation (30 days) in earliest day between the years. Figure 7.4 shows that the earliest date is best predicted with radiation sum from day 245 (previous year) to day 100 current year (R^2 = 0.60). A small further increase in accuracy can be gained by including rainfall sum and temperature sum from day 50 to 110, which raises the accuracy to R^2 = 0.69. Models with only rainfall or only temperature could not accurately predict earliest sowing date.

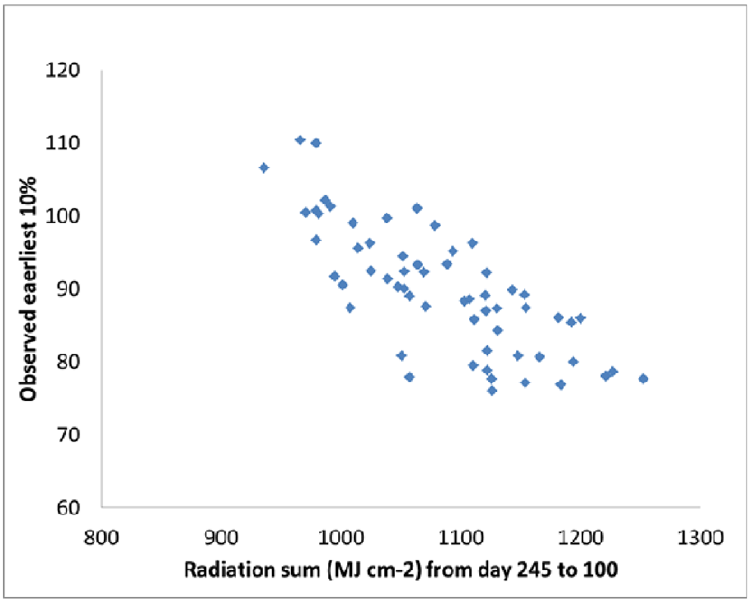
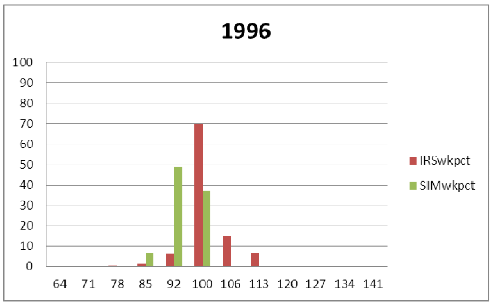
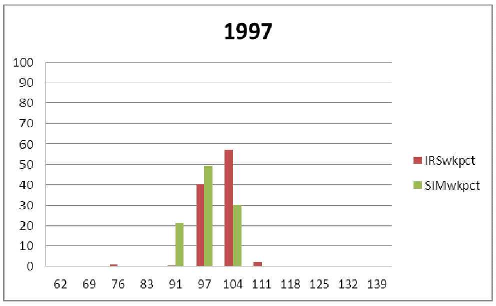


Figure 7.4 Earliest sowing day (first 10%) and its correlation with the radiation sum between day 245 (previous year) to day 100 in current year

Beyond the earliest date, we found that the daily percentage of sowing depends on rainfall. According to the most accurate rule, 7% of the cropped area will be sown on any day, for which in the past 8 days rainfall was less than 19 mm. Further gains in accuracy can be obtained with separate rules for *suitable* for each region. Such rules are currently under investigation. Figure 7.5 shows four examples of observed and simulated weekly percentages of sowing during two late years (1998 and 1999) and two normal years (1976 and 1977).





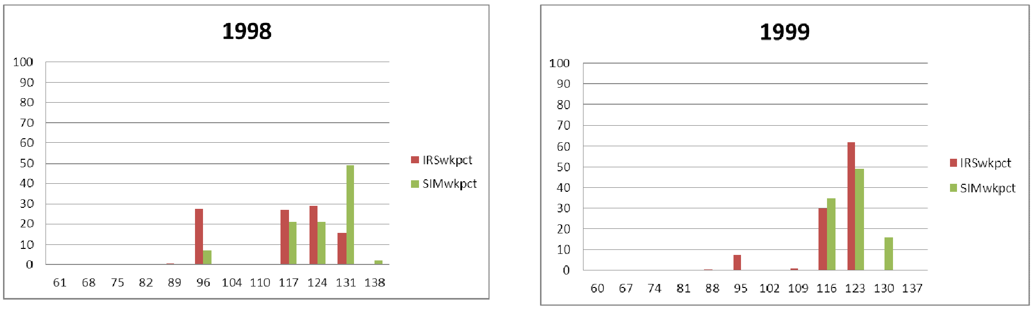


Figure 7.5 Weekly percentages of sowing in the Noordoostpolder in two normal years (1996 and 1997) and two late years (1998 and 1999). Red (dark) bars: observed, green (light) bars: simulated. Y-axis is the percentage of sowing, X-axis is the day number. For example, a bar at day 100 with 70% sown (see 1996) means that 70% has been sown in the period from day 93 to 100

7.3.4 Climate change Scenarios

The striking outcome of these analyses is that, contrary to expectations, the sowing date is not or only weakly affected by temperature, whereas we also systematically searched for temperature effect. We have found that radiation plays an important role in determining the start of the growing season. At the time of writing we do not yet understand the underlying mechanism, but the 60% variation in earliest sowing dates as explained by radiation in the preceding 200 to 260 days, cannot be ignored and calls for further research. It might be that a higher value for total solar radiation is related to a more dry winter and spring and thus to a more dry topsoil, allowing earlier sowing.

In the crop growth simulations for scenarios of climate change with and without management adaptation (see Chapter 4), the sowing date in case of adaptation has been advanced by 15 days compared to the current date (from day 100 to 85). The simulation results showed that this adaptation would increase yields by 8%. The question raised here is: is such a shift in sowing date realistic? We answer this question from two perspectives: (1) the risk of bolting as modeled with the model by Milford et al (2009) and (2) the sowing rule as discussed above.

Calculations with the model and cultivar parameters in Milford et al (2009), combined with Dutch weather data, indicate that there is no risk of bolting at a sowing date of 85, not in the current climate and also not in the future climate. From this perspective, a 15 day shift in sowing date appears to be viable.

Based on our model for earliest sowing of sugar beet and assuming that the same rule will remain valid in the future, we anticipate a shift in sowing date becoming 1 to 5 days earlier. From this perspective, a change of 15 days earlier appears to be unlikely.

7.4 Conclusions

We have identified the weather extremes that were responsible for the largest negative yield anomalies in ware potato and sugar beet. For ware potato in the province of Flevoland in the last 50 years the two most important weather extremes are: 1. a wet start of the season delaying planting which in turn reduces the yield; 2. a wet end of the season that inhibits harvesting operations. Quantitative meteorological definitions of these extremes have been developed. Climate change scenarios indicated either no change or increased frequency of the extremes identified here. We have shown that statements on changes in frequency are uncertain due to the lack of long (> 30 years) historical weather data and due to the uncertainty in climate change projections in terms of rainfall. In climate change scenarios, the uncertainty in rainfall projections is much larger than the uncertainty in temperature projections. In sugar beet, late sowing appears to be a major cause, though not the only cause, of low yields in specific years. We find that sowing dates depend on the radiation total over the last 200 to 260 days and on rainfall in the period of day 80 to 130. Our data suggest that, if farmers don't change their rules for selecting their sowing date, a shift in sowing date becoming 1 to 5 days earlier can be expected.

The method developed here, of identifying relevant weather extremes through a form of reverse engineering, in which we start with yield anomalies, weather data and descriptions of management and weather and we derive quantitative definitions of extremes, is widely applicable provided that sufficient data are available. In our reconstruction of historical data we noted that since 1990, far less data are available than before 1990 (with a notable exception for the availability of data from the Dutch sugar beet institute IRS).

A striking point in our highly empirical analysis is that the main extremes are related to rainfall (and in case of sugarbeet also radiation) and not to temperature. There is a large uncertainty in climate change scenarios of rainfall. This raises the question whether at this stage calls for adaptation to these extremes are necessary. The outcomes of our research can help meteorological modelers to focus their research on those extremes that really matter for agriculture.

8 Sensitivity analyses for arable farming in 2050 in Flevoland

J. Wolf

8.1 Introduction

For farm analyses we know that the FSSIM optimization model, including PMP to calibrate FSSIM exactly to the observed cropping pattern in the Base year 2005, cannot be applied with the same objective function to the scenarios for year 2050. The reason is that we cannot establish to what extent the unobserved costs as derived from the PMP calibration, will still apply in 2050. Hence, we cannot relate the cropping pattern in 2050 to that in 2005. As analyses for year 2050 are of interest from a climate change impact point of view, we have developed a much more simple approach (without optimization).

In addition, relative changes in yields, product prices, variable costs, additional labour, farm size and subsidies towards 2050 are uncertain. This is a second reason to apply for farm level analyses for 2050 a sensitivity analysis that still can show in a clear way to what extent there are trade-offs and interactions between changes in these variables. For more information about the applied methodology, see Chapter 9 of the AgriAdapt project report no. 1 about Methodologies.

8.2 Short description of the methodology

Economic results have been produced for arable farming in Flevoland. The calculations have been done assuming fixed cropping patterns. These cropping patterns (Table 8.1) are based on the farm structural change work by Mandryk et al. (2011; Chapter 3 of this report). The calculations have been done first for the main arable farm types in Flevoland in the Base year 2005 (i.e. 2005-run). Economic results (e.g. gross margin per ha of crop, gross margin per labour hour per crop) for the crop types grown on the farm types in Flevoland in the Base year are given in Table 8.3. Second, the calculations have been repeated for the same farm types in Flevoland with the same cropping patterns, farm area, labour use per crop type, product prices, costs but with yields calculated for the A1-W scenario for 2050 (i.e. inclusive effects of Climate change and increased atmospheric CO_2) with crop adaptation, called 2050-A1-W-only run. Third, the calculations have been done again for the same farm types in Flevoland with the same cropping patterns, farm area, labour use per crop type, product prices, costs, but with yields calculated for the B2-G scenario for 2050, called 2050-B2-G-only run. Fourth and fifth, the calculations have been repeated for the same farm types in Flevoland with the same farm area and labour use per crop type, but with cropping patterns (Table 8.1), product **P**rices (Table 8.4), costs and yields for respectively the A1-W and the B2-G scenarios for 2050 (see Table 8.2), called respectively, 2050-A1-W-P and 2050-B2-G-P runs.

Sixth and Seventh, the calculations have finally been done for the same farm types in Flevoland with the same farm area and labour use per crop type, but with cropping patterns, product prices, costs, and yields for respectively the A1-W and the B2-G scenarios for 2050, and also with further yield increases due to **T**echnological (i.e. crop genetic and management) improvements, called respectively, 2050-A1-W-P-T and 2050-B2-G-P-T runs. The used yields and methods are described in Chapter 5.

Table 8.1 Cropping patterns on the main arable farm types in Flevoland, Netherlands in Base year 2005 and scenarios A1-W and B2-G scenarios for 2050

Farm type Scenario, Crop type[1]	Production orient.,very large High intensive specialized: flower bulb, **type A**	Production orient., medium size Medium intensity specializ.: vegetables, **type B**	Production oriented, large size Medium intensive diverse: mainly root crops, **type C**	Entrepreneur oriented, large size Medium intensity diverse: mainly root crops, **type D**	Entrepreneur oriented, large size High intensive diverse: mainly rootcrops/specializ.: root crops, **type E**
Base year 2005					
Seed potato	0.00	0.00	32.00	30.50	n.a.
Onion	16.64	6.82	8.73	8.32	
Tulips	8.32	3.41	4.36	4.16	
Winter wheat	36.04	14.77	18.91	18.02	
Total area	61.00	25.00	64.00	61.00	
A1-W scen. 2050					
Seed potato	0.00	n.a.	32.00	30.50	27.28
Onion	25.81		13.54	12.90	7.07
Tulips	16.42		8.62	8.21	4.50
Winter wheat	18.77		9.84	9.39	5.15
Total area	61.00		64.00	61.00	44.00
B2-G scen. 2050					
Seed potato	0.00	0.00	32.00	30.50	n.a.
Onion	34.86	14.29	18.29	17.43	
Tulips	8.71	3.57	4.57	4.36	
Winter wheat	17.43	7.14	9.14	8.71	
Total area	61.00	25.00	64.00	61.00	

[1] Cropping patterns are based on the scenarios of farm structural change for assessing adaptation strategies to climate change for Flevoland (Mandryk et al., 2011; Chapter 3). Note that root/tuber, flower bulb, vegetable and remaining area fractions from this study are represented by respectively, seed potato, tulip, onion, and winter wheat in the present study

Summarizing, the analyses have been done in three steps compared to the Base year 2005, with first, only the climate change and increased CO_2 effect on yields included, second, the changes in product prices, costs and cropping patterns towards 2050 also included and finally, the effects of crop genetic and management improvements on crop yields in 2050 included, too. These different scenarios and their inputs are described in Table 8.2 in more detail.

