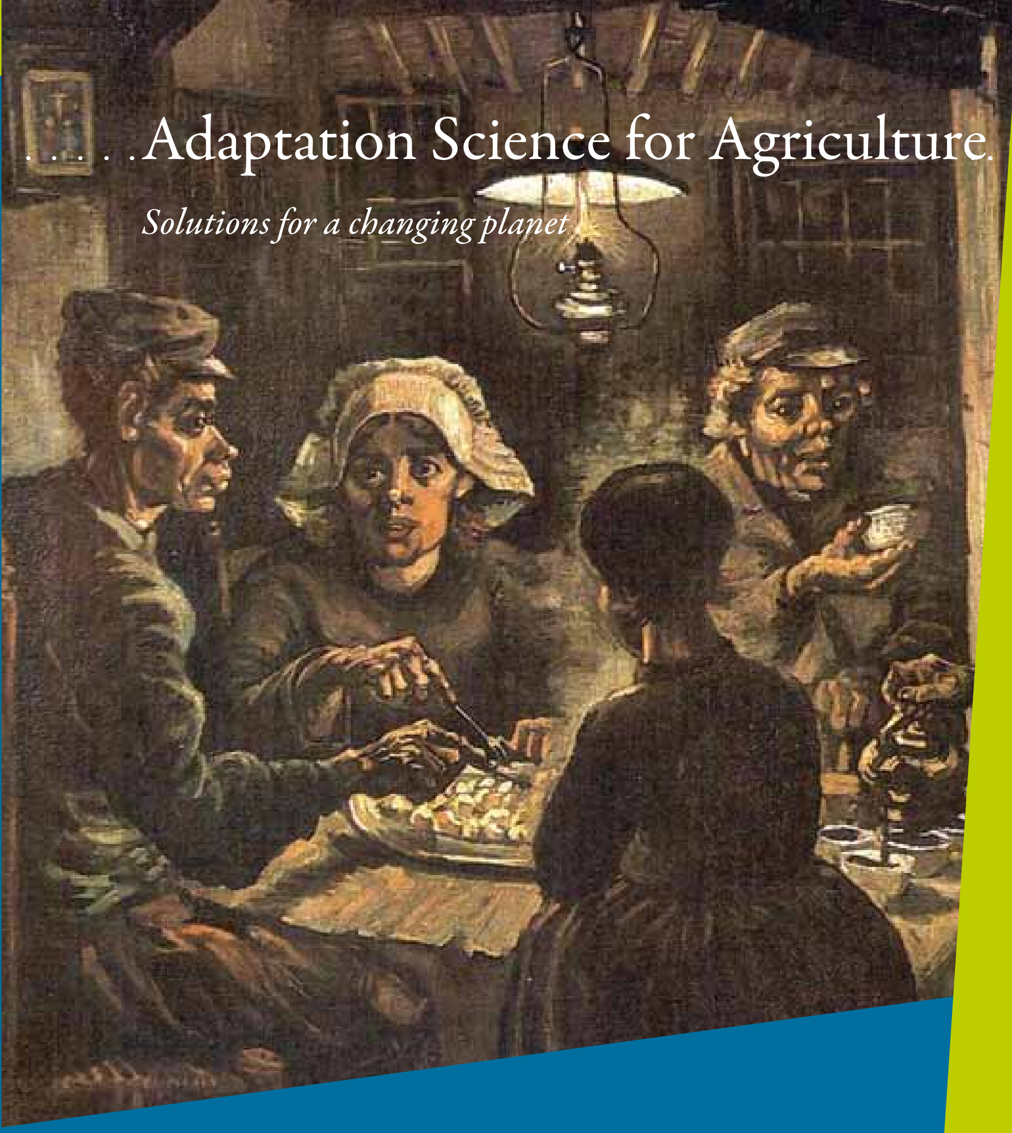


Adaptation Science for Agriculture

Solutions for a changing planet

Dr H. Meinke

Inaugural lecture upon taking up the post of
Professor of Crop and Weed Ecology
at Wageningen University on 14 January 2010

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Adaptation Science for agriculture

Solutions for a changing planet

Dr H. Meinke

Inaugural lecture upon taking up the post of
Professor of Crop and Weed Ecology
at Wageningen University on 14 January 2010

