# Climate change impact and adaptation research requires integrated assessment and farming systems analysis: a case study in the Netherlands



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LETTER

# Climate change impact and adaptation research requires integrated assessment and farming systems analysis: a case study in the Netherlands

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## Abstract

Rather than on crop modelling only, climate change impact assessments in agriculture need to be based on integrated assessment and farming systems analysis, and account for adaptation at different levels. With a case study for Flevoland, the Netherlands, we illustrate that (1) crop models cannot account for all relevant climate change impacts and adaptation options, and (2) changes in technology, policy and prices have had and are likely to have larger impacts on farms than climate change. While crop modelling indicates positive impacts of climate change on yields of major crops in 2050, a semi-quantitative and participatory method assessing impacts of extreme events shows that there are nevertheless several climate risks. A range of adaptation measures are, however, available to reduce possible negative effects at crop level. In addition, at farm level farmers can change cropping patterns, and adjust inputs and outputs. Also farm structural change will influence impacts and adaptation. While the 5th IPCC report is more negative regarding impacts of climate change on agriculture compared to the previous report, also for temperate regions, our results show that when putting climate change in context of other drivers, and when explicitly accounting for adaptation at crop and farm level, impacts may be less negative in some regions and opportunities are revealed. These results refer to a temperate region, but an integrated assessment may also change perspectives on climate change for other parts of the world.

## 1. Introduction

Climate change impact assessments in agriculture are usually based on crop simulation models, as the crop level is the basic level at which climate directly affects agriculture (Rötter *et al* 2011, Challinor *et al* 2014, Rosenzweig *et al* 2014). Additionally, statistical models are used to assess impacts on crop yields and farmers' income, implicitly including adaptation (Mendelsohn 2007, Antle and Capalbo 2010, Lobell and Burke 2010). Recently, much effort has been going into the improvement of crop and economic models and their coupling (Rosenzweig *et al* 2013, Nelson *et al* 2014). A drawback of all these approaches is that the farm level is not explicitly considered, while decisions regarding production, management and adaptation are made at this level. Farm level responses influence impacts of climate change and variability (Reidsma *et al* 2010, Himanen *et al* 2013) and should be considered in impact assessments.

Farm level decisions are not only influenced by climate. Technological development, policy and the market largely influence agricultural decision making. Their influence has been larger than climate change (Chiotti and Johnston 1995, Hermans *et al* 2010) and there are no reasons to assume this may change in the near future. The impact of climate change should thus be considered in the context of these other changes.

In addition, it has become evident that a significant challenge for agriculture with regard to climate change

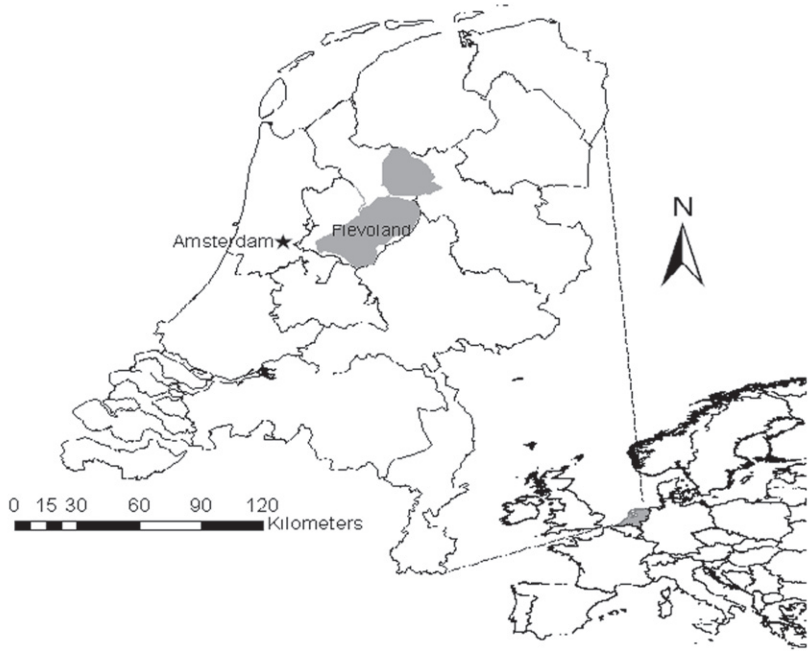


**Figure 1.** The location of the case study Flevoland in the Netherlands.

can be expected from changes in the magnitude and frequency of extreme conditions like droughts, hail, storms and excessive wet periods (Trnka *et al* 2011, Gobin 2012, Iglesias *et al* 2012). Transparent information on how such changes affect crops is needed for farmers and other stakeholders in order to design adaptation strategies.