Table 8.2 Description of the different scenarios, for which the economic calculations have been done for the main actual and future farm types in Flevoland, the Netherlands

Scenario	Description of inputs
Base year 2005	Actual yields and management data for 2005 on loamy soils in Flevoland, Netherlands from KWIN, 2009; Cropping pattern and farm size from Mandryk et al., 2011 (Chapter 3, Table 3.5)
Scenario 2010-A1-W-only	Yields for A1-W scenario in 2050 from Table 5.2 (as based on crop simulations for A1 scenario for 2050 with adaptation); other input data are similar to those for Base year 2005 except for small changes in fertiliser costs related to the yield changes
Scenario 2010-B2-G-only	Yields for B2-G scenario in 2050 from Table 5.2 (as based on crop simulations for B2 scenario for 2050); other input data are similar to those for Base year 2005 except for small changes in fertiliser costs related to the yield changes
Scenario 2050-A1-W-P	Yields for A1-W scenario in 2050 from Table 5.2 (as based on crop simulations for A1 scenario for 2050 with adaptation); product **P**rices are based on CAPRI modeling for A1-W scenario (Table 8.4); cropping pattern for A1-W scenario in 2050 is from Mandryk et al. (2011; see Table 8.1); costs increase with the cost trend (+45% in total from 2005 to 2050) as used in the CAPRI modelling; small changes in fertiliser costs do occur as related to the yield changes; farm size and labour demand per crop type are similar to those in the Base year
Scenario 2050-B2-G-P	Yields for B2-G scenario in 2050 from Table 5.2 (as based on crop simulations for B2 scenario for 2050); product **P**rices are based on CAPRI modeling for B2-G scenario (Table 8.4); cropping pattern for B2-G scenario in 2050 is from Mandryk et al. (2011; see Table 8.1); costs increase with the cost trend (+45% in total from 2005 to 2050) as used in the CAPRI modelling; small changes in fertiliser costs do occur as related to the yield changes; farm size and labour demand per crop type are similar to those in the Base year
Scenario 2050-A1-W-P-T	Idem scenario 2050-A1-W, but includes also further yield increases (from Table 5.2 for A1-W scenario) due to **T**echnological (i.e. crop genetic and management) improvements
Scenario 2050-B2-G-P-T	Idem scenario 2050-B2-G, but includes also further yield increases (from Table 5.2 for B2-G scenario) due to **T**echnological (i.e. crop genetic and management) improvements

Description of current farm types and current and future cropping patterns

Most actual crop yields and input data and costs are from KWIN (2009) and are averages for 2003-2007, all prices include VAT, and total variable costs include costs for contract work, taxes, energy, N, P and K fertilizers, and crop protection. Table 8.3 gives the economic data (e.g. gross margin per ha of crop, gross margin per labour hour per crop) for the crop types grown on the farm types in Flevoland in the Base year. This shows that seed potato gives the highest gross margin per labour hour, that onion might also be an interesting crop, that wheat is mainly grown to restore soil quality and can only be a main crop on large farms in regions with low land prices, and that tulip production requires a large amount of additional labour and is only possible if the costs for hired labour are relatively low.

Table 8.3 Economic data for crop types on loamy soils for farms in Flevoland in the Base year 2005; yields and the required total inputs and input cost are derived from KWIN (2009) and are averages for 2003-2007

Crop type	Winter wheat	Seed potato	Onion	Tulip
Yield (ton/ha)	9	39.0	66.1	18.0
Product price (euro/ton)	150	300	90	1111
Gross production (euro/ha)	1575[a]	11700	5949	20000
Var. costs (euro/ha)	967	4067	3358	7140
Gross margin (euro/ha)	608	7633	2591	12860
Labour demand (hour/ha)	13	70	37	604
Gross margin in euro / labour hour	46.8	109.0	70.0	21.3

[a] Gross production is only for winter wheat higher than the yield times the product price, as wheat straw has a value and hence, is also included in the gross production

The cropping patterns in the main arable farm types in Flevoland in 2005 and 2050 (Table 8.1) are based on the scenarios of farm structural change for assessing adaptation strategies to climate change for Flevoland (Mandryk et al., 2011; Chapter 3 of this report). The following steps have been followed to derive the cropping pattern in Table 8.1: a) available information consisted of first, root-tuber area fraction per farm type and scenario and second, total arable area, root-tuber area, flower bulb area and vegetable area per farm per scenario in the whole region, b) next, one minus the root-tuber area fraction per farm type is distributed over the three categories flower bulbs, vegetables, and remaining area according to the mean distribution per scenario in the region, c) root-tuber, flower bulb, vegetable and remaining area fractions are represented by respectively, seed potato, tulip, onion, and winter wheat.

Description of future farm types and assumptions

For year 2050 we use: a) changes in product prices for all crop types that have been calculated with CAPRI for both the A1-W and the B2-G scenarios (Table 8.4), b) cost trend of +45% from 2005 to 2050 in total for all crops and scenarios, as used in the CAPRI calculations, c) no change in labour demand compared to year 2005, assuming that the gradual yield increase towards 2050 will go together with a similar increase in labour use efficiency, d) land area per farm that is kept similar to that in 2005, as the returns-to-scale are not known and probably limited, e) modeled yields for the future that are always based on simulated yields for potential growing conditions as in Flevoland (i.e. with sufficient irrigation, drainage, nutrient supply and crop protection for optimal growth), f) future yields that are modeled for respectively, the W-climate change scenario from KNMI and a CO_2 concentration of 567 µmol/mol from the high emission scenario A1FI for 2050 (see Chapter 4) with some management adaptation and for the G-scenario from KNMI and a CO_2 concentration of 478 µmol/mol from the low emission scenario B2 for 2050, g) the yields for the **2050-A1-W-only** and **2050-B2-G-only** and the **2050-A1-W-P** and **2050-B2-G-P** runs (Table 8.2) that are calculated as the potential yields for respectively the A1-W and B2-G scenarios times (one minus the actual yield gap), h) the yields for the **2050-A1-W-P-T** and **2050-B2-G-P-T** runs that are calculated as the potential yields for respectively the A1-W and B2-G scenarios times (one minus the reduced yield gap in 2050) times the genetic improvement factor (=1.3 and 1.1 for respectively, the A1-W and B2-G scenarios), i) inputs and input costs per crop type that are assumed to be similar for the different scenarios (i.e. no correction of variable costs for scenarios with e.g. additional labour demand; only point b above and changes with changing cropping pattern) except for the fertilizer costs, which linearly change with the yield changes between the scenarios.

Table 8.4 Changes in product prices (euro for 2050) for arable cropping in the Netherlands due to respectively the A1-W and B2-G scenarios for 2050, as calculated with the CAPRI model for yield changes and for GDP change and thus change in the demand for agricultural products in scenarios for 2050 (Ewert et al., 2011)

Crop type	A1-W scenario	B2-G scenario
Seed potato[1]	+15%	+5%
Onion[1]	+15%	-12%
Tulips[1]	+15%	-12%
Winter wheat	+67%	-11%

[1] Change for potato is used for seed potato; change for Other vegetables is used for onion and tulips

8.3 Results from application of the methodology at farm and regional level

Outcomes per farm type for the Base year and the different scenarios

The cropping patterns on the main farm types in Flevoland are given for the Base year 2005 in Table 8.1. The farm types C and D use half of their area for seed potato and farm type E even a larger fraction. The remaining area per farm is distributed over onions, tulips and winter wheat, with each time the same area distribution. The farm types A and B have no seed potato cultivation and the whole farm area is used for onions, tulips and winter wheat, with again the same area distribution.

The A1-W and the B2-G scenarios for 2050 result in a decrease in winter wheat area compared to the Base year, which area is used now for more onion and tulip cultivation (Table 8.1). The A1-W scenario gives a much stronger increase in tulip area and a smaller increase in onion area compared to the B2-G scenario, which results in a much higher labour demand under the A1-W scenario. The seed potato area does not increase, probably being already at its maximum.

The prices of agricultural products more positively change for the high economic growth and emission A1-W scenario due to its strongly increasing demand for agricultural products than the prices for the low growth and emission B2-G scenario (Table 8.4). Note that these prices are in euros for 2050. This means that these prices have to be divided by the cost trend between 2005 and 2050 (i.e. factor 1.45) to get the prices in euros for 2005. Hence, even for the A1-W scenario in 2050 the prices in euros of 2005 have become lower than the actual prices in 2005.

For the Base year the farm types C and D with a large seed potato production have the highest gross production, the highest gross margin (Table 8.5) and also the highest gross margin per labour hour (61.5 euro/hour). This gross margin per labour hour is not corrected for fixed costs for machinery, equipment, stables, etc. and is probably a good indicator for the required gross margin for an economically sustainable farm. To make the results for 2050 and 2005 comparable, we have to correct the calculated gross margin per labour hour for the 2050 scenarios with the cost trend of +45% between 2005 and 2050 in total.

Table 8.5 Economic results for farm types in Flevoland in the ***Base year 2005***; actual cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived from KWIN (2009) and are averages for 2003-2007

Farm type	A	B	C	D	E
Gross production (Euros)	322138	132028	543309	517919	n.a.
Var. costs (Euros)	150133	61532	208876	199110	
Gross margin (Euros)	172005	70497	334434	318809	
Labour demand (hour)	6109	2504	5442	5190	
Gross margin in euro / labour hour	28.2	28.2	61.5	61.4	
Gross margin in euro 2005 / labour hour	28.2	28.2	61.5	61.4	

The 2050-A1-W-only and the 2050-B2-G-only scenario runs give the results for a situation similar to that in the Base year, except that the effects of climate change and increased atmospheric CO_2 on crop yields for both scenarios in 2050 have been included (Table 8.2). The yield increases are stronger for the High emission 2050-A1-W-only scenario due to mainly the higher atmospheric CO_2 concentration than those for the 2050-B2-G-only scenario (Table 5.2). This results in stronger increases in gross production, gross margin and gross margin per labour hour (+50% to +90%) in the 2050-A1-W-only scenario run (Table 8.6) compared to those in the 2050-B2-G-only scenario run (Table 8.7: +25% to + 60%).

Table 8.6 Economic results for farm types in Flevoland for ***2050-A1-W-only scenario run*** (i.e. only climate change and increased CO_2 effects on yields) with management adaptation; actual cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived in the way described in Table 8.2

Farm type	A	B	C	D	E
Gross production (Euros)	487182	199672	707202	674190	n.a.
Var. costs (Euros)	155285	63643	214490	204461	
Gross margin (Euros)	331897	136029	492712	469728	

Labour demand (hour)	6109	2504	5442	5190	
Gross margin in euro / labour hour	54.3	54.3	90.5	90.5	
Gross margin in euro 2005 / labour hour	54.3	54.3	90.5	90.5	

Table 8.7 Economic results for farm types in Flevoland for ***2050-B2-G-only scenario run*** (i.e. only climate change and increased CO_2 effects on yields); actual cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived in the way described in Table 8.2

Farm type	A	B	C	D	E
Gross production (Euros)	430704	176524	626807	597547	n.a.
Var. costs (Euros)	153105	62750	211427	201542	
Gross margin (Euros)	277599	113774	415381	396006	
Labour demand (hour)	6109	2504	5442	5190	
Gross margin in euro / labour hour	45.4	45.4	76.3	76.3	
Gross margin in euro 2005 / labour hour	45.4	45.4	76.3	76.3	

The 2050-A1-W-P and 2050-B2-G-P scenario runs give the results for a situation where the yields have increased for the A1-W and B2-G scenarios (as in the previous runs) for 2050, but also the product **P**rices (Table 8.4), the costs and the cropping patterns have been changed for both scenarios in 2050 (see Tables 8.1 and 8.2). These three new factors result in higher gross production, much higher variable costs, and much higher gross margins and labour demand and thus, in a roughly similar gross margin per hour in the 2050-A1-W-P scenario but in clearly lower values when expressed in euros of 2050 (Table 8.8 vs. Table 8.6), and in much higher variable costs and thus, much lower gross margin and gross margin (in euro 2005) per hour in the 2050-B2-G-P scenario (Table 8.9 vs. Table 8.7).

Table 8.8 Economic results for farm types in Flevoland for ***2050-A1-W-P scenario run*** (i.e. changes in product **P**rices, costs, cropping patterns and yields for the scenario in 2050) with management adaptation; future cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived in the way described in Table 8.2

Farm type	A	B	C	D	E
Gross production (Euros)	947294	n.a.	1016713	968805	702509
Var. costs (Euros)	332006		367153	349869	255451
Gross margin (Euros)	615288		649560	618936	447058
Labour demand (hour)	11117		8075	7693	4956
Gross margin in euro / labour hour	55.3		80.4	80.5	90.2
Gross margin in euro 2005 / labour hour [1]	38.1		55.4	55.5	62.2

[1] Based on cost trend of +45% in total from 2005 to 2050

Table 8.9 Economic results for farm types in Flevoland for **2050-B2-G-P scenario run** (i.e. changes in product **P**rices, costs, cropping patterns and yields for the scenario in 2050); future cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived in the way described in Table 8.2

Farm type	A	B	C	D	E
Gross production (Euros)	469573	192470	667408	636218	n.a.
Var. costs (Euros)	289451	118641	342004	326002	
Gross margin (Euros)	180122	73829	325404	310216	
Labour demand (hour)	6777	2778	5796	5527	
Gross margin in euro / labour hour	26.6	26.6	56.1	56.1	
Gross margin in euro 2005 / labour hour [1]	18.3	18.3	38.7	38.7	

[1] Based on cost trend of +45% in total from 2005 to 2050

The 2050A1-W-P-T and 2050-B2-G-P-T scenarios give results for the same situation as described in the previous paragraph (i.e. effects of climate change and increased atmospheric CO_2 on yield level and changes in product prices, costs and cropping patterns) but in addition, they include further yield increases due to **T**echnological (i.e. crop genetic and management) improvements (see Table 8.2). These additional yield increases result in respectively, strong and moderate increases in gross production, practically no changes in variable costs, and respectively, strong and moderate increases in gross margin and gross margin per labour hour for the 2050-A1-W-P-T (Table 8.10 vs. Table 8.8) and the 2050-B2-G-P-T scenarios (Table 8.11 vs. Table 8.9).