WAGENINGEN UNIVERSITY
WAGENINGEN UR

ISBN 987-90-8585-271-1

Adaptation Science for agriculture

solutions for a changing planet

If the end is what we wish for, the means must be what we deliberate about.
Aristotle, Nicomachean Ethics, Book 3, 350 AD

It is our competitive advantage that we show courage after carefully deliberating our actions. Others, in contrast, are courageous from ignorance but hesitant upon reflection.
Pericles' Funeral Oration; Thucydides 2, 40, 3, 431 AD

Esteemed Rector Magnificus, esteemed members of the academic board, dear colleagues, family and friends, ladies and gentlemen:

It is a great privilege and honour talking here today. Thank you for coming. My address will be in English – the global language of science. However, on this occasion I would like to acknowledge the cultural importance and impact of the Dutch language.

Daarom wil ik mijn Nederlandse collega's welkom heten in hun eigen taal: ik ben blij dat u hier bent. Uw steun is heel belangrijk voor mij. Dank u wel!

Und ich möchte auch meine Deutsche Familie und Freunde begrüßen – Danke für Eure Unterstützung und dass Ihr heute gekommen seid um mit mir dieses Ereignis zu feiern.

Today I would like to share with you my motivation behind accepting the chair in 'Crop and Weed Ecology' at Wageningen University.

I would like to share with you some thoughts and some ideas but also generate a discussion how all of us might be able to devote our intellectual capacities and

. . .

efforts towards the creation of a better world. Specifically, I would like to explore how this chair – Crop and Weed Ecology – can make a difference through good research and teaching.

We live in a world of increasingly rapid changes. Change creates risks and opportunities. Change is also a simple fact of life. Nature's response to change is evolution. Today I will make the case that we need to use science to 'turbo-charge' evolutionary processes; we need to become more proactive in order to keep abreast of the continuously accelerating change process.

When forces of change begin to exert pressure, there are only 4 possible responses: 1) We can ignore them, 2) we can try to resist, 3) we can attempt to mitigate against these forces or 4) we can adapt.

Whatever we do – or whatever we don't do – in response to this pressure is our choice – even inaction is a choice. And ultimately we are all accountable for our choices. This means that we are inevitably part of the change process in a constant struggle to improve the human condition. We cannot escape it. Nobody can.

Today I want to talk to you about the role of plant science in this rapidly changing world. I want to highlight the importance of a systems analytical approach to ensure profitable and ecologically sound crop production. I want to highlight the relevance of a chair such as Crop and Weed Ecology for our societies.

Many of my examples will refer to climate as a key driver of change in agricultural systems. I need to make one point very clear: even though I will focus on climate risks, the approach I am suggesting is about risk management in agriculture generally, regardless of the underlying driver. However, given the importance of climate risks - and lately of course the increasing need to adapt to a changing climate - I have decided to focus on climate risks.

I have already mentioned the four possible responses to change: inaction, denial, mitigation and adaptation. When it comes to global and climate change, inaction and denial are no longer acceptable responses. By now we know far too much about the processes responsible for climate change; we also know far too much about their consequences to simply sit back and do nothing. It would be immoral to leave all the consequences of our affluent lifestyles simply to future generations to deal with. I fear that they will judge us harshly anyhow; and rightly so.

This leaves us with mitigation and adaptation. Now mitigation is most effective when action is taken early in order to prevent the system to evolve to a stage where drastic changes will occur. I think it is too late for this.

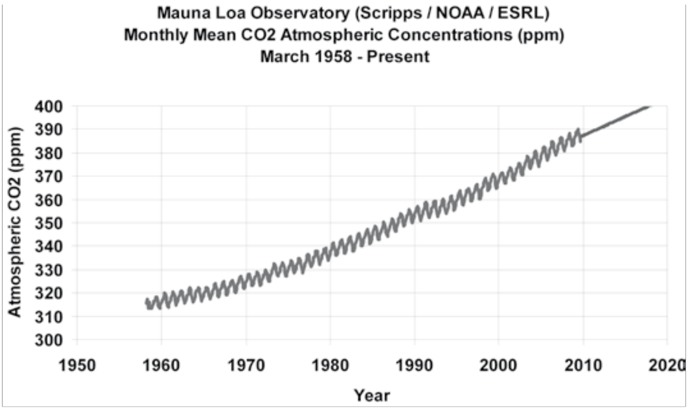


Fig. 1: Monthly CO_2 measurements taken at Mauna Loa Observatory (March 1958 – Present).