Also the chapter on food security and food production systems in the latest IPCC WG2 report (Porter *et al* 2014) relies strongly on crop level analyses, and impacts of climate change are not put in the context of other changes, leading to rather pessimistic conclusions. Results from crop models and statistical analyses are synthesized in the IPCC report, but little information is given on main risks and adaptation measures at farm level. In this paper, we argue that integrated assessment (IA; (Rotmans and Van Asselt 1998, Van Ittersum *et al* 2008) and farming systems analysis (Janssen and van Ittersum 2007) are needed for climate change impact assessments in agriculture. The farm level is particularly important, as this is the level at which decisions to cope with changes, including adaptation, take place. Adaptation refers to efforts to prepare for or adjust to climate change, and for agriculture; this includes all measures at crop, farm, sectoral and regional level.

In this paper we illustrate that using IA and farming systems analysis gives a broader and more nuanced picture of climate change impacts, with a case study for Flevoland, the Netherlands (figure 1). Our first aim was to assess impacts of climate change towards 2050 in the context of other changes, both at crop and at farm level. Our second aim was to complement crop simulation models with participatory approaches and bio-economic farm modelling to improve understanding of main climate risks and identify a more comprehensive portfolio of adaptation measures.

## 2. Methodology

### 2.1. Framework

Integrated assessment provides added value compared to disciplinary research, as it allows to better understand the complexity of the system (Rotmans and Van Asselt 1998). At the same time, the complexity causes communication to be an on-going challenge. In this paper we highlight innovative approaches and the main results, and for details we refer to already published papers (see below; appendix 1).

As changes at higher levels influence the local level, assessments were performed at two levels of organization (figure 2). At the EU level and for the year 2050, the crop model LINTUL-FAST was applied to assess changes in crop yields due to climate change, and a statistical model was used to assess changes due to technological development (Angulo *et al* 2013). Climate change scenarios were based on the SRES storylines and a 15 GCM model ensemble. Next, the partial equilibrium market model CAPRI was used to assess changes in agricultural commodity prices due to changes in supply (based on LINTUL-FAST) and demand (Britz *et al* 2007, Ewert *et al* 2011). These EU level price changes were input for the regional level assessment for Flevoland (appendix 2).

Flevoland (figure 1) is a province with mainly arable agriculture (75% of the area). Most important crops in Flevoland are potato (31% of arable area), sugar beet (17%), winter wheat (17%) and onion

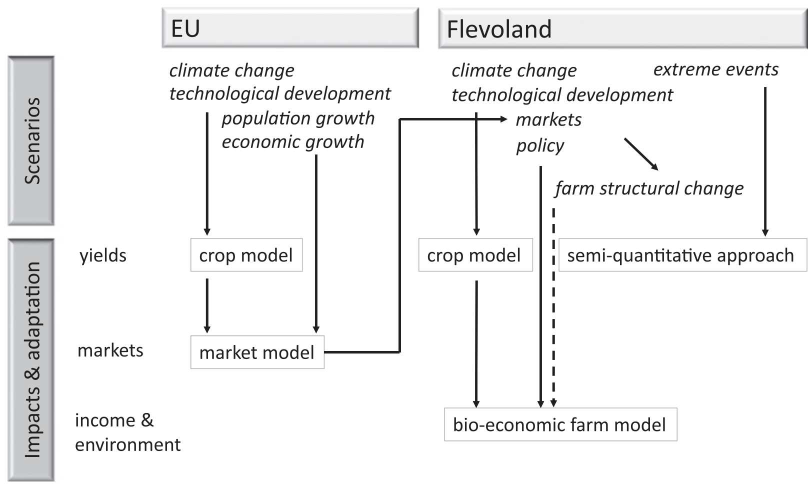


**Figure 2.** Framework of the study, including the drivers and methods used to assess impacts and adaptation.

(11%) (in 2008–2010; CBS Statline and LEI). The province was reclaimed from the lake IJsselmeer in the 1950s, and has high quality soils, good infrastructure, allotment of land and high water availability, all favourable for agricultural production (Rienks and Meulenkamp 2009).

At the provincial level, four climate change scenarios from the Royal Netherlands Meteorological Institute (KNMI) were used, i.e. the KNMI'06 scenarios (appendix 3; van den Hurk *et al* 2006). In this paper we focus on results from one scenario (W+) for the year 2050 since it is our aim to show climate change impacts and adaptation in the context of other drivers of change, rather than showing differences between different climate scenarios. The W+ scenario relates to a global 2 °C increase, and assumes changes in air circulation patterns resulting in drier summers in the Netherlands. $CO_2$ concentrations were assumed to be 567 $\mu$mol $CO_2$ mol$^{-1}$. The climate change scenario W + was linked to the global economy scenario similar to the IPCC SRES storyline A1, according to Riedijk *et al* (2007). Where relevant, for example to show uncertainty, we additionally present results from the B2/G scenario, which is a regional communities scenario, with a global 1 °C increase, no changes in air circulation patterns, slightly increasing annual precipitation, and $CO_2$ concentrations of 478 $\mu$mol $CO_2$ mol$^{-1}$. Assessments of impacts of climate change and adaptation are described in the next sections.

### 2.2. Drivers affecting crop yields in Flevoland at crop level

Impacts of climate change and adaptation on crops in Flevoland were assessed with the crop growth simulation model WOFOST (appendix 4; Wolf *et al* 2011, Boogaard *et al* 2013). Simulated adaptation measures included (i) changing the sowing date (i.e. 15 days earlier except for winter wheat) and (ii) changing the crop varieties (assuming more southern varieties with a 10% increase in temperature requirements for phenological development).