Table 8.10 Economic results for farm types in Flevoland for ***2050-A1-W-P-T scenario run*** (i.e. changes in product prices, costs, cropping patterns and yields for the scenario in 2050 with further yield increases from **T**echnological (i.e. crop genetic and management) improvements); future cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived in the way described in Table 8.2

Farm type	A	B	C	D	E
Gross production (Euros)	1358043	n.a.	1425501	1358316	979778.1
Var. costs (Euros)	345351		383306	365264	266910.3
Gross margin (Euros)	1012692		1042195	993052	712867.8
Labour demand (hour)	11117		8075	7693	4956.14
Gross margin in euro / labour hour	91.1		129.1	129.1	143.8
Gross margin in euro 2005 / labour hour [1]	62.8		89.0	89.0	99.2

[1] Based on cost trend of +45% in total from 2005 to 2050

Table 8.11 Economic results for farm types in Flevoland for ***2050-B2-G-P-T scenario run*** (i.e. changes in product prices, costs, cropping patterns and yields for the scenario in 2050 with further yield increases from **T**echnological (i.e. crop genetic and management) improvements); future cropping pattern is given in Table 8.1; yields and the required inputs and input cost are derived in the way described in Table 8.2

Farm type	A	B	C	D	E
Gross production (Euros)	535984	219690	757187	721807	n.a.
Var. costs (Euros)	293503	120302	347010	330773	
Gross margin (Euros)	242481	99388	410177	391034	
Labour demand (hour)	6777	2778	5796	5527	
Gross margin in euro / labour hour	35.8	35.8	70.8	70.8	
Gross margin in euro 2005 / labour hour [1]	24.7	24.7	48.8	48.8	

[1] Based on cost trend of +45% in total from 2005 to 2050

The economic results for the different farm types in Flevoland and for the Base year 2005 and the different scenarios are summarized in Table 8.12. Farm types C and D with half of the farm area used for seed potato production, result in the Base year in much higher values for the gross margin per labour hour than those for farm types A and B. This difference between the farm types can be explained from the economic values per crop type (Table 8.3) in combination with the cropping pattern per farm type in the Base year (Table 8.1). Effects of climate change and increased atmospheric CO_2 on the gross margin per labour hour are clearly positive. The 2050-A1-W-only scenario with some management adaptation gives 30% to 50% higher yields and thus gross production compared to those in the Base year (Table 8.6 vs. Table 8.5), which results in 50% to 90% higher total gross margin and gross margin per labour hour (Table 8.12). The 2050-B2-G-only scenario gives 15% to 35% higher yields and thus gross production compared to those in the Base year (Table 8.7 vs. Table 8.5), which results in 25% to 60% higher total gross margin and thus gross margin per labour hour.

Table 8.12 Summary of the Economic results (i.e. Gross margin per labour hour, in euros of 2005) for farm types in Flevoland and for arable farming in Flevoland as a whole for the Base year and for the different scenarios. More detailed information per scenario can be found in Tables 8.5 - 8.11. Note that compared to the Base year the following changes are applied in the scenarios: a) ***Scen. 2050-only***: effect of climate change and increased CO_2 on yields, b) ***Scen. 2050-P***: idem point **a** plus changes in product **P**rices, costs and cropping patterns for the scenarios in 2050 (A1-W or B2-G), and c) ***Scen. 2050-P-T***: idem point **b** plus further yield increase from **T**echnological (i.e. crop genetic and management) improvements

Farm type Scenario	A	B	C	D	E	Reg[1]
Gross margin in euro-2005 / labour hour [2]						
Base year 2005	28.2	28.2	61.5	61.4		56.2
Scen. 2050-A1-W-only	54.3	54.3	90.5	90.5		84.7

Scen. 2050-B2-G-only	45.4	45.4	76.3	76.3		71.4
Scen. 2050-A1-W-P	38.1		55.4	55.5	62.2	48.9
Scen. 2050-B2-G-P	18.3	18.3	38.7	38.7		34.2
Scen. 2050-A1-W-P-T	62.8		89.0	89.0	99.2	79.2
Scen. 2050-B2-G-P-T	24.7	24.7	48.8	48.8		43.5

[1] Regional average for Flevoland; based on area fractions for the five farm types (Mandryk et al., 2011)
[2] Based on cost trend of +45% in total from 2005 to 2050

If in addition to the effects of climate change and increased atmospheric CO_2 we also include the changes in product prices, costs and cropping patterns from 2005 towards 2050, the gross margins per labour hour, as expressed in euros of 2005 (Table 8.12), strongly decrease for both scenarios and all farm types (e.g. by minus one third for scenario 2050-A1-W-P compared to scenario 2050-A1-W-only). These strong decreases in gross margin can be explained from the stronger increases in costs over time than the increases in product prices (Table 8.4). Finally, if we also assume that further yield increases are possible by way of crop genetic and management improvements, the changes in gross margin per labour hour for the 2050-A1-W-P-T scenario are nil to slightly positive compared to the scenario 2050-A1-W-only (Table 8.12). Only for the 2050-A1-W-P-T scenario with the highest yields and best management in 2050, the gross margins per labour hour, when expressed in euros of 2005, are higher than those in the Base year for all farm types (Table 8.12). For the 2050-B2-G-P-T scenario the gross margins per labour hour are still lower than those in the Base year for all farm types, which is mainly caused by its more limited yield increases. This indicates the need for improved crop cultivars and management to increase the gross margin per labour hour. Note that in the 2050-A1-W-P and 2050-A1-W-P-T scenarios we have assumed that the product prices increase by about +20% from 2005 to 2050 (Table 8.4) and that the costs have increased by 45%.

Outcomes for arable farming in Flevoland for the Base year and the different scenarios
For arable farming in Flevoland as a whole, the changes in the economic results for the different scenarios have also been established. These mean values for the gross margin per labour hour in arable farming in Flevoland (Table 8.12) have been derived from the values for the five different farm types, using the area fractions for the different farm types (Table 8.1; Mandryk et al., 2011) as weighing factors. The differences in gross margin per labour hour between the Base year and the six scenarios appear to be roughly similar to those described above for the individual farm types.

Sensitivity analysis
The outcomes for the different scenarios (Tables 8.5 - 8.12) show that the differences in gross margin per labour hour are mainly determined by first, the increase in product prices from 2005 to 2050 (and in particular, the degree that these price increases are lower than the cost trend) and second, the yield increase from 2005 to 2050. Figure 8.1 (left versus right figure) shows that for the current cropping pattern the gross margins per labour hour are higher than those for the A1-W scenario-cropping pattern with similar price and yield changes. The A1-W cropping pattern has a larger area fraction with tulips (Table 8.1) than the current cropping

pattern, which is the explanation for this lower gross margin per labour hour (Table 8.3). The results for the A1-W cropping pattern (Figure 8.1, right) show that, for example, the gross margin per labour hour on farm type C in the Base year of 61.5 euro/hour (Table 8.5) can be attained in year 2050, when the yields increase to 140% compared to the Base year and the product prices increase to 120% (in euros of 2050). The 2050-A1-W-P scenario run results on farm type C in a gross margin per labour hour of 55.4 euro-2005/hour (Table 8.8), which corresponds with an increase in yield to 130% and in price to 120% (Table 8.4) in Figure 8.1. The 2050-A1-W-P-T scenario run results on farm type C in a gross margin per labour hour of 89.0 euro-2005/hour (Table 8.10), which corresponds with an increase in yield to 182% (due to further crop genetic and management improvements) and in price to 120% (Table 8.4) in Figure 8.1.

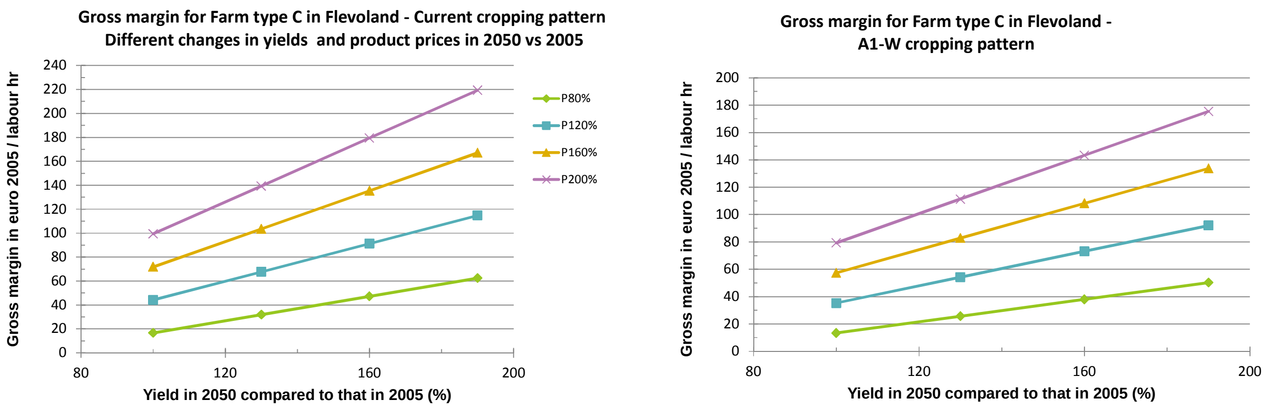


Figure 8.1 Gross margin per labour hour (expressed in euro for 2005) on farm type C in Flevoland, the Netherlands for different values for respectively, the future product prices (expressed in euros of 2050) and the relative yields in 2050 (as dependent on the assumed yield increases due to climate change and increased CO_2 and crop genetic and management improvements); note that the euro for 2005 is equal to 1.45 euro in 2050; Left: current cropping pattern, Right: cropping pattern for A1-W scenario for 2050 (Table 8.1)

8.4 Evaluation of the results

Sensitivity analyses at farm level have been carried out for different combinations of emission and climate change scenario (A1-W vs. B2-G) and the corresponding crop yields, five main farm types in Flevoland, certain assumptions about the changes towards 2050 in product prices, costs and cropping pattern, and possibly too about the yield increases from crop genetic and management improvements towards 2050. The calculation results (see Table 8.12) show that they are strongly dependent on these assumptions which are uncertain to a different extent. However, the importance of the different assumptions can easily be shown, as for example done in Figure 8.1 for the possible changes in product prices and yields towards 2050.

Results per crop type for farms in Flevoland (Table 8.3) show that currently seed potato gives the highest gross margin per labour hour, onion might also be an interesting crop, wheat is mainly grown to restore soil quality and can only be the main crop on large farms in regions with low land prices (thus not here), and that tulip production requires a large amount of additional labour and is only possible if the prices of hired labour are relatively low. These conclusions also apply to the future scenarios for 2050 but probably more strict, as the gross margins per labour hour for the scenarios in 2050 are often lower than those in the Base year (Table 8.12).

Results for the different farm types in Flevoland in the Base year 2005 (Table 8.5) show that the highest gross margin and gross margin per labour hour do occur on farm types C and D with a large part of the land area used for seed potato.

The changes in product prices from 2005 to 2050 as calculated with CAPRI for the B2-G and the A1-W scenarios (Table 8.4), appear to be respectively, slightly negative and slightly positive, and anyway smaller than the cost trend (+45% from 2005 to 2050). The consequence is that moderate increases in yields and product prices between 2005 and 2050 are necessary to maintain the actual values (Table 8.5: 61.5 euro/hour on farm type C) for the gross margin per labour hour in 2050 (Figure 8.1).

The increases in yield, gross production, and thus gross margin are stronger for the A1-W scenario with its higher atmospheric CO_2 concentration (Table 8.6) than for the B2-G scenario (Table 8.7), compared to the Base year results (Table 8.5).

The A1-W and B2-G scenarios for 2050 result in a decrease in winter wheat areas compared to the Base year, which areas are then used for more onion and tulip production (see Table 8.1 as based on the work by Mandryk et al., 2011). The A1-W scenario gives a much stronger increase in tulip area than the B2-G scenario, which results in a much stronger increase in labour demand (Table 8.8 vs. Table 8.9), compared to the Base year.

The scenarios for 2050 apply the following changes compared to the Base year 2005: a) effect of Climate change and increased CO_2 on yield (**CC-only**), b) idem plus changes in product prices, costs and cropping patterns (**P**), and c) idem plus further yield increase from technological (i.e. crop genetic and management) improvements (**T**). For the A1-W scenario, **CC-only** results in a yield increase by 30% to 50%, which gives an increase in gross margin and gross margin per labour hour of +50% to +90%. **P** gives a moderate to strong increase in gross production per farm, a strong increase in variable costs, and a much higher gross margin and labour demand. This results in roughly similar gross margins per labour hour but in clearly lower values, when expressed in euros of 2005. **T** results in a yield increase by about 40%, which gives an increase in gross margin and gross margin per labour hour by 60%.

For example, for farm type C, the effects of **CC-only**, **P** and **T** on the gross margin per labour hour are respectively 1.5*0.6*1.6= 1.45, which explains the change from 61.5 euro-2005/hour in the Base year to 89.0 euro-2005/hour in the 2050-A1-W-P-T scenario (Table 8.12). Hence, the differences in gross margin per labour hour between the scenarios for 2050 and the Base year 2005 are mainly determined by first, the increase in product prices from 2005 to 2050 (and in particular, the degree that these price increases are lower than the assumed cost trend) and second, the yield increase from 2005 to 2050 (Figure 8.1).