Just to re-enforce this point, here is a very famous diagram, which I am sure you all have seen before in one form or another. It is a continuation of Keeling's original atmospheric CO_2 concentration curve.

The beginning of Keeling's CO_2 measurements coincides with the year of my birth. The measurements show that in my lifetime alone, CO_2 has increased by 70ppm, from 315ppm to 385ppm today. Compared to the pre-industrial levels of around 280ppm, CO_2 concentrations have now increased by 105ppm or 38%. If we extrapolate this curve using the trend of the last 20 years, we will break the 400 ppm barrier sometime between 2016 and 2018. We will be well into the 400 ppm range by the time I will retire. Not too many statisticians would argue with me about this extrapolation. I regard this as a fairly certain; it is a foreseeable event.

There is something else that is close to certain: these increases in greenhouse gasses (GHG) are already impacting on our climate and climate sensitive sectors of our society. At a global scale we can see the impacts, many of them, from melting ice caps, retreating glaciers to the extinction of species, because there is no mountain high enough for them to escape to. We monitor and measure species diversity and we know that biodiversity is seriously under threat (for many reasons, not just climate change). But from here on, any certainty quickly dissipates.

Now let's have a look at a second famous diagram. This is work by Rahmstorf from 2007. It shows two different measurements of annual, global temperature data with the IPCC projections for the different emission scenarios superimposed. I only want to point out one aspect of this diagram: it shows that ever since the IPCC began issuing projections, sometime in the mid 1990s, we have been tracking at the upper end of the scenario envelope.

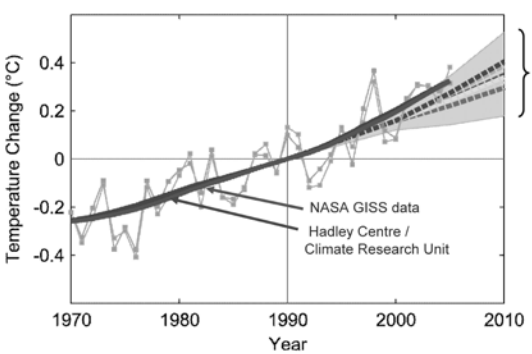
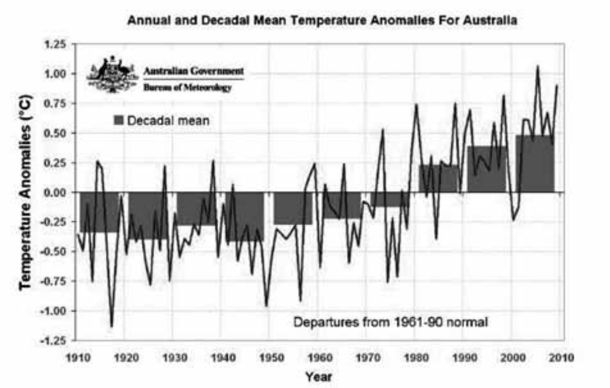


Fig. 2: Annual global mean land and ocean combined surface temperature from wo different data sets GISS and the Hadley Centre Climatic Research Unit up to 2006 (taken from Rahmstorf et al., 2007).

There is now speculation that by the time the next IPCC report will be released, real temperatures might exceed even the worst projections. This, of course, means that any mitigation efforts have been totally ineffective.