Crop models assess impacts of gradual climate change, but these models are designed to assess potential or water-limited yields rather than actual yield, and hence the influence of (sub-optimal) management is largely neglected (e.g. Reidsma *et al* 2009). Moreover, when climate change will become apparent, also technological development will have taken place (Ewert *et al* 2005).

Crop model results therefore need to be put into context. Regarding technological development, a literature review was performed to investigate the possibilities to increase the potential yield level in 2050 due to changes in physiological, phenological and morphological characteristics of crops (Wolf *et al* 2011). Moreover, data were analysed to assess genetic progress in Dutch potential crop yields over the past 30 years (Rijk *et al* 2013). Although technological development cannot be completely separated from climate change adaptation, in this paper we assume technological development to be independent of climate change.

Progress in genetic yield potential (technological development) still leads to substantial yield increases. Yield potential ($Y_P$) can be expressed as a function of light intercepted (LI), radiation use efficiency (RUE), and the partitioning of biomass to yield, or harvest index (HI): $Y_P = \mathrm{LI} \cdot \mathrm{RUE} \cdot \mathrm{HI}$. LI and HI have been optimized for, in particular, grain crops during the past decades, and future genetic progress in yield of grain (and other main) crops will most likely be achieved by focusing on constraints to RUE (Reynolds *et al* 2005, Fischer *et al* 2014). Long *et al* (2006) describe six potential routes of increasing RUE by improving photosynthetic efficiency, and collectively, these changes could improve RUE and, therefore, $Y_p$ still substantially (Fischer and Edmaedes 2010, Fischer *et al* 2014).

Regarding management, we assumed that yield gaps (1 minus actual yield/simulated potential yield) can be reduced towards 2050, but to no less than 20%. Due to years with extreme conditions, disease infestations in wet years, economic and environmental efficiency, farmers generally do not realize the full potential and hence the exploitable yield is often assumed 80% of the potential (Cassman 1999, Van Ittersum *et al* 2013).

Other limitations of crop models are that (i) the impact of extreme events including pests and diseases cannot be simulated adequately (e.g. Jamieson *et al* 1999), (ii) they do not address crop quality, and (iii) only few adaptation options can be simulated. To address these issues, the Agro Climatic Calendar (ACC) was developed, a semi-quantitative and participatory method that specifically focused on the impacts of extreme events and pests and diseases under climate change (Schaap *et al* 2011, Schaap *et al* 2013). Current extreme climate factors affecting crop yield and quality were identified, and the impact of these climate factors expressed as the potential economic loss of a single event, were estimated by scientists, experts and stakeholders. Economic losses were defined as percentages of crop output (€ $ha^{-1}$ $yr^{-1}$). Low and high impact levels were estimated, as economic losses can differ depending on local conditions and farm management.

The future risks from extreme climate factors were expressed as changed frequencies of their occurrence in the 30-year period around 2050 compared with a 30-year period around 1990. Main climate risks are the climate factors that have high economic impacts (€ $ha^{-1}$ $yr^{-1}$), calculated by multiplying potential economic loss as a result of a single event with the change in frequencies. Identifying the main climate risks allows to target adaptation measures. After identifying adaptation measures, a cost-benefit analysis including annual costs, investment costs and effectiveness in damage reduction was performed to estimate most effective adaptation measures (Schaap *et al* 2013).

### 2.3. Drivers affecting crop production and farm income in Flevoland at farm level

Farm performance is not only influenced by crop yields. Farm performance is primarily measured by farm income, which also depends on farm plans, prices of inputs and outputs, and farm size. Farmers can adapt their farm plans and management, and besides climate change and technological development, markets and policies are the main drivers affecting farm performance. Farms are diverse with respect to available resources, constraints and farmer's objectives (figure 3), and therefore they adapt differently to changes in drivers.

Benchmarking (using Data Envelopment Analysis; DEA; Cooper *et al* 2007) and bio-economic farm modelling (using the Farming Systems Simulator; FSSIM; Louhichi *et al* 2010) were used to assess the impact of different drivers at farm level (see Kanellopoulos *et al* 2014). By using DEA, current 'best' farm activities (i.e. technical efficient) were identified from a survey of 75 farms (from the Farm Accountancy Data Network) fully characterized by their input and output data (averages from 2000 to 2006). FSSIM allowed to assess the impact of farm level adaptation, including changes in cropping patterns, inputs and outputs.

We assessed impacts of management, climate change, farm level climate change adaptation, price and policy changes, and technological development with FSSIM; each in addition to the previous change. First, the impact of management was assessed by comparing the optimal, profit maximizing production plans derived from using FSSIM, with the observed situation. Although farmers have various objectives, profit maximization was found to be the most important one in the region (Mandryk *et al* 2014). Similar to yield gaps, a large part of this income gap may be closed towards 2050 by increasing efficiency and profitability.