The changes in product prices and yield levels towards 2050 for the main crop types in Flevoland are rather uncertain. The mean calculated values for the gross margin per labour hour on possible farms in Flevoland in 2050 may strongly vary in dependence of these assumed changes over time (Figure 8.1, Table 8.12). We may assume that the future product prices for main crop types in Flevoland as seed potato and onion (Tables 8.3 and 8.4), are not only determined by the global market shifts for the main food crops as modeled by CAPRI, but are strongly determined by the changes in the agricultural production potential in Flevoland towards 2050 and those in competitive agricultural areas too. Flevoland currently has favourable conditions to produce very high yields of crops as seed potato and onion and hence, has a high competitive potential. This will still be the case in 2050, being related to the optimal temperature regime, optimal water supply and good soil quality for potato and onion production in the future, too. If conditions for agricultural production will not remain favourable in some of the main competitive areas, becoming too hot and/or too dry, we may assume that product prices will increase more strongly than those based on the CAPRI modeling (Table 8.4). If so, economic results for farming in Flevoland in 2050 will become more favourable than those given in Table 8.12.

9 Exploring arable farming in Flevoland and adaptation strategies to climate change using Data Envelopment Analysis

A. Kanellopoulos

9.1 Introduction

Adaptation strategies of farmers are explored here in a globalized economy scenario with strong climate change (A1-W scenario with management adaptation) in 2050. Data Envelopment Analysis (DEA) was used to analyze and identify the current production technology. The Farm System SIMulator (FSSIM) was used to simulate farmer's behavior and evaluate the consequences of the effects of climate change in the future. A number of indicators are quantified, to be used for designing effective policy decisions.

In Section 9.2 we briefly describe methodological issues focusing on the set-up of the modeling exercise. More information about the applied methodology can be found in Chapter 10 of the AgriAdapt project report no. 1 about Methodologies. In Section 9.3 we present and discuss the results of the analysis. Finally, in Section 9.4 we present the main conclusions.

9.2 Short description of the methodology

9.2.1 DEA for identifying current production function

Data Envelopment Analysis (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). Mathematical programming methods are employed to rank or screen DMUs in terms of converting inputs into outputs. For the modeling exercise presented here, DEA is used to assess the capacity of a farm to convert multiple inputs (e.g. agrochemicals, labour, land, capital etc.) into multiple outputs (e.g. potatoes, onions, wheat, etc.) and compare it with the capacity of all other farms to convert inputs into outputs. The best current agricultural activities are identified and form the current production function (i.e. input-output relationship).

9.2.2 Simulating farmer's behavior using FSSIM

FSSIM was used to maximize the objective of the farmer, subject to existing resource and policy constraints. The agricultural activities identified with DEA were offered to the model as the set of production options that is currently available to farmers. Each linear combination of these activities is a possible production plan of the farm that maximizes the objective function. A PMP based calibration approach (Kanellopoulos et al., 2010) was used to recover non-linear terms in the objective function related to un-observed costs and to implicitly account for farmer's objectives different from gross margin maximization. The used calibration procedure guarantees exact reproduction of observed data on input and output levels. The calibrated model was used for assessing the A1-W climate change scenario.

9.2.3 Set up of the modeling exercise

The effects of the A1-W scenario were evaluated in arable farms in Flevoland (the Netherlands). Individual farm data (i.e. inputs, outputs and farm resources) of 85 individual representative farms from FADN were used. The base year scenario was calculated by averaging FADN data of years 2000-2006. The data were not balanced implying that the number of observations per farm is not the same for all farms in the sample (due to stratification in FADN sampling procedure).

The proposed DEA procedure was used to specify the technical relationships between important inputs and outputs. Inputs used in the DEA procedure were: capital (€), crop protection (€), fertilizer (€), energy use (€), labour (distinguishing between hired and family labour in hours), other inputs (€). The outputs used were: potatoes, onions, sugar beet, wheat (tons), other arable output (€), total livestock output (€) and other outputs (€). Technical efficient farms (best farm practices) were identified and formed the DEA frontier, which was assumed to be the current production function. A farm is characterized as "best" farm practice when at a certain input level, there is no linear combination of the inputs and outputs of the other existing farms that results in lower input level without increasing the level of another input or decreasing the level of an output.

Expected yield and input (i.e. fertilizers) changes due to climate change scenario A1-W were calculated for year 2050 without and with technological change (see Chapter 5). The calculated inputs and outputs of future activities were used to identify the new input-output relationships for the A1-W scenario using DEA. Expected changes in yields and fertilizers for A1-W scenario without (i.e. ***2050-A1-W-only or 2050***) and with (***2050-A1-W-T or 2050***$^{+}$) technological change is presented in Table 9.1.

Table 9.1: Current yield and expected yield and fertilizer changes for 2050-A1-W-only (***2050***, without technological improvement) and 2050-A1-W-T (***2050***$^{+}$, with technological improvement) scenarios[1]

	Current	Yield change (%)		Fertilizer change (%)	
	Yield	2050	2050^{+}	2050	2050^{+}
Soft wheat	8	14	72	17	90
Potatoes	57	7	47	9	58
Sugar beet	74	30	69	37	86
Vegetables	66	20	56	25	69
Other arable crops [2]	6	20	92	25	115

[1] Yield changes are based on the actual yields for the A1-W scenario for 2050 with adaptation without and with technological (i.e. crop varieties and management) improvement, as calculated in Section 5.3

[2] Yield and fertilizer changes for "other arable crops" are calculated based on information for barley which is the most important crop in terms of area in "other arable crops" in Flevoland.

For calculating additional fertilizer inputs with yield change, we have assumed a linear relationship between yield increase and additional fertilizer applications and costs. Assuming that 20% of the actual crop nutrient uptake is supplied by the soil, the actual fertilizer nutrient application is related to 80% of the actual yield. Hence, a yield increase by 10% requires an increase in fertilizer nutrient application by 12.5% (compared to the current situation). The total fertilizer application of each farm was disaggregated at crop level using a simple statistical procedure. Fertilizer inputs from a survey (Zander et al., 2007) were used as prior information.

According to the agro-climate calendar (ACC, see Chapter 6) the increased occurrence of important extreme events like prolonged wet periods during spring and dry conditions during spring and summer will have a negative effect on expected yields. Information on historical and future occurrence of extreme events and impact of these events on the yields of important crops were used to calculate the effect on average yields from 2006 to 2050 (Table 9.2). The average effects of an increase in extreme events are calculated as:

*Average effect = (Expected Frequency2050 – Historic Frequency) * Effect*

The most important extreme events affect mainly the yields of potatoes and onions which are the most vulnerable crops.

Table 9.2: Current and future frequencies of extreme events, effects on yields and the average effects on yields[1]

	Frequency		Effect		Average effect	
Extreme event	Historic	Expected	Potatoes	Onions	Potatoes	Onions
Prolonged wet conditions in Spring	0.33	0.37	-30%		-1.2%	
Dry conditions in spring	0.1	0.13		-75%		-2.3%
Dry condition in summer	0.13	0.37		-40%		-9.6%
Total effect					-1.20%	-11.85%

[1] Average effects of increased extreme events on yields are calculated as the difference between expected and historic frequency times the effect

Simulated prices for 2050 (Table 9.3) in the A1-W climate change scenario were generated with the Common Agricultural Policy Regionalized Impact (CAPRI) modeling system (Heckelei and Britz, 2000). This is a partial equilibrium model that accounts for socio-economic changes in Europe and calculates region specific prices for the main agricultural products. See for more information about the procedure to calculate the future prices the AgriAdapt report by Ewert et al. (2011).

FSSIM was used to simulate each of the 85 individual farms and to assess possible adaptation strategies in the A1-W scenario with and without technology improvement. A number of intermediate model runs were designed to show the separate effect of respectively: calibration, expected average yield changes due to climate change, increased occurrence of extreme events, future (alternative) activities, price changes, increasing available resources and technological change (e.g. new more productive varieties).

Table 9.3: Current prices and simulated price changes for the A1-W scenario for 2050 (compared to the current ones) as simulated with the CAPRI model (Ewert et al., 2011)

	Price* 2006	Price Change 2050
Potatoes	121	15
Sugar Beet	111	15
Wheat	119	67
Onions	104	15
Livestock outputs	1	15
Other arable outputs	1	15
Other output	1	15
Crop Protection	1	43
Energy	1	43
Fertilizers	1	48
Other input	1	43

* Price of inputs and outputs expressed in monetary units that were assumed to be 1

Model runs

In the first model run (*Profit*), it is assumed that farmers are gross margin maximizers. The available farm resources are allocated to the best current production possibilities and optimum farm plans are calculated. For all model runs, inputs like capital, other inputs, (rented) utilized agricultural area and outputs like livestock output, other output were assumed to be fixed (we set an upper bound). Hiring labour and renting land was allowed but we set an upper bound to the observed levels of hired labour and rented land in order to account for limited access to labour and land market respectively.

In the second model run (*Calibr*), FSSIM is calibrated to base year observed input and output levels. The difference between the gross margins of this model run with the gross margin of the previous one represents cost that farmers are willing to take for maintaining their own current production strategy that satisfies their multiple objectives.

In the third model run (*B2050*), the expected yield change due to climate change, without accounting for the effect of extreme events, is evaluated using the calibrated FSSIM model. Both scenarios with and without technological change (Table 9.1) are evaluated.

In the fourth model run (*Extreme*), the effect of the increased occurrence of extreme events (i.e. prolonged wet conditions during spring and dry conditions during spring and summer) are taken into account (Table 9.2).

In the fifth model run (*Alter.*), alternative adaptation measures are offered. The basic adaptation strategies and their effect on the average outputs and inputs are summarized in Table 9.4. All possible combinations of the different adaptation strategies were also taken into account resulting in 127 different types of adaptation strategies and in total 127*85 = 10795 activities. It is important to notice that the average effect of the offered adaptation strategy is calculated using the frequencies of the extreme events and not the increase of the frequencies like in the previous scenario (e.g. the beneficial effects of more organic matter in top soil applies to all incidences of the extreme events and not only to the increased occurrence).

In the sixth model run (*Price*), the future price changes (Table 9.3), simulated with CAPRI, are used. This model run includes all important factors in the A1-W for 2050 scenario.

Finally, in model runs 7 to 10 (*Scaling*), it is allowed to increase labour, capital, other inputs, livestock outputs and other outputs. In model run 7, we allow for 20% more hired labour. In model run 8, on top of model run 7, we allow for 20% more capital. In model run 9, on top of model run 8 we allow for 20% more other inputs and in model run 10, on top of model run 9 we allow for 20% more livestock output and other outputs.

It is important to notice that specifications of model run 4 to 10 are additive (conditions of 4 are added to 5 etc.).

Table 9.4: The effect of alternative activities on the inputs and outputs of an average year

	Code*	Capital (1000 €)	Mainte-nance (€)	Labour (hrs/ha)	Energy (€/ha)	Potatoes (%)	Onion (%)	Sugar beet (%)	Wheat (%)	Other arable output (%)
More org. matter top soil	A1000000	0		10	100	4%	4%	1%	1%	1%
GPS steering	A0100000	20	300	10		14%				
Automatic inflation	A0010000	20	300	8		9%				
Irrigation in Spring	A0001000	20	400	20	100		50%			
Re-sowing	A0000100	20		18	250		24%			
Higher sowing density	A0000010	40		18	0		4%			
Irrigation in Summer	A0000001	40	400	28	100		34%			

* The 7 digit code of the activities provides information about the combination of adaptation strategies of a specific activity. For example, activity A1001000 combines the effects of adaptation 1 (more organic matter) and 4 (Irrigation in spring). The effects are assumed to be additive

FSSIM results from individual farms are aggregated to farm type level according to the economic farm size (measured in NGO[3]) dimension of the typology presented in Wolf et al., 2011. All representative farms in the sample are classified in three different farm sizes: small farms (20≤NGO<70), medium farms (70≤NGO<150)

[3] NGO is a national size unit used in the Netherlands which corresponds to 1.166 European size units (ESU)

and large farms (NGO ≥150). The number of farms represented by each representative farm is used to average inputs and output levels for the average farm that is considered representative for arable farming in Flevoland as a whole. Results of the application of DEA for this average farm are given in Section 9.3.

9.3 Results from application of the methodology at farm and regional level

Results of the application of DEA for identifying current best farm practices that form the current production functions are presented in Table 9.5. Current input and output levels of an average arable farm in Flevoland are presented as benchmark. These results for the average farm can be considered representative for Flevoland as a whole, whereas the results for the small, medium and large farm types (see Appendix A) indicate the degree of differences in results between farm types. From the difference between current situation and best farm practices it can be concluded that farms in Flevoland are very close to best current practice. Only few farms could perform better and can produce with fewer inputs the same or more amounts of outputs. This result is explained by the modern and uniform arable farming systems in Flevoland. A detailed set of inputs and outputs was used in DEA to identify the best farm practices. This increases the possibility that one farm performs very well in keeping the level of one of the inputs very low or the level of one of the outputs very high (compared with all the other farms). As a result many of the farms are characterized as "best" farm practices. Of course, this does not say anything about the economic performance of these farms. Input and output prices and the result of the FSSIM simulations determine if those "best" farm practices are also gross margin maximizing activities. Best farm practices for the future A1-W scenario are characterized by a large increase of fertilizer use and production of main crops. This is in line with our assumptions for changes of inputs and output levels in A1-W scenario as presented in Table 9.1.