And yes, I know, every single piece of scientific evidence is contentious, can be disputed. The point is: it is not the individual pieces of evidence that matter. What matters is that collectively the case is so compelling that inaction amounts to malicious negligence. Just a few very selective examples should suffice:



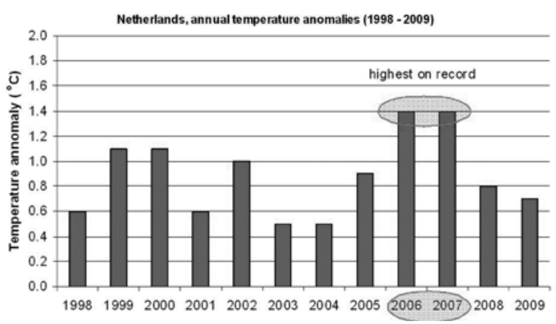


Fig. 3: Annual temperature anomalies for Australia (top; Australian Bureau of Meteorology, 2010) and The Netherlands (bottom; KNMI, 2010).

Consider the rapidly melting ice caps and glaciers; remember the European heat wave of 2003; or the fact that both April and November 2009 were the second warmest months in over 300 years in the Netherlands. Similarly in Australia, where in 2009 the city of Adelaide had its earliest heat wave ever, a sweltering 43°C last November.

Last year was also Australia's second-warmest year on record, with the annual mean temperature 0.9°C above average (Australian Bureau of Meteorology, 2010).

Similarly in the Netherlands 2009 was 0.7°C above the long-term average (10.5°C versus 9.8°C) and the 13^{th} 'warm' year in a row (KNMI, 2010). Globally 2009 was the 5^{th} warmest year on record (Australian Bureau of Meteorology, 2010).

Consider the Australian floods and bush fires of February 2009 that killed 173 people – these events occurred simultaneously, in different parts of the country. This map shows the land surface temperature anomalies in the week leading up to these disasters; it clearly shows the intensity of these two contrasting extreme events.

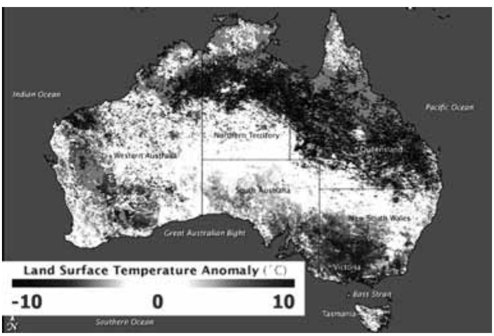


Fig. 4: Land surface temperature anomalies from January 25 to February 1, 2009 compared to the average mid-summer temperatures between 2000-2008. The colour version of this map is available at http://earthobservatory.nasa.gov/IOTD/view.php?id=36900. It shows the northern part of Australia in intense blue, while the southern parts (particularly Victoria) are intensely red. The temperature anomalies are up to minus 10 degrees in the north and plus 10 degrees in the south.

Meanwhile many of our natural ecosystems such as coral reefs - places of incredible bio-diversity and beauty - are destroyed at alarming rates by increasing ocean temperatures and acidity. In short: the accumulated evidence is overwhelming.

Which brings me back to my earlier comments: Mitigation, that is the avoidance of processes that lead to climate change, is most effective and cheapest when taken early. This means that we should have begun decarbonising our economies way back in the 1960s when CO_2 levels were still below 350ppm. We chose not to do this.

This choice has two consequences: Firstly, it increases the urgency for mitigation action to avoid further substantial damage and secondly it increases the urgency to adapt as a certain amount of climate change is now unavoidable (Howden et al., 2007).

Although **mitigation** is **politically** extremely difficult, **scientifically** we can approach it competently: We need to reduce our GHG emissions by decarbonising our economies. This is a paradise for innovative industries and it creates much room for disciplinary-based innovations: from alternative energy sources to carbon capture such as clean coal technologies and CO_2 storage facilities (such as the one currently proposed for Barendrecht in the Netherlands), from reducing methane emissions from rice paddies or livestock (just think about the recent headlines of a

Table 1: Key differences between mitigation and adaptation actions.

	Mitigation	**Adaptation**
Purpose	avoid anthropogenic climate change (one well-defined, global and common objective)	adapt to multiple climate change impacts to minimise negative and maximise positive outcomes (many ill-defined, local and potentially conflicting goals)
Approach	develop and deploy GHG-friendly technologies	optimise systems' performance under variable and changing social, environmental and policy conditions
Goal of actions taken	reduce global GHG emissions (one well-defined and measurable outcome of collective actions)	at local level, minimise risks and maximise opportunities associated with climate change(many ill- defined, individual outcomes that are hard to measure)
Actions	many local actions with one, globally shared goal: to reduce GHG emissions	many local actions with many, potentially conflicting goals

. . .

new breed of sheep that burp less) to riding your bike instead of using the car. While there is one goal, namely the reduction of GHG emissions, the means of achieving this goal are diverse and varied – the more, the better.