Secondly, the impact of climate change without farm level adaptation in 2050 was assessed with FSSIM keeping the farm activities (from the profit maximizing production plans in the current situation) the same, but allowing changes in yields due to climate change and associated fertilizer input. Climate change impacts on yields were based on WOFOST output (table 1; for A1/W+ including crop level adaptation, for B2/G excluding crop level adaptation). Thirdly, the impact of farm level climate change adaptation was assessed by allowing farms to change their activities to maximize profit under climate change. Fourth, the impacts of changes in prices (based on the market model CAPRI, section 2.1) and policy (in A1/W+ abolishment of sugar beet quota and subsidies) were assessed. Lastly, the impacts of possible technological development (table 1) were added. In these FSSIM simulations effects of extreme events were not included.

### 2.4. Considering farm structural change

The 75 farms assessed using FSSIM (section 2.3) differ in their farm structure, influencing impacts of climate and socio-economic change. In the period 1980–2010 the average farm size increased with 20% and the number of arable farms decreased with 30% (Mandryk *et al* 2012). As farm structure will change towards 2050, it needs to be considered in climate change impact assessments. Historical analysis and stakeholder workshops were used to derive relationships between drivers (technology, markets, policy, climate change) and farm type dimensions (farm size, intensity, specialization and orientation), and scenario analyses were performed to project farm structural change towards 2050 (Mandryk *et al* 2012). In this paper we did not use changes in farm structure as a

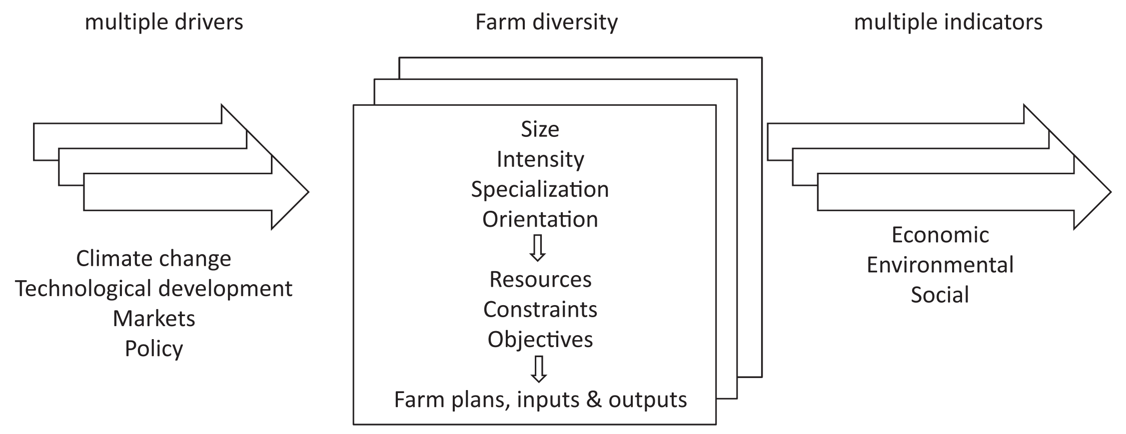


**Figure 3.** Farm level assessments should account for the diversity in farms, and for multiple impacts from multiple drivers.

basis for FSSIM simulations (section 2.3), but re-calculated average regional impacts based on farm structural change. This means that farm area did not increase in FSSIM simulations, but for calculating average impacts we considered that there are relatively more large farms, for which impacts differed from medium sized farms.

## 3. Results and discussion

### 3.1. Drivers impacting crop yields

*3.1.1. Crop yield change due to gradual climate change, adaptation, management and technological development*

According to crop model simulations, climate change impacts in the A1/W+ scenario were slightly positive for winter wheat and potato, and very positive for onion and sugar beet (table 1). The high temperatures in A1/W+ caused yield changes to be less positive than in the B2/G scenario, except for sugar beet for which a temperature increase of 2.6 °C (see appendix 3) was still positive. Especially for winter wheat and potato effects were mainly positive because of the yield-increasing [$CO_2$] effect (see appendix 4). Except for sugar beet, the positive impacts of climate change could be more than doubled with simple adaptation measures, as simulated with the crop model (table 1). Including this climate change adaptation, impacts were in the range of +6 to +33% (f.e. $1.286 \times 1.037 = 1.33$ refers to a 33% increase for sugar beet).

In Flevoland, the yield gaps between the potential and actual yields in 2006–2008 were small for the main crops (⩽25%), indicating near optimal crop management at present. As observed in table 1, a further closure of the yield gap (assuming 80% of the potential yield as the exploitable yield gap) is still possible for winter wheat and potato, but not for onion and sugar beet. In the A1/W+ scenario we assumed closure of this gap, in B2/G a 1/3 closure (similar to Ewert *et al* 2005).