Table 9.5: Input-output differences between current and best practices for an average farm in Flevoland for the current situation and for the A1-W scenario without (2050-A-W-only or ***2050***) and with technological improvement (2050-A-W-T or ***2050+***)

		DEA Best practices		
	Current situation	Current (%)	2050 (%)	2050+ (%)
Capital (machinery + buildings) (€)	336156	0	-2	-1
Crop Protection (€)	14706	-2	-3	-2
Energy (€)	13621	-2	-3	-2
Family Labour (hours)	2867	-1	-2	-1
Fertilizers (€)	6601	-1	51	114
Hired Labour (hours)	1813	-2	-2	-2
Other input (€)	149911	0	-2	-1
Owned UAA (ha)	19	0	0	0

Rented UAA (ha)	30	0	0	0
Potatoes (tones)	531	2	6	47
Sugar Beet (tones)	475	-1	30	69
Wheat (tones)	49	0	18	80
Vegetables (tones)	406	1	19	56
Other arable outputs (€)	52871	0	0	0
Livestock outputs (€)	29131	0	0	0
Other output (€)	31663	1	-2	1
Total subsidies (€)	7752	0	1	1

Results for an average arable farm in Flevoland from all FSSIM model runs are presented in Table 9.6. Detailed results for all three farm types described in previous sub-section are presented in Table A-1 to A-3 of Appendix A. The simulated inputs and outputs in the *Calibr* model run represent the current situation since the PMP based calibration procedure guarantees exact reproduction of historical input-output levels. Comparing the gross margins achieved in the Profit model run with the gross margin that is currently achieved in (*Calibr* model run), it can be concluded that in all farm types, farmers sacrifice a substantial part of their profit for maintaining their current production activity. Small farms sacrifice 44% of the potential gross margin while medium and large farms sacrifice 43 and 54% of the potential gross margin respectively (Table A-1 to A-3 of Appendix A). Despite the large difference in gross margins between the *Profit* and *Calibr* model run, it was found that 28% of the farmers currently maximize their profit (i.e. in the profit model run the current activity is selected). In the Profit model run, the production of main cash crops like potatoes, onions and other arable output (i.e. mainly tulips, bulbs and field scale vegetables) increase (Table 9.6). This is achieved by increasing areas but also by intensifying production (selecting systems with higher yields). The shift of production to cash crops and higher yields causes an increase in inputs of fuels (energy), crop protection and sometimes fertilizers (Table 9.6).

In the *B2050* model run, in the 2050-A1-W-only (without technological change) scenario the increased expected yields (Table 9.1) causes a substantial increase of gross margins compared to the current situation in the *Calibr* model run (Table 9.6). Compared to the current situation (i.e. *Calibr)* , inputs of fertilizers, energy and crop protection increase in all farm types (Table A-1 to A-3 of Appendix A). Nevertheless, lower labour and capital inputs are required (Table 9.6). The higher yields ensure a satisfactory income (compared to the current situation) and as a result, farmers attempt to satisfy other important objectives like capital and labour minimization that have been taken into account implicitly with calibration. Moreover, in the *Profit* model run it was shown that capital and labour were not the main limiting factors for maximizing profit in the base year conditions. Since capital and labour requirements were not increased in the B2050 model run, maximization of gross margin in this run is also not limited by these inputs. In the *B2050* model run of the 2050-A1-W-T scenario, where technological improvement is assumed and improved varieties (in terms of yields) were offered to the model, similar but more dramatic changes are observed (Table 9.6). Areas of onions and potatoes decrease compared to 2050-A1-W scenario. The consequence is that the inputs of fertilizer increase substantially. Another interesting result is that in the *B2050* model run of 2050-A1-W-T scenario, the fraction of hired labour increases substantially compared to the fraction of hired labour in the *B2050* model run of the 2050-A1-W-only scenario (Table 9.6). This is related to the large increase in other arable output in the 2050-A1-W-T scenario and the seasonality of labour involved in growing crops like tulips and field scale vegetables. The fraction of hired labour is higher in the large farms where the increase in other arable outputs is largest.

The effect of the increased occurrence of extreme events in the *Extr* model run is minor in both scenarios and all farm types (Table A-1 to A-3 of Appendix A). The average yields of main crops decrease which causes a marginal decrease in gross margins. No major adaptation or changes in production orientation (crop rotation, inputs etc.) occurred. In general, in the case of extreme events accessibility to credit is vital for farmers in order to recover from the catastrophic consequences of extreme events. Accessibility to credit and the possibility to recover from an extreme event is not taken into account in FSSIM explicitly. However, accessibility to credit is currently not an issue for arable farmers in Flevoland and consequently accounting for extreme events by assuming a decrease of the average yields is a reasonable assumption for modeling the behavior of arable farmers in Flevoland.

In the *Alter* model run, a number of adaptation options are offered (Table 9.4). In the 2050-A1-W-only scenario only the gross margin of large farms benefited marginally (compared to the *Extr* model run) (Table A-3 of Appendix A). The main reason for this is that activities, which require investment decisions and involve additional maintenance costs, become profitable only at larger scales of production. At lower scales, the beneficial effects of alternative activities level out with additional costs related to maintenance of machinery, energy and labour. The adoption level of alternative activities (ha) from all farm types in different model runs and for both scenarios (2050-A1-W-only and 2050-A1-W-T) are presented in Table 9.7. In the 2050-A1-W-only scenario, the adoption of alternative activities is highest at the large farms. Alternative activities with no or low investments are mainly selected. In the 2050-A1-W-T scenario, the adoption of alternative activities is minor and lower than the adoption in the 2050-A1-W-only scenario. The higher crop yields because of technology change in the 2050-A1-W-T scenario ensure a relatively high gross margin compared to the current gross margin in the *Calib* model run (Table 9.6). Other objectives related to minimization of capital and family labour apparently receive more priority than the adoption of alternative activities. In the 2050-A1-W-T scenario, the alternative activities which contribute to avoiding part of the consequences of extreme events in potatoes, are mainly selected. This is because these activities have the highest beneficial effect on the achieved gross margin.

Accounting for the expected price changes, as calculated by CAPRI (Table 9.3) and used in the *Price* model run, results in a substantial decrease of gross margin in the 2050-A1-W-only scenario (Table 9.6). Areas of potatoes, onions and sugar beet decrease in all farm types (Table A-1 to A-3 of Appendix A). Production shifts further from main arable products to other arable outputs (i.e. tulips and vegetables). Given the 2050 prices and without any technological change, it becomes less profitable to grow the current cash crops. Adoption rate of alternative activities in large farms decreases substantially, since all adaptation strategies included in this analysis benefit mainly potatoes and onions (Table A-3 of Appendix A). Current activities are preferred that lead to higher production of tulips and vegetables (other arable output). Resource availability in small and medium farms do not allow for selecting such activities with high levels of other arable output (Tables A-1 and A-2 of Appendix A). This is why adoption rate of alternative activities does not change that much in these farm types. In the 2050-A1-W-T scenario, the effects of price change is smaller than in 2050-A1-W-only scenario because of the higher assumed yields of main crops. Small farms react mainly by decreasing scale of production (smaller area, lower capital inputs and other inputs). This is achieved by decreasing the areas of potatoes and onions (Table A-1 of Appendix A). This results in a small increase in gross margin compared to the *Alter* model run (no price effect). However, the gross margin is still lower compared to the current gross margin in the *Calibr* model run. Medium and large farms increase the level of alternative activities (Table 9.7) which benefit the onion and potato yields. All farms decrease the levels of livestock output and other output and specialize more in arable production (Table A-1 to A-3 of Appendix A).

In model runs 7 to 10, the consequences of expanding hired labour, capital, other inputs, other outputs and livestock outputs, respectively were investigated. In all farms in both evaluated scenarios, capital availability is the most important factor for increasing adoption of alternative activities (compared to *Price* model run) (Table 9.6). Additional capital is invested in adapting or purchasing machinery that allows a higher density of sowing.

Table 9.6 : Simulated input-output levels, areas and yields of an average farm in Flevoland in the different model runs for the A1-W scenarios

			Scenario A1-W-only without technological change								Scenario A1-W-T with technological change							
							Scaling								Scaling			
	Profit	Calibr	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10
Capital (1000 €)	213	335	270	266	266	222	223	229	230	232	242	242	242	227	227	235	239	243
Crop protect. (1000 €)	21	15	17	16	16	14	14	14	15	15	15	15	15	16	16	16	17	17
Energy (1000 €)	19	13	18	18	18	18	19	19	21	21	21	21	21	22	23	23	23	24
Fertilizers (1000 €)	7	7	10	9	9	7	7	7	8	8	13	12	12	11	11	12	12	12
Family labour (hrs)	2512	2854	2382	2373	2361	2160	2175	2191	2154	2178	2010	1999	1999	1978	1985	2004	1942	1960
Hired labour (hrs)	1285	1776	1423	1416	1475	1489	1602	1672	1650	1653	1608	1611	1611	1605	1733	1778	1871	1875
Area (ha)	46	49	47	46	47	40	40	40	40	40	44	43	43	43	42	43	42	43
Other input (1000 €)	104	149	127	127	126	113	114	115	120	121	134	133	133	130	131	132	144	146
Gross margin (1000 €)	284	146	275	263	267	134	135	138	141	143	333	326	326	346	351	354	367	373
Livestock output (1000 €)	0	29	11	11	11	10	10	10	10	10	11	11	11	4	4	4	4	4
Other output (1000 €)	17	32	21	21	21	20	20	21	20	21	19	19	19	18	18	18	18	19
Onions (tons)	591	412	544	441	468	325	321	325	336	342	550	454	458	453	444	463	475	476
Potatoes (tons)	896	547	648	632	642	523	528	537	545	548	741	721	727	776	780	791	742	753
Sugar beet (tons)	457	467	814	803	811	636	635	653	638	630	849	836	838	888	884	904	850	858
Wheat (tons)	29	49	62	67	66	72	71	72	66	66	85	87	87	109	108	108	99	100
Oth. arable output (1000 €)	79	53	105	109	104	129	134	135	149	149	269	274	272	280	289	289	331	334
Areas																		
Onions (ha)	12	11	11	10	10	7	7	7	8	8	9	8	8	8	8	8	8	8
Potatoes (ha)	16	12	12	12	12	10	10	10	10	10	10	10	10	11	11	11	10	11
Sugar beet (ha)	9	7	9	9	9	7	7	7	7	7	7	7	7	7	7	7	7	7
Wheat (ha)	3	6	7	7	7	8	7	8	7	7	6	7	7	8	8	8	7	7
Other crops (ha)	6	13	9	9	9	8	8	8	8	9	11	11	11	8	8	8	9	9
Yields																		
Onions (tons/ha)	48	37	52	44	46	44	44	45	45	45	63	55	55	55	55	56	57	57
Potatoes (tons/ha)	57	44	55	54	55	51	51	52	52	52	72	70	71	71	71	71	71	71
Sugar beet (tons/ha)	49	70	91	92	92	94	93	94	93	94	119	119	119	122	122	122	122	123
Wheat (tons/ha)	9	8	9	9	9	9	10	10	9	10	13	13	13	14	14	14	14	14

Table 9.7: Adaptation level (in ha) for different adaptation strategies in the model runs for the A1-W scenarios with and without technological change

	2050-A1-W-only scenario [1]						2050-A1-W-T scenario [2]					
	Alter	Price	Mod run7	Mod run8	Mod run9	Mod run10	Alter	Price	Mod run7	Mod run8	Mod run9	Mod run10
Small farm												
More org. matter top soil	8	4	4	4	3	3	3	3	3	3	3	3
GPS steering	2	2	3	4	3	4	2	2	2	2	2	2
Automatic inflation	1	2	2	2	2	2	2	2	2	2	2	2
Irrigation in Spring												
Re-sowing	2			2								
Higher sowing density	7	9	9	19	19	17	9	8	9	17	15	16
Irrigation in Summer												
Medium farm												
More org. matter top soil	14	5	5	5	5	5	3	2	3	3	4	2
GPS steering	6	11	7	11	9	8	6	6	6	6	3	3
Automatic inflation	2		5	5	4	3	2	4	4	6	2	3
Irrigation in Spring	2	2	2	2	2	2						
Re-sowing	2	2	2	2	0							
Higher sowing density	27	35	30	43	42	37	28	32	37	44	41	42
Irrigation in Summer	2	2	2	2	2	2						
Large farm												
More org. matter top soil	49	12	12	12	12	13	18	8	11	11	13	14
GPS steering	11	5	2	9	6	2				7	5	7
Automatic inflation	7	2	5	6	6	4				7	2	7
Irrigation in Spring	11	2	4	4	2	4						
Re-sowing	15	2	2		3	1						
Higher sowing density	64	40	36	46	49	42	37	44	47	66	60	60
Irrigation in Summer	12	2	4	6	4	4				2	2	2

[1] Without technological change
[2] With technological change

9.4 Discussion of the results

Given the set-up of the evaluated A1-W scenarios, the most important driving factors towards 2050 (within a globalized economy and strong climate change context), are the yield increase due to climate change, the expected price change and the degree of technological innovation that focus on crop productivity. The effects of climate change (i.e. increases in temperature and atmospheric CO_2 concentration) are projected to have a positive economic effect on arable farming. However, a substantial increase in inputs such as biocides, fertilizers, and energy, is also expected. Increase in those inputs combined with a shift of production to other arable crops (mainly tulips and vegetables), can lead to additional environmental pressure per ha. Nevertheless, the environmental pressure per ton of product is projected to decrease.