Based on the literature review, the increase in potential yield by genetic improvement was estimated at 1% per year. This estimate corresponds well with the estimate based on the historical yield trends (Reilly and Fuglie 1998, Ewert *et al* 2005, Angulo *et al* 2013). Assuming that the genetic improvement will decrease over time and will become zero in year 2050, we estimated the total increase in yield potential from genetic improvement for the A1/W+ scenario for the year 2050 at 30% of the current yield potential in Flevoland. As genetic improvement depends on many factors, we did not differentiate between different crops. For the B2/G scenario we assumed the increase to be 1/3 of A1/W+ (similar to Ewert *et al* 2005), resulting in a 10% increase due to lower investments in research and development.

There have been indications that yields are stagnating in Europe (Brisson *et al* 2010), but Rijk *et al* (2013) showed that in the Netherlands genetic progress between 1980 and 2010 has been substantial and largely linear. When extrapolating these trends (similar to the method of Angulo *et al* (2013) in an A1 scenario), yield increases between 2010 and 2050 would be 47% for winter wheat, 28% for sugar beet, and 11% for ware potato (table 1; in brackets). This would imply that winter wheat can benefit more from genetic improvements than potato.

Synthesizing, table 1 suggests that genetic improvements will likely have the largest impact on crop yields in 2050. The positive impact of climate change is large for sugar beet and onion, but smaller for potato and winter wheat. Results for Flevoland in the EU level assessment were similar, even though different methods were used. Projected increases in actual yields were smaller for potato, which is due to the use of historical trend analysis for future projections of technological development (Ewert *et al* 2005, Angulo *et al* 2013), and which was also observed in Rijk *et al* (2013) (breeding focus in potato is on quality and resistance to pest and diseases rather than on yield).

**Table 1.** Relative contributions of management, climate change, adaptation and technological development to yield changes (%) in Flevoland in two scenarios towards 2050. The numbers presented show additive effects of drivers, i.e. the percentage difference on top of the effects of all drivers included in the columns left of the specific driver (the overall increase is a multiplication of all effects). For technological development, values based on extrapolating trends from Rijk *et al* (2013) are also given in brackets. To indicate robustness, in the last column values for overall yield increase are compared with results for Flevoland from the EU level study (Angulo *et al* 2013), where a different crop model was used and a different method to assess technological development.

| | | | Crop model WOFOST | | Literature review (statistics) | | |
|---|---|---|---|---|---|---|---|
| Crop | Actual yield in 2000–2009 (t fresh $ha^{-1}$) | Management: yield gap closure (%) | Climate change (%) | Adaptation (%)[a] | Technological development:genetic potential (%) | Overall increase in actual yield (%)[b] | Overall increase in actual yield (%) by Angulo *et al* (2013) |
| A1/W+ | | | | | | | |
| Potato ware | 54.1 | 4.8 | 2.2 | 8.4 | 30 (11) | 51 | 28 |
| Sugar beet | 73.4 | 0 | 28.6 | 3.7 | 30 (28) | 73 | 80 |
| Winter wheat | 9.2 | 7.2 | 2.7 | 3.4 | 30 (47) | 48 | 54 |
| Onion | 62.8 | 0 | 14.2 | 14.6 | 30 | 70 | |
| B2/G | | | | | | | |
| Potato ware | 54.1 | 1.6 | 8.4 | n.a. | 10 | 21 | 16 |
| Sugar beet | 73.4 | 0 | 19.3 | n.a. | 10 | 32 | 40 |
| Winter wheat | 9.2 | 2.4 | 10.5 | n.a. | 10 | 25 | 25 |
| Onion | 62.8 | 0 | 20.3 | n.a. | 10 | 32 | |

[a] n.a.—not applied.

[b] The overall increase is a multiplication of all effects. For example, for potato ware: $1.048 \times 1.022 \times 1.084 \times 1.30 = 1.51$, which relates to a 51% increase.

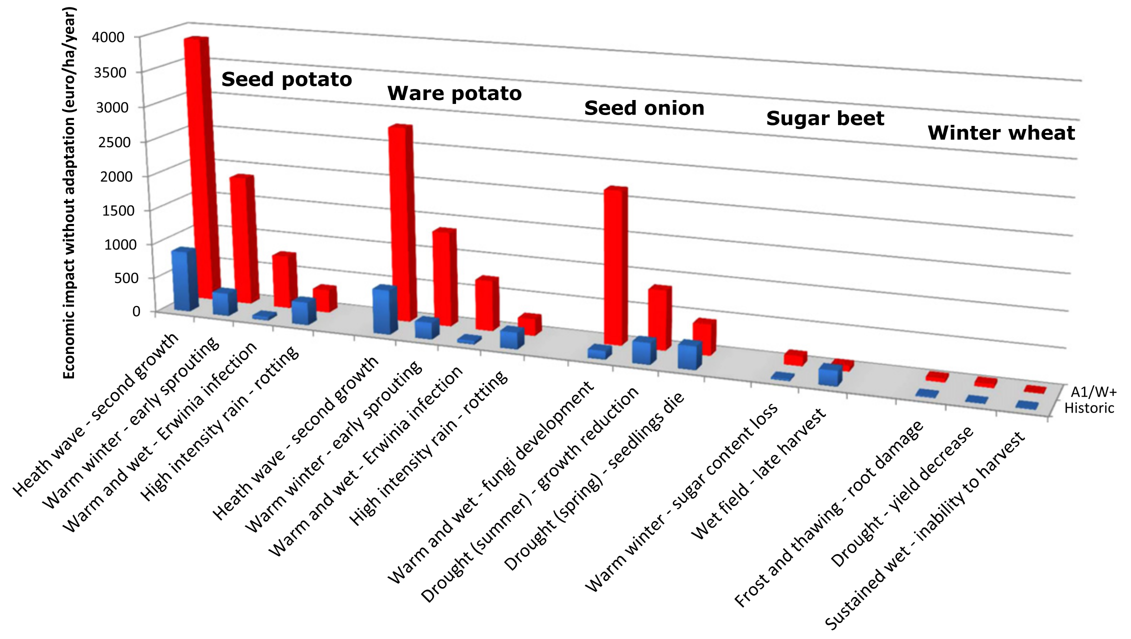


**Figure 4.** Negative economic impacts of climate risks without adaptation (euro ha$^{-1}$ yr$^{-1}$) for the five major crops in Flevoland for historic 1990 climate (blue) and the 2050 A1/W+ climate scenario (green) (adapted from: Schaap *et al* 2013).

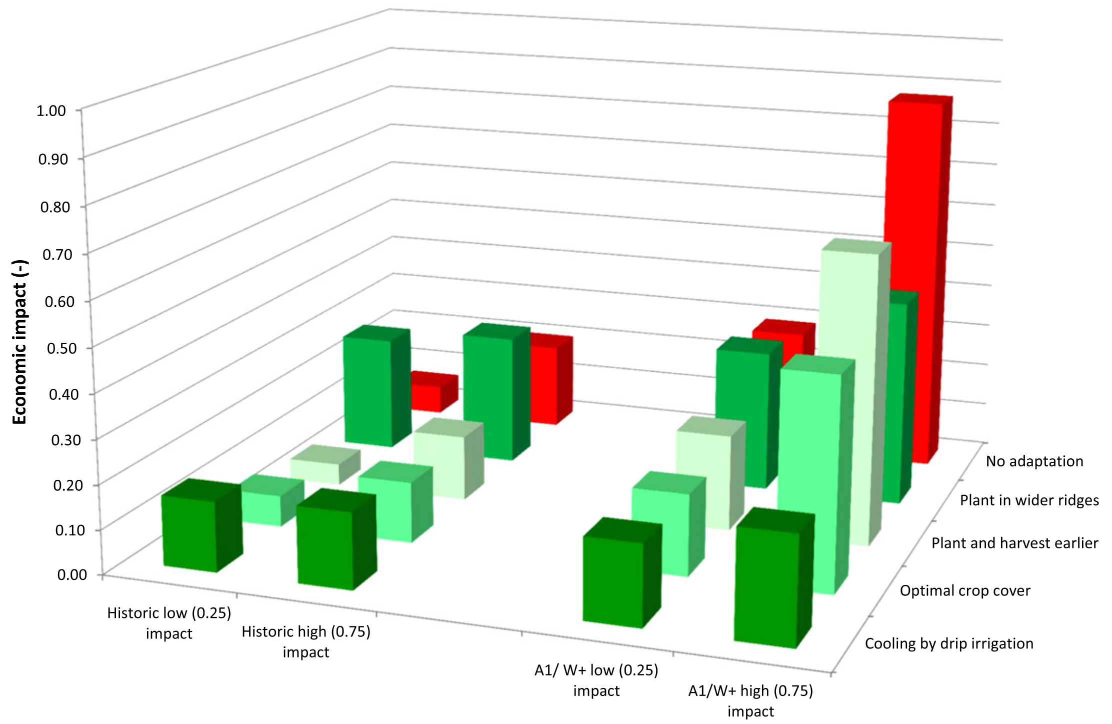


**Figure 5.** Negative economic impacts of the largest climate risk heat wave that causes second-growth in seed potato and ware potato, for different adaptation measures and for no adaptation (expressed as fraction of the standard gross margin). The economic impacts considering costs and benefits of adaptation are shown per average year in the historic time period (1976–2005) and in the A1/W+ scenario around 2050 (2036–2065) (adapted from: Schaap *et al* 2013). Low and high impact levels are included (% economic loss), as estimated impacts differ per farm depending on soil type and management.

### *3.1.2. Crop yield change influenced by extreme events, pests and diseases, and adaptation*

Results of the ACC show that while gradual climate change as simulated by WOFOST resulted in positive changes for all crops (table 1), extreme events can pose large risks. Currently, the largest risks are wet fields in spring and autumn for potatoes, causing delayed planting and harvesting, and damage to tubers (Schaap *et al* 2011, Van Oort *et al* 2012). Towards 2050, in the A1/W+ scenario especially heat waves (−88%) and warm winters (−43%) for potatoes, and warm and wet periods (−36%) for onions were calculated to have large negative impacts if no adaptation takes place (figure 4). Risks for sugar beet and winter wheat were small, so impacts of climate change likely remain positive.