The *Price* model run, using CAPRI price changes for 2050, causes a large decrease in farm gross margins (compared to *B2050* model run) in the 2050-A1-W-only scenario without technological change. In the model, the farmers react by decreasing the scale of production. However, in actual conditions (where off-farm income is possible), such a decrease in gross margins can cause large structural changes with small farmers to stop farming and large farmers to change production orientation. Of course, it is important to notice that such large changes in the supply of main crops like potatoes and onions may definitely have a feed-back effect on the prices, which will cancel out part of the effect of the assumed price change. In the 2050-A1-W-T scenario (with technological change) the effects of prices on farm incomes are even positive. The large yields compensate for the relative low price increase (when compared to input prices) and the production of crops like onions and potatoes remains profitable. In reality, development of new more productive crop varieties, as assumed in the 2050-A1-W-T scenario, is not straightforward and may require large investments at the (supra)national level.

Effective policy decisions that target at promoting production of currently grown crops, should promote research and development projects to make new highly productive varieties available and to stimulate the lowering of yield gaps by improved management. At the same time, it appears that lack of new more productive varieties as in the 2050-A1-W-only scenario, results in higher adoption rate (compared to the 2050-A1-W-T scenario) of alternative activities (being highest at the large farms) with improved management practices (e.g. investing in precision agriculture systems or increasing top soil organic matter content, see Table 9.7). It appears that making new more productive varieties available competes with promoting the use of technologies that focus on the adaptation to extreme events (like the activities in Table 9.4). From the results of the analysis, it was shown that accessibility to capital can increase the adoption rate of the tested adaptation strategies.

Appendix A

Simulated input-output levels, areas and yields of the different farm types in Flevoland in the model runs for the A1-W scenarios

Table A-1 : Simulated input-output levels, areas and yields of an average ***small*** farm in Flevoland in the model runs for the A1-W scenarios

			2050-A1-W-only scen. without technological change								2050-A1-W-T scen. with technological change							
							Scaling								Scaling			
	Profit	Calibr	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10
Capital (1000 €)	104	135	116	117	116	117	117	120	120	120	113	112	112	111	112	117	121	121
Crop protect. (1000 €)	11	7	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7	7
Energy (1000 €)	10	5	11	11	11	9	10	10	14	14	13	13	13	13	13	13	15	15
Fertilizers (1000 €)	5	4	5	5	5	4	4	4	4	5	7	6	6	6	6	6	6	6
Family labour (hrs)	1984	2126	1815	1802	1787	1664	1673	1678	1636	1660	1562	1536	1535	1495	1496	1519	1470	1489
Hired labour (hrs)	788	978	793	793	798	959	1002	1026	988	991	831	831	831	831	878	895	1063	1067
Area (ha)	27	27	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Other input (1000 €)	62	74	67	67	67	61	62	62	65	65	66	66	66	64	64	67	73	74
Gross margin (1000 €)	151	84	149	143	144	67	67	69	76	76	170	168	167	172	174	178	189	190
Livestock output (1000 €)	0	5	5	5	5	5	5	5	5	5	5	5	5	1	1	1	1	1
Other output (1000 €)	11	18	13	13	13	14	14	14	13	14	12	12	12	11	11	12	11	11
Onions (tons)	422	246	331	266	275	193	193	197	218	228	307	241	245	219	219	230	265	262
Potatoes (tons)	458	299	369	356	364	285	286	291	308	315	427	407	413	414	413	425	411	409
Sugar beet (tons)	289	294	437	444	444	379	377	390	384	379	500	498	499	513	513	527	500	498
Wheat (tons)	13	28	25	29	28	44	44	44	41	39	57	59	58	67	67	66	56	58
Oth. arable output (1000 €)	35	23	48	50	48	59	61	62	74	72	118	124	123	129	132	135	161	162
Areas																		
Onions (ha)	9	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5
Potatoes (ha)	8	7	7	7	7	6	6	6	6	6	6	6	6	7	7	7	6	6
Sugar beet (ha)	6	4	5	6	6	5	5	5	5	4	5	5	5	5	5	5	5	5
Wheat (ha)	2	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5
Yields																		
Onions (tons/ha)	48	43	52	45	45	42	41	42	43	43	60	51	51	47	47	49	52	52
Potatoes (tons/ha)	57	43	56	55	55	48	48	49	49	50	66	64	65	63	63	64	64	64
Sugar beet (tons/ha)	51	65	80	80	80	84	84	84	85	85	110	109	109	108	107	109	108	108
Wheat (tons/ha)	7	8	7	7	7	8	8	8	8	8	12	12	12	12	12	12	12	12

Table A-2 : Simulated input-output levels, areas and yields of an average ***medium*** farm in Flevoland in the model runs for the A1-W scenarios

			2050-A1-W-only scen. without technological change								2050-A1-W-T scen. with technological change							
							Scaling								Scaling			
	Profit	Calibr	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10
Capital (1000 €)	260	395	324	318	318	262	264	273	272	274	265	264	263	253	253	263	274	275
Crop protect. (1000 €)	24	19	22	22	22	19	19	20	20	20	20	21	21	20	20	21	22	22
Energy (1000 €)	16	12	15	15	15	15	16	16	16	15	16	16	16	16	17	18	17	17
Fertilizers (1000 €)	8	8	10	10	10	8	8	8	8	8	13	13	13	12	12	12	13	13
Family labour (hrs)	2664	3326	2540	2563	2551	2527	2537	2574	2528	2580	2125	2138	2139	2188	2193	2215	2164	2172
Hired labour (hrs)	470	685	582	583	590	630	728	804	810	793	636	644	644	634	729	804	810	818
Area (ha)	54	54	53	53	53	51	51	51	51	52	50	50	50	50	50	51	51	51
Other input (1000 €)	112	151	133	136	133	125	126	127	135	136	144	146	145	138	138	139	157	158
Gross margin (1000 €)	340	193	359	343	345	173	173	178	178	179	398	382	384	408	413	420	434	437
Livestock output (1000 €)	1	35	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1
Other output (1000 €)	18	36	23	23	23	21	21	22	22	23	19	19	19	19	19	19	20	21
Onions (tons)	659	464	645	513	529	392	392	390	390	403	669	557	561	530	528	537	550	552
Potatoes (tons)	1085	761	862	859	867	767	769	791	797	793	1030	1028	1042	1049	1050	1093	1032	1037
Sugar beet (tons)	600	622	1097	1065	1067	927	929	958	921	920	1121	1086	1090	1141	1142	1172	1119	1124
Wheat (tons)	47	76	94	100	100	121	120	124	108	111	107	112	112	127	126	129	123	122
Oth. arable output (1000 €)	59	4	91	98	92	106	109	109	128	123	265	266	265	264	271	272	320	322
Areas																		
Onions (ha)	14	11	12	11	11	9	9	9	9	9	10	10	10	9	9	9	9	9
Potatoes (ha)	19	16	15	15	15	14	14	15	15	15	13	14	14	14	14	14	13	14
Sugar beet (ha)	11	8	11	11	11	9	9	10	9	9	9	9	9	9	9	9	9	9
Wheat (ha)	5	8	9	10	10	12	12	12	10	11	8	8	8	9	9	9	8	8
Yields																		
Onions (tons/ha)	48	41	54	46	47	44	44	44	43	45	65	56	56	58	58	58	59	59
Potatoes (tons/ha)	58	46	57	56	57	53	53	54	54	54	78	75	76	77	77	78	77	76
Sugar beet (tons/ha)	54	75	97	98	98	99	99	99	97	99	122	121	121	125	125	126	125	125
Wheat (tons/ha)	10	9	10	10	10	10	10	11	10	10	14	14	14	15	15	15	15	15

Table A-3 : Simulated input-output levels, areas and yields of an average ***large*** farm in Flevoland in the model runs for the A1-W scenarios

			2050-A1-W-only scen. without technological change								2050-A1-W-T scen. with technological change							
							Scaling								Scaling			
	Profit	Calibr	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10
Capital (1000 €)	428	758	586	575	576	439	439	449	452	462	535	536	535	483	480	491	492	505
Crop protect. (1000 €)	40	27	32	32	32	26	26	26	27	27	31	30	30	33	33	33	34	35
Energy (1000 €)	44	34	39	39	39	42	44	45	45	45	48	48	48	49	52	53	52	52
Fertilizers (1000 €)	10	12	21	20	20	14	14	14	15	15	27	27	27	24	24	25	25	25
Family labour (hrs)	3639	4125	3595	3563	3559	2976	3011	3033	3019	3011	2979	2982	2981	2936	2960	2964	2857	2884
Hired labour (hrs)	3387	4913	3876	3844	4094	3720	4021	4194	4183	4206	4568	4569	4571	4555	4915	4997	5002	5000
Area (ha)	86	99	90	89	90	63	62	63	63	63	78	77	77	75	74	75	73	74
Other input (1000 €)	197	332	266	266	262	228	230	230	237	241	288	284	284	283	285	284	305	308
Gross margin (1000 €)	549	248	493	472	483	255	259	262	262	267	662	652	652	704	717	711	731	749
Livestock output (1000 €)	0	82	37	37	36	30	29	30	30	31	35	35	35	16	16	16	16	17
Other output (1000 €)	31	62	39	40	38	35	34	35	35	37	37	37	37	34	33	33	34	36
Onions (tons)	929	762	959	792	875	575	558	569	565	557	1015	864	870	943	904	951	908	920
Potatoes (tons)	1763	923	1097	1059	1078	841	860	864	850	852	1194	1157	1157	1367	1383	1362	1240	1286
Sugar beet (tons)	716	724	1430	1400	1434	948	946	966	952	931	1405	1392	1393	1530	1511	1534	1416	1451
Wheat (tons)	47	70	117	122	122	87	85	87	84	84	129	129	129	190	186	188	176	179
Oth. arable output (1000 €)	208	179	261	267	254	327	340	342	356	364	642	648	648	666	693	684	760	768
Areas																		
Onions (ha)	19	23	20	19	19	12	12	12	12	12	16	15	15	16	15	16	15	15
Potatoes (ha)	31	22	21	20	20	16	16	17	16	16	16	16	16	19	19	19	17	18
Sugar beet (ha)	17	10	15	14	15	10	10	10	10	9	11	11	11	11	11	11	11	11
Wheat (ha)	5	9	12	12	12	9	9	9	9	8	9	9	9	13	12	13	12	12
Yields																		
Onions (tons/ha)	49	33	49	42	46	47	46	47	47	47	64	57	57	60	59	60	59	61
Potatoes (tons/ha)	56	43	53	52	53	52	52	52	52	52	72	72	72	72	73	73	72	73
Sugar beet (tons/ha)	43	70	97	98	98	99	99	99	99	100	126	127	127	134	134	134	134	135
Wheat (tons/ha)	9	8	10	10	10	10	10	10	10	10	14	14	14	15	15	15	15	15

Literature

Abildtrup J, Audsley E, Fekete-Farkas M et al., 2006. Socio-economic scenario development for the assessment of climate change impacts on agricultural land use: a pairwise comparison approach. Environmental Science & Policy 9(2):101-115

Adams, A. J. (1986). "The photoperiodic clock of the cabbage whitefly, Aleyrodes proletella: Resonance experiments at three temperatures." Journal of Insect Physiology 32(6): 567-572.

Adams, R. M., R. A. Fleming, et al. (1995). "A reassessment of the economic effects of global climate change on U.S. agriculture." Climate change 30(2): 147-167.

Alcamo, J., J. M. Moreno, et al. (2007). Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. O. F. C. M.L. Parry, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge, UK: 541-580.

Allen, S.G., S.B. Idso, B.A. Kimball, J.T. Baker, L.H. Allen, J.R. Mauney, J.W. Radin & M.G. Anderson, 1990. Effects of air temperature on atmospheric CO_2-plant growth relationships. Report TR048. U.S. Dep. of Energy/U.S. Dep. of Agriculture, Washington DC, USA.

Andersen, E., Elbersen, B., Godeschalk, F., Verhoog, D., 2007. Farm management indicators and farm typologies as a basis for assessment in a changing policy environment. Journal of Environmental Management, 82: 352-362.

Angulo, C., Ewert, F., Rumbauer, C., Lock, R., Enders, A., Van Ittersum, M., Wolf, J., Meuter, E., Roetter, R., 2010. Modelling impacts of Climate change and technology development on crops in Europe. Agro 2010, the XI ESA congress, Montpellier, France, p. 35-36.

Audsley E, Pearn KR, Simota C et al, 2006. What can scenario modelling tell us about future European scale agricultural land use, and what not? Environmental Science & Policy 9(2):148-162

Barbier, B. and Bergeron, G., 1999. Impact of policy intervention on land management in Honduras: results of a bio-economic model. Agricultural Systems 60: 1-16.

Bardier, B. and Carpentier, C., 2000. The conditions for sustainability of tropical agriculture. Bioeconomic models applied to five contrasting faming systems. In mini-symposium on modelling at the international association of agricultural economomists Berlin.

Berentsen, P. B. M., and Tiessink, M., 2003. Potential Effects of Accumulating Environmental Policies on Dutch Dairy Farms. Journal of Dairy Science, 86: 1019-1028.

Berry PM, Rounsevell MDA, Harrison PA, Audsley E., 2006. Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. Environmental Science & Policy 9(2):189-204

Bindi M, Olesen JE., 2010. The responses of agriculture in Europe to climate change. Regional Environmental Change:1-8

Bohunovsky, L., Jäger, J., Omann, I., 2010. Participatory scenario development for integrated sustainability assessment. Regional Environmental Change, 1-14.