In figure 5 adaptation measures are presented for the largest future climate risk, heat waves causing second growth in potatoes (Bodlaender *et al* 1964). Without adaptation, economic impact was −29 to −88% in the A1/W+ scenario. When applying drip irrigation, this impact could be reduced to −18 to −24%. In addition, other measures can be adopted to further reduce the impact. Relevant for farmers is that while drip irrigation is not cost-effective in the current climate, it was assessed to be the most cost-effective adaptation measure in the A1/W+ scenario (Schaap *et al* 2013). Also for other main climate risks adaptation measures are available (Schaap *et al* 2013).

### 3.2. Drivers impacting farm income and crop production at farm level

Similar to the crop level, the impacts of different drivers were assessed at farm level, now investigating changes in 'farm income' and 'crop production'. Table 2 suggests that although observed yields are close to potential yields (table 1), more efficient management regarding inputs (capital, labour, land, crop protection, fertilizers, energy, other inputs) and outputs (yields, prices), and changes in cropping patterns, could still lead to a 89% increase in farm income (i.e., the difference between observed and profit maximizing plans). This especially led to an increase in potato production (see also Kanellopoulos *et al* 2014).

Climate change impacts on farm income without farm level adaptation were larger in A1/W+ than in B2/G, due to larger crop yield increases (table 1). Increases in farm income were smaller (+7.3% in A1/W+) than the projected yield increases (+6 to +33% depending on the crop). One reason is that in the 'climate change only' simulation, current policies were considered, in which sugar beet production is constrained by sugar beet quota. If cropping area is fixed, it is not interesting to increase sugar beet yields, as the price obtained for production above the quota is relatively low.

When allowing adaptation of cropping patterns, and their inputs and outputs, gross margin increases were almost tripled (table 2; $1.073 \times 1.116 = 1.197$, a 20% increase compared to 7%). Changes were however still partly related to the sugar beet quota: higher sugar beet yields lead to smaller sugar beet areas, and hence a proportional decrease in farm activities including sugar beet. Other activities with more wheat and other arable output (mainly flower bulbs) became more interesting. On average, the impacts of farm level adaptation (table 2) were in the same range as impacts of crop level adaptation (table 1).

When adding changes in policy and prices, in A1/W+, farm income slightly decreased, but in B2/G it strongly decreased until 40% of the present level (see table 2: $1.89 \times 1.048 \times 1.09 \times (1-0.814) = 0.40$). In A1/W+ sugar beet production largely increased due to the abolishment of the sugar beet quota, while changes in relative prices caused vegetable production to increase. Although it is clear that impacts of price changes are large, we should note that price changes are highly uncertain. Nelson *et al* (2014) demonstrated that different models estimate highly different price changes when simulating climate change scenarios.

Finally, impacts of technological development were assessed. In the A1/W+ scenario farm income increased more (64%) than the estimated yield increases (table 1: 30%). In the B2/G scenario the negative impacts of changes in prices could however still not be compensated. For both scenarios, when including the impact of management, the overall change in gross margin compared to the observed situation was +235% for A1/W+ and −40% in B2/G. When excluding management changes, as these may not be possible for all farms and farmers also have other objectives than profit maximization (Mandryk *et al* 2014), the change was +77% in A1/W+ and −68% in B2/G. Overall, we conclude that climate change affects farm income, but impacts were small in comparison to possible effects of changes in management, technology, markets and policy.

### 3.3. Impacts of farm diversity and farm structural change

While changes for average farms give a good indication of impacts of different drivers, impacts differed across farms. Figure 6 shows that impacts of climate change were relatively less positive for very large farms than for smaller farms. This is related to the relatively large share of potato area on very large farms. When farm level adaptation was included, impacts were however similar on all farm types, as larger farms have more capacity to increase the area of other arable output (mainly flower bulbs). The difference in impact among farm size classes was larger for price and policy changes. In A1/W+, very large farms were not affected (same level as previous sub-scenario), while the cumulative impact was −32% for medium farms. Also this is related to the capacity to change crops. In B2/G, impacts were very negative for all farm size classes, but also more for medium farms. The impact of technological development was relatively similar for all farm types, but together with other impacts resulted in more positive (A1/W+) or less negative impacts (B2/G) for larger farms.

Mandryk *et al* (2012) projected that in 2050 in the A1/W+ scenario, the percentage of medium farms decreases from 22% to 4%, while the percentage of very large farms increases from 32% to 49% (in B2/G the change is small). Instead of averaging farm income changes across 75 farms assuming no change in farm structure (as in table 2), we must take into account that in 2050 there may well be fewer but larger farms.