Boogaard, H.L., Eerens, H., Supit, I., Van Diepen, C.A., PA1-Ward, I., Kempeneers, P., 2002. Description of the MARS crop yield forecasting system (MCYFS). Study commissioned by Joint Research Centre of the European Commission, Alterra, Wageningen, the Netherlands, 179 p.

Boogaard, H.L., Van Diepen, C.A., Rötter, R.P., Cabrera, J.M.C.A., Van Laar, H.H., 1998. User's guide for the WOFOST 7.1 crop growth simulation model and WOFOST control center 1.5. Technical document 52, Winand Staring Centre, Wageningen, the Netherlands, 144 p.

Boons-Prins, E.R., De Koning, G.H.J., Van Diepen, C.A., Penning de Vries, F.W.T., 1993. Crop specific simulation parameters for yield forecasting across the European Community. Simulation Reports CABO-TT no. 32, CABO-DLO, Wageningen, the Netherlands, 43 p. + Appendices.

Bouyssou, D. (1999). Using DEA as a tool for MCDM: some remarks. Journal of the Operational Research Society 50: 974-978.

Borkowski, N., Hecker, J.M., Louhichi, K., Blanco Fonseca, M., Janssen, S., van Ittersum, M.K., Stokstad, G. and Zander, P., 2007. Surveying crop management data for bio-economic farm models. In: Hatfield, J., Donatelli, M., Rizzoli, A. (Eds.), Farming Systems Design 2007: An international symposium on Methodologies for Integrated Analysis of Farm Production Systems, Catania, Sicily, Italy, 1: 33-34.

Bradshaw B, Dolan H, Smit B., 2004. Farm-level adaptation to climatic variability and change: crop diversification in the Canadian prairies. Climate change 67:119-141

Bresser AHM., 2005. Effecten van klimaatverandering in Nederland. Milieu en Natuur Planbureau, Bilthoven,

Britz W., 2005. CAPRI Modelling System Documentation. Common Agricultural Policy Regional Impact Analysis, Bonn, Germany

Bus, C. B., C. D. van Loon, et al. (2003). Teelt van pootaardappelen. Wageningen, Praktijkonderzoek Plant en Omgeving Sector AGV, Wageningen University and Researchcentre.

Charnes, A., Cooper, W.W. and Rhodes, E., 1978. Measuring the efficiency of decision making units. European Journal of Operational Research 2: 429-444.

Chloupek, O., P. Hrstkova, et al. (2004). "Yield and its stability, crop diversity, adaptability and response to climate change, weather and fertilisation over 75 years in the Czech Republic in comparison to some European countries." Field Crops Research 85(2-3): 167-190.

Commission E., 2010. Communication from the Commission to the European parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future. Brussels 18.11.2010,

Cooper, W. W., Seiford L. M. and Zhu J., 2004. Data Envelopment Analysis: Models and Interpretations, Chapter 1, 1-39, in W.W. Cooper, L.M. Seiford and J. Zhu, eds, Handbook on Data Envelopment Analysis, Kluwer Academic Publisher, Boston.

Cooper, W. W. Seiford, L. M. and Tone K., 2007. Data Envelopment Analysis: A comprehensive text with models, application, references and DEA-solver software. Springer science and business media.

Cure, J.D. & B. Acock, 1986. Crop responses to carbon dioxide doubling: A literature survey. Agric. For. Meteorol. 38: 127-145.

Czajkowski, R., G. Grabe, et al. (2009). "Distribution of Dickeya spp. and Pectobacterium carotovorum subsp. carotovorum in naturally infected seed potatoes." European Journal of Plant Pathology 125(2): 263-275.

Daniel F-J, Perraud D., 2009. The multifunctionality of agriculture and contractual policies. A comparative analysis of France and the Netherlands. Journal of Environmental Management 90(Supplement 2):S132-S138

Darwinkel, A. (1997). Teelthandleiding wintertarwe. Wageningen, Praktijkonderzoek Plant & Omgeving B.V. Sector AGV, Wageningen University and Researchcentre.

De Temmerman, L., J. Wolf, J. Colls, M. Bindi, A. Fangmeier, J. Finnan, K. Ojanpera and H. Pleijel, 2002. Effect of climatic conditions on tuber yield (Solanum tuberosum L.) in the European 'CHIP' experiments. Europ. J. of Agronomy 17: 243-255.

De Wit, J., Swart, D., Luijendijk, E., 2009. Klimaat en Landbouw Noord-Nederland: 'effecten van extremen'. Grontmij, Houten, Netherlands.

Dockerty T, Lovett A, Appleton K, Bone A, Sünnenberg G., 2006. Developing scenarios and visualisations to illustrate potential policy and climatic influences on future agricultural landscapes. Agriculture, Ecosystems & Environment 114(1):103-120

Dogliotti, S., Rossing, W.A.H., and Van Ittersum, M.K., 2003. ROTAT, a tool for systematically generating crop rotations. European Journal of Agronomy, 19: 239-250.

Dokter H, Oppewal J., 2009. Interview met minister Verburg: "Toeslagen verschuiven, maar ik weet niet hoeveel". Boerderij, 35. pp. 4-6

Downing, T. E., E. M. Barrow, et al. (2000). Quantification of uncertainty in climate change impact assessment. Climate Change, Climatic Variability and Agriculture in Europe. P. A. H. T.E. Downing, R.E. Butterfield and K.G. Lonsdale., University of Oxford, UK : Environmental Change Institute. 21**:** 417-435.

Easterling W, Apps M., 2005. Assessing the consequences of climate change for food and forest resources: A view from the IPCC. Climate change 70(1-2):165-189

Easterling WE., 1996. Adapting North American agriculture to climate change in review. Agriculture and Forest Meteorology 80:1-53

Easterling WE, Aggarwal PK, Batima P et al., 2007. Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 273-313

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.-F., Schmidhuber, J., Tubiello, F.N., 2007. Food, fibre and forest products. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J.v.d., Hanson, C.E. (Eds.), Climate change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate change. Cambridge University Press, Cambridge, UK, pp. 273-313.

Eitzinger, J., H. Formayer, et al. (2008). "Aspects on results and uncertainty of cimate change impact simulation studies for agricultural crop production in Europe." Die Bodenkultur 59(1-4).

European Commission. (2010). "Farm Accountancy Data Network (FADN)." Retrieved March 22nd, 2010, from http://ec.europa.eu/agriculture/rica/methodology1_en.cfm.

Ewert, F., D. Rodriguez, et al. (2002). "Effects of elevated CO₂ and drought on wheat: Testing crop simulation models for different experimental and climatic conditions." Agriculture, Ecosystems and Environment 93(1-3): 249-266.

Ewert, F., Rounsevell, M.D.A., Reginster, I., Metzger, M.J., and Leemans, R.., 2005. Future scenarios of European agricultural land use I. Estimating changes in crop productivity. Agriculture, Ecosystems & Environment 107: 101-116.

Ewert F, C. Angulo, C. Rumbaur et al., 2011. Scenario development and assessment of the impacts of climate and market changes on crops in Europe – Methodology and Assessment results. AgriAdapt Project Reports no. 2 & 3, University of Bonn, Bonn, Germany

Ewert F, Rounsevell MDA, Reginster I, Metzger MJ, Leemans R., 2005. Future scenarios of European agricultural land use: I. Estimating changes in crop productivity. Agriculture, Ecosystems & Environment 107(2-3):101-116

Ewert, F., Van Ittersum, M.K., Bezlepkina, I., Therond, O., Andersen, E., Belhouchette, H., Bockstaller, C., Brouwer, F., Heckelei, T., Janssen, S., Knapen, R., Kuiper, M., Louhichi, K., Alkan Olsson, J., Turpin, N., Wery, J., Wien, J.E., Wolf, J., 2009. A methodology for enhanced flexibility of integrated assessment in agriculture. Environmental Science & Policy 12, 546–561

Frère, M. and G.F. Popov, 1979. Agrometeorological crop monitoring and forecasting. FAO Plant Production and Protection Paper 17. FAO, Rome.

Goudriaan, J., 1986. A simple and fast numerical method for the computation of daily crop photosynthesis. Agricultural and Forest Meteorology 38: 249-254.

Goudriaan, J. & M.H. Unsworth, 1990. Implications of increasing carbon dioxide and Climate change for agricultural productivity and water resources. p. 111-130. In: Impact of carbon dioxide, trace gasses, and Climate change on global agriculture. ASA Special Publication no. 53. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, USA.

Habekotté, B., 1994. TCG_CROP, een model voor berekening van produktie-en milieuvariabelen van verschillende gewassen: ontwikkeld ten behoeve van het project 'Introductie Geïntegreerde Akkerbouw'. DLO- Centrum voor Agrobiologisch onderzooekm Wageningen university. Simulation reports CABO-TT nr. 35.

Haverkort, A. and A. Verhagen (2008). "Climate Change and Its Repercussions for the Potato Supply Chain." Potato Research 51(3): 223-237.

Haverkort, A. J. (2008). Personal communications with plant production ecologist at Wageningen University and Research centre. Wageningen.

Heckelei, T., Britz, W., 2000. Concept and explorative application of an EU-wide; regional agricultural sector model (CAPRI project). Working paper. Institute of Agricultural Policy, Market Research, and Economic Sociology, University of Bonn, Bonn, Germany (http://www.agp.uni-bonn.de/agpo/rsrch/capri/eaaecapri.pdf).

Henseler M, Wirsig A, Herrmann S, Krimly T, Dabbert S., 2009. Modeling the impact of global change on regional agricultural land use through an activity-based non-linear programming approach. Agricultural Systems 100(1-3):31-42

Hermans CML, Geijzendorffer IR, Ewert F et al (2010) Exploring the future of European crop production in a liberalised market, with specific consideration of climate change and the regional competitiveness. Ecological Modelling 221(18):2177-2187

Hermans, T. and A. Verhagen (2008). Spatial impacts of climate and market changes on agriculture in Europe. Wageningen, Wageningen UR, Alterra and Plant Research International**:** 75.

Howden, S. M., J. F. Soussana, et al. (2007). "Adapting agriculture to climate change." Proceedings of the National Academy of Sciences of the United States of America 104(50): 19691-19696.

IPCC, 2000. Emission scenarios. Cambridge University Press.

IPCC, 2001: Climate change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Jackson, S. D. (1999). "Multiple Signaling Pathways Control Tuber Induction in Potato." Plant Physiol. 119(1): 1-8.

Jain, A.K., H.S. Kheshgi, and D.J. Wuebbles, 1994: Integrated Science Model for Assessment of Climate Change. Lawrence Livermore National Laboratory, UCRL-JC-116526.

Janssen, S., 2009. Managing the Hydra in integration: developing an integrated assessment tool for agricultural systems. PhD thesis (http://edepot.wur.nl/10616).

Janssen, S., Louhichi, K., Kanellopoulos, A., Zander, P., Flichman, G., Hengsdijk, H., Meuter, E., Andersen, E., Belhouchette, H., Blanco, M., Borkowski, N., Heckelei, T., Hecker, M., Li H., Oude Lansink, A., Stokstad, G., Thorne, P., Van Keulen, H., and Van Ittersum, M. K., 2010. A generic bio economic farm model for environmental and economic assessment of agricultural systems. Under review.

Janssen, S., van Ittersum, M.K., 2007. Assessing farm innovations and responses to policies: a review of bio-economic farm models. Agricultural Systems 94, 622–636

Jones, G., M. White, et al. (2005). "Climate Change and Global Wine Quality." Climate change 73(3): 319-343.

Jongeneel RA, Polman NBP, Slangen LHG., 2008. Why are Dutch farmers going multifunctional? Land Use Policy 25(1):81-94

Kaiser HM, Riha SJ, Wilks DS, Rossiter DG, Sampath R., 1993. A farm-level analysis of economic and agronomic impacts of gradual climate warming. American Journal of Agricultural Economics 75(2):387-398

Kanellopoulos, A., Berentsen, P., Heckelei, T., Van Ittersum, M., Oude Lansink, A., 2010. Assessing the Forecasting Performance of a generic bio-economic farm model calibrated with two different PMP variants. Journal of Agricultural Economics, 61: 274-279.

Kattenberg, A. (2008). De toestand van het klimaat in Nederland 2008. De Bilt, The Netherlands, Royal Dutch Meteorological Institure (KNMI).

Koomen E, Kuhlman T, Groen J, Bouwman A., 2005. Simulating the future of agricultural land use in the Netherlands. Tijdschrift voor Economische en Sociale Geografie 96(2):218-224

KWIN (Quantitative Information on Arable and Horticultural production) report, 2001. 25th edition, PPO report 301, PPO, Lelystad, The Netherlands.

KWIN (Quantitative Information on Arable and Horticultural production) report, 2009. 27th edition, PPO report 383, PPO, Lelystad, The Netherlands.

Lazar, C., Genovese, G.(eds.), 2004. Methodology of the MARS Crop Yield Forecasting System. Volume 2. Agrometeorological data collection, processing and analysis. European Communities (ISBN 92-894-8181-1) 98 p.

Long, S.P., Zhu, X.-G., Naidu, S.L., Ort, D.R., 2006. Can improvement in photosynthesis increase crop yields? Plant, Cell & Environment 29: 315-330.

Louhichi, K., Janssen, S.J.C., Li, H., Zander, P., Stokstad, G., Kanellopoulos, A., van Ittersum, M.K., van der Maden, E., Hengsdijk, H., Flichman, G., Blanco Fonseca, M., Rizzoli, A.E., 2006. D3.3.6 – A first version of FSSIM for the arable farming sector to be used within Prototype 1 of SEAMLESS-IF. SEAMLESS Integrated Project, EU 6th Framework Programme

Louhichi, K. Kanellopoulos, A., Janssen, S., Flichman, G., Blanco., M., Hengsdijk, H., Heckelei, T., Berentsen, P., Oude Lansink, A., Van Ittersum, M., 2010. FSSIM, a bio-economic farm model for simulating the response of EU farming systems to agricultural and environmental policies. Agric. Sys. 103: 585-597.

Louhichi, K., Janssen, S., Kanellopoulos, A., Li, H., Borkowski, N., Flichman, G., Hengsdijk, H., Zander, P., Blanco, M., Stokstad, G., Athanasiadis, I.N., Rizzoli, A.E., Huber, D., Heckelei, T., van Ittersum, M.K., 2009. A generic Farming System Simulator In: Brouwer, F., van Ittersum, M.K. (Eds.), Environmental and agricultural modelling: integrated approaches for policy impact assessment. Springer, Dordrecht.

Mandryk et al., 2011. Section of Ph.D. Thesis.

Maracchi, G., O. Sirotenko, et al. (2005). "Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe." Climate change 70(1-2): 117-135.

Meerburg BG, Korevaar H, Haubenhofer DK, Blom-Zandstra M, Keulen H v., 2009. The changing role of agriculture in Dutch society. Journal of Agricultural Science 147(5):511-521

Naeff, H. S. D. (2006). Geactualiseerd GIAB Nederland 2005. Wageningen, Alterrra.

Nakicenovic N, Swart R., 2000. Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Nonhebel S., 1997. Harvesting the sun’s energy using agro-ecosystems. Quantitative Approaches in Systems Analysis No 13. Wageningen, AB-DLO.

Olesen JE, Bindi M., 2002. Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy 16(4):239-262

Olesen, J. E. and K. Grevsen (1993). "Simulated effects of climate change on summer cauliflower production in Europe." European Journal of Agronomy **2**(4): 313-323.

Parry, M. L., C. Rosenzweig, et al. (2004). "Effects of climate change on global food production under SRES emissions and socio-economic scenarios." Global Environmental Change 14(1): 53-67.

Peltonen-Sainio P, Jauhiainen L, Trnka M et al., 2010. Coincidence of variation in yield and climate in Europe. Agriculture, Ecosystems & Environment 139(4):483-489

Piorr A, Ungaro F, Ciancaglini A et al., 2009. Integrated assessment of future CAP policies: land use changes, spatial patterns and targeting. Environmental Science & Policy 12(8):1122-1136

Porter, J. R. and M. A. Semenov (2005). "Crop Responses to Climatic Variation." Philosophical Transactions: Biological Sciences 360(1463): 2021-2035.

Prato T, Zeyuan Q, Pederson G, Fagre D, Bengtson L, Williams J., 2010. Potential Economic Benefits of Adapting Agricultural Production Systems to Future Climate Change. Environmental Management 45(3):577-589

Reidsma P, Ewert F ., 2008. Regional farm diversity can reduce vulnerability of food production to climate change. Ecology and Society 13(1)

Reidsma P, Ewert F, Lansink AO, Leemans R., 2010. Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. European Journal of Agronomy 32(1):91-102

Reidsma P, Ewert F, Oude Lansink A, Leemans R., 2009. Vulnerability and adaptation of European farmers: a multi-level analysis of yield and income responses to climate variability. Regional Environmental Change 9(1):25-40

Reidsma P, Tekelenburg T, van den Berg M, Alkemade R., 2006. Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union. Agriculture, Ecosystems & Environment 114(1):86-102

Reilly, J.M., & Fuglie, K.O., 1998. Future yield growth in field crops: what evidence exists? Soil & Tillage Research 47: 275-290.

Reilly, J., F. Tubiello, et al. (2003). "U.S. Agriculture and Climate Change: New Results." Climate change 57(1): 43-67.

Reilly, J. M. (2002). Agriculture: The potential Consequences of Climate Variability and Change. University Press. Cambridge.

Reynolds M.P., Pellegrinischi, A., Skovmand, B., 2005. Sink-limitation to yield and biomass: a summary of some investigations in spring wheat. Annals of Applied Botany 146: 39-49.

Reynolds M.P., Foulkes, M.J., Slafer, G.A., Berry, P., Parry M.A.J., Snape, J.W., Angus, W.J., 2009. Raising yield potential in wheat. Journal of Experimental Botany 60: 1899-1918.

Riedijk A, van Wilgenburg R, Koomen E, Borsboom-van Beurden J., 2007. Integrated scenarios of socio-economic and climate change; a framework for the "Climate changes Spatial Planning" programme. Spinlab Reseach Memorandum SL-06. VU, MNP, Amsterdam, pp. 49

Rienks W., 2009. Landbouwatlas van Nederland. ROM3D, Hengevelde

Roest A, Vermeij I, Jager JH, Everdingen WHv, 2010. Definities en gegevens van multifunctionele landbouw in databestanden. LEI, Den Haag,

Romero, C., Rehman, T., 2003. Multiple criteria analysis for agricultural decisions (second edition). Developments in agricultural economics 11, Elsevier, Amsterdam, The Netherlands, pp. 186.

Rosenzweig, C., J. Phillips, et al. (1996). "Potential impacts of climate change on citrus and potato production in the US." Agricultural Systems 52(4): 455-479.

Rotmans, J. and van Asselt, M.B.A. Integrated assessment: growing child on its way to maturity, 1996. An editorial essay, Climate change 34:327–336.

Rounsevell MDA, Annetts JE, Audsley E, Mayr T, Reginster I., 2003. Modelling the spatial distribution of agricultural land use at the regional scale. Agriculture, Ecosystems & Environment 95(2-3):465-479

Rufino, M.C., Tittonell, P., Wijk, M.T. van, Castellanos-Navarrete, A., Delve, R.J., Ridder, N. de, Giller, K.E., 2007. Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livestock Science 112: 273–287.

Schaap, B., Blom-Zandstra, G., Geijzendorffer, I., Hermans, T., Smidt, R., Verhagen, J., 2009. Klimaat en Landbouw Noord-Nederland, Rapportage van fase 2. Plant Research International, Nota 629, Wageningen, Netherlands

Schaap B, Blom-Zandstra G, Hermans T, Meerburg BG, Verhagen A (2011) Impact changes of climatic extremes on arable farming in the north of the Netherlands. Regional Environmental Change:1-11

Schaap, B., et al., 2011. Results from stakeholders interactions and meetings. AgriAdapt Project Report no. 6, PRI, Wageningen, The Netherlands.

Schar, C., Vidale, P.L., Luthi, D., Frei, C., Haberli, C., Liniger, M.A., Appenzeller, C., 2004. The role of increasing temperature variability in European summer heatwaves. Nature 427, 332-336.

Slafer & Andrade, 1991. Changes in physiological attributes of the dry mater economy of bread wheat (Triticum aestivum) through genetic improvement of grain yield potential at different regions in the world – a review. Euphytica 58: 37-49.

Smit AB, Jager, J.H., Prins, H., 2004. Gevolgen van de hervorming van het Europese landbouwbeleid voor de landbouw in Noord-Nederland. LEI, Den Haag, Netherlands

Smit, B. and M. W. Skinner (2002). "Adaptation options in agriculture to climate change: a typology." Mitigation and Adaptation Strategies for Global Change **7**(1): 85-114.

Spitters, C.J.T., 1986. Separating the diffuse and direct component of global radiation and its implications for modelling canopy photosynthesis. Part II: Calculation of canopy photosynthesis. Agricultural and Forest Meteorology 38: 231-242.

Stewart, T., 1996. Relationships between Data Envelopment Analysis and Multicriteria Decision Analysis. Journal of Operational Research Society 47: 654-665.

Supit, I., Hooijer, A.A., Van Diepen, C.A. (Eds.), 1994. System description of the WOFOST 6.0 crop simulation model implemented in CGMS. Publication EUR15956EN, Joint Research Centre, European Commission, Luxembourg.

Temme AJAM, Verburg PH., 2011. Mapping and modelling of changes in agricultural intensity in Europe. Agriculture, Ecosystems and Environment 140(1-2):46-56

Timmer, R. (2008). Personal communications, Applied Plant Research at Wageningen University and Researchcentre.

van Bruchem C, Silvis H., 2008. Agrarische structuur, trends en beleid. Ontwikkelingen in Nederland vanaf 1950. Rapport 2008/060. LEI Wageningen UR, Den Haag, Van der Burgt, G. J. H. M., Oomen, G. J. M., Habets A. S. J., and Rossing W. A. H., 2006. The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. Nutrient Cycling in Agroecosystems, 74: 275-294.

Van den Hurk, B., A. Klein Tank, G. Lenderink, A. van Ulden, G. J. van Oldenborgh, C. Katsman, H. van den Brink, F. Keller, J. Bessembinder, Burgers, G., G. Komen, W. Hazeleger and S. Drijfhout, 2006: KNMI Climate change Scenarios 2006 for the Netherlands. KNMI Scientific Report WR 2006-01, De Bilt, The Netherlands.

Vandermeulen V, Gellynck X, Van Huylenbroeck G, Van Orshoven J, Bomans K., 2009. Farmland for tomorrow in densely populated areas. Land Use Policy 26(4):859-868

van der Ploeg JD, Laurent C, Blondeau F, Bonnafous P., 2009. Farm diversity, classification schemes and multifunctionality. Journal of Environmental Management 90(Supplement 2):S124-S131

van Dorland R, Jansen, B., Dubelaar-Versluis, W., 2008. De staat van het klimaat 2007. uigave PCCC, De Bilt/Wageningen, Netherlands

van Drunen M, Berkhout F (2008) Applying WLO for climate change. IVM Institite for Environmental Studies Vriije Universiteit, Amsterdam, Netherlands

Van Ittersum, M.K., Ewert, F., Heckelei, T., Wery, J., Alkan Olsson, J., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., Rizzoli, A.E., van der Wal, T., Wien, J.E., Wolf, J., 2008. Integrated assessment of agricultural systems - A component-based framework for the European Union (SEAMLESS). Agricultural Systems 96, 150-165.

Venema G, B. Doorneweert, K. Oltmer et al., 2009. Wat noemen we verbrede landbouw? Verkenning van definities en informatiebehoeften. . LEI Wageningen UR, Den Haag, Netherlands

Waldhardt R, Bach M, Borresch R et al., 2010. Evaluating today's landscape multifunctionality and providing an alternative future: A normative scenario approach. Ecology and Society 15(3)

Weaver, P.M., Rotmans, J., 2006. Integrated sustainability assessment: What is it, why do it and how? International Journal of Innovation and Sustainable Development 1, 284-303.

Westhoek HJ, van den Berg M, Bakkes JA , 2006. Scenario development to explore the future of Europe's rural areas. Agriculture, Ecosystems & Environment 114(1):7-20

Wolf, J., Hessel, R., Boogaard, H.L., 2008. New calibration for winter wheat, Crop growth modeling and Yield forecasting. ASEMARS project report no. 18, Alterra, Wageningen, The Netherlands

Wolf, J., Hessel, R., Boogaard, H.L., Wit, A. de, Akkermans, W., Diepen, C.A. van, 2010. Modeling winter wheat production over Europe with WOFOST – the effect of two new zonations and two newly calibrated model parameter sets. In: Methods of Introducing System Models into Agricultural Research. Volume 2 in the ASA-SSSA-

CSSA book series: Advances in Modeling Agricultural Systems: Trans-disciplinary Research, Synthesis, Modeling, and Applications, in press.

Wolf, J. and C. A. van Diepen (1995). "Effects of climate change on grain maize yield potential in the European Community." Climate change 29(3): 299-331.

Wolf, J., Van Oijen, M., 2002. Modelling the dependence of European potato yields on changes in climate and CO2. Agric. and Forest Meteorology 112:217-231.

Wolf, J., Van Oijen, M., 2003. Model simulation of effects of changes in climate and atmospheric CO2 and O3 on tuber yield potential of potato (cv. Bintje) in the European Union. Agriculture, Ecosystems & Environment 94: 141-157.

Wolf, J., Kanellopoulos, A., Adenäuer, M., Andersen, E., Heckelei, T., Janssen, S., Reidsma, P., Therond, O., Van Ittersum, M.K., 2011. Effects of High prices on arable farming systems across the European Union, Agric. Systems, in prep.

Wolfe, D., L. Ziska, et al. (2008). "Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers." Mitigation and Adaptation Strategies for Global Change 13(5): 555-575.

Zander, P., Borkowski, N., Hecker, J. M., Uthes, S., Stokstad, G., Rørstad P. Kr., and Bellocchi, G., 2009. Conceptual Approach to Identify and Assess Current Activities. P.D 3.3.9. SEAMLESS integrated project, EU 6th Framework program, contract no. 010036-2, (www. SEAMLESS-IP.org).

Zimmermann A, Heckelei T, Domínguez IP, 2009. Modelling farm structural change for integrated ex-ante assessment: review of methods and determinants. Environmental Science & Policy 12(5):601-618.

Zwankhuizen, M. J. and J. C. Zadoks (2002). "Phytophthora infestans's 10-year truce with Holland: a long-term analysis of potato late-blight epidemics in the Netherlands." Plant Pathology 51(4): 413-423.