**Table 2.** Relative contributions of management, climate change, farm level adaptation, policy and prices, and technological development to farm income changes (%) and crop production (tons) in Flevoland for two scenarios towards 2050, averaged across the 75 simulated farms. The numbers presented show additive effects of drivers, i.e. the percentage difference on top of the effects of all drivers included in the columns left of the specific driver.

| | 2006–2010 | | 2050 | | | | | |
|---|---|---|---|---|---|---|---|---|
| A1/W+ | Observed | Management (%) | Climate change (%) | Adaptation (%) | Policy and prices (%) | Technological development (%) | Overall effect of changes in 2050 (%) | Overall change incl. management (%) |
| Farm income (103 euros) | 40.9 | 89.0 | 7.3 | 11.6 | −9.5 | 63.7 | 77 | 235 |
| Potato production (tons) | 581.3 | 22.4 | 5.1 | −1.9 | 3.7 | 31.2 | 40 | 72 |
| Sugar beet production (tons) | 512.0 | −8.4 | 1.6 | 3.2 | 58.1 | 19.0 | 97 | 81 |
| Soft wheat production (tons) | 57.6 | −3.7 | 1.3 | 5.3 | −0.9 | 2.3 | 8 | 4 |
| Vegetables production (tons) | 461.9 | −8.2 | 4.3 | 4.7 | 40.6 | 30.8 | 1 | 84 |
| B2/G | | | | | | | | |
| Farm income (103 euros) | 40.9 | 89.0 | 4.8 | 9.0 | −81.4 | 49.4 | −68 | −40 |
| Potato production (tons) | 581.3 | 22.4 | 3.4 | 0.4 | −7.3 | 8.4 | 4 | 28 |
| Sugar beet production (tons) | 512.0 | −8.4 | 0.8 | 1.7 | −1.5 | 1.9 | 3 | −6 |
| Soft wheat production (tons) | 57.6 | −3.7 | 1.2 | 5.0 | −5.7 | 1.0 | 1 | −3 |
| Vegetables production (tons) | 461.9 | −8.2 | 2.8 | 1.9 | −11.8 | 2.6 | −5 | −13 |

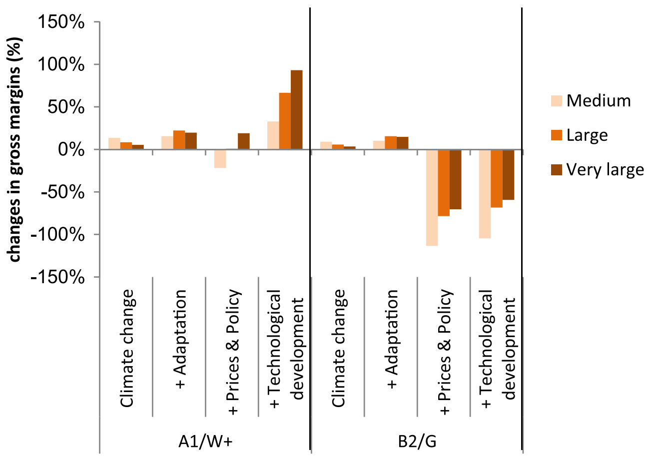


**Figure 6.** Changes in gross margins (in %) due to the cumulative impacts of climate change, adaptation, price and policy changes, and technological development for the A1/W+ and B2/G scenarios (each change in addition to the former; note the difference with tables 1 and 2) for different farm types, compared to gross margins of the profit maximization production plans in the base period (i.e. observed + improved management in table 1). Note: medium = <70 NGE, large = 70–150 NGE, very large = >150 NGE. NGE is a Dutch size unit, representing gross income form cultivating a certain crop or keeping a certain animal. In 2008, 1 NGE equalled 1420 euros.

When considering the changes in percentage of medium, large and very large farms, for B2/G resulting average farm income did not change much, but for A1/W+ the positive impact from all changes together increased from +77% to +132% (compared to observed + improved management). Increasing farm size can thus also be considered as an adaptation at regional level.

## 4. Concluding remarks

Crop models project modest positive impacts of climate change on crop yields in the Dutch province Flevoland. The increasing frequency of extreme events can cause this positive impact to become negative, but a portfolio of adaptation measures is available to reduce these negative impacts. Farmers can adapt sowing dates and cultivars, but measures that cannot be simulated by crop models, such as drip irrigation and planting in wider ridges to reduce the impacts of heat waves on potato production, may be more relevant. When putting climate change in the context of other future changes, it appears that price changes and especially technological development will likely have more impact on farm incomes in Flevoland towards 2050. By adapting farm activities and management, most farm types are able to increase the positive impacts or reduce the negative ones of climate and other changes. Besides climate change, also future changes in prices, policy and technology are uncertain and hence, the estimated impacts will strongly depend on the scenario. Additional uncertainty analyses regarding objectives, available resources and model parameters will allow further assessments of the robustness of impacts and adaptation (Troost and Berger 2014, Holzkämper et al 2015).

Considering the ranges of climate change impacts in other world regions (Porter et al 2014), also in other regions other drivers may have more impact than climate change. While in Flevoland yield gaps are small, in many developing regions, improving management may have much larger impacts than climate change (Kassie et al 2014, Rurinda et al 2013, Xiao and Tao 2014). We conclude that integrated assessment and farming systems analysis are needed to place the impacts of climate change into context, to enhance insight in adaptation measures and strategies, and to better inform farmers, policy makers and other actors.

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