Yet, as the recent experience at COP15 in Copenhagen has shown, politically mitigation is difficult; very difficult. But if we think that mitigation is difficult, with **adaptation**, things get even more complicated as there is no single, agreed goal of what adaptation is supposed to achieve. The issue of competing claims and conflict agendas looms largely in the adaptation debate. Questions need to be answered such as: Who is adapting to what and with which consequences? And the issue of scale suddenly raises its head even more than before (Table 1).

While reducing GHG emissions at any scale anywhere contributes to the 'global good', which is the overarching goal of mitigation, adaptation actions are largely independent, local and very context-specific. Hence, compared to mitigation, real adaptation actions are even harder to agree on and incredibly complex to achieve. Adaptation actions are highly contestable: what works well for certain sections of a community, can be to the detriment of others (Nelson et al., 2010).

Many people still object to the fact that something as dangerous as humanly induced climate change can actually result in opportunities and benefits for certain sectors and groups of individuals. This leaves science with a big conundrum: how can we best apply our narrow and very specific scientific knowledge to the issues of adaptation? How can we capitalise on opportunities without causing further damage?

Although adaptation is nothing new, the scientific adaptation agenda is – until only a few years ago, *adaptation to climate change* was seen by many as an issue to be avoided because it gave the impression of inevitability, of a system out of our control. It was regarded as politically dangerous and damaging. However, the evidence and urgency has now increased to such an extent that even the die-hards acknowledge that the time for adaptation action is now.

I want to briefly put adaptation in relation to agriculture in historical context. For this I will use 3 examples:

1) The Norse

Exactly 1024 years ago, in 986, Erik the Red led a group of Viking families from Iceland to settle in the southern parts of Greenland. 422 years later, in 1408, a wedding performed in the Hvalsey Church (Fig. 5) is the last recorded event before all settlements were again abandoned (Lundberg, 1999). What went wrong?

Fig. 5: Ruins of the Hvalsey Church, Greenland (photo by Philippe Stoop, http://www.panoramio.com/photo/397524).

At the time of settlement, Greenland's climate was considerably warmer than during the 20th century. The new settlers were farmers engaged in animal husbandry and cropping, who managed to accumulate enough food and fodder during the short summer season for a reasonable living.

However, the mild climatic conditions were fairly short-lived in geological terms and by about 1200, progressively cooler conditions made life extremely difficult. In some years, no supply ships were able to reach Greenland due to persistent sea ice preventing the passage of ships (Lundberg, 1999). By the early 1300s, significant changes in temperature are recorded in such diverse materials as glacier ice, fossil vegetation and pollen deposited in lake sediments, chemical signatures in isotopic composition of sea sediments, animal and human bones (Fricke et al., 1995).

This cooling climate led to agricultural practices that became progressively less sustainable and, as a consequence, depleted Greenland of its natural capital - its grasslands, animal resources and cropping opportunities.

For instance, fossil pollen indicates that the expansion of grasslands into increasingly marginal areas led to erosion. Land degradation forced people to push production even further until it exceeded the regenerative capacity of Greenland's environment, leading to a downward spiral of productivity and ultimately starvation (Panagiotakopulu and Buckland, 2007). Isotopic evidence from ice cores indicates that the 14th century was the coldest known in Greenland for 700 years.

Today, the arctic is warming at twice the rate of the rest of the world and agriculture is predicted to increase significantly in a region so far free of many pests and diseases (Jensen et al., 2009). Greenlanders are proud of the fact that they are again engaged in agriculture: home-grown potatoes, broccoli and strawberries have recently become part of the Greenland diet, while options for growing barely on a larger scale are being explored (Fig. 6). Greenland is capitalising on some of the arising opportunities from climate change.

Fig. 6: Potato growing in Greenland; Photos: John Rasmussen (http://news.nationalgeographic.com/news/2007/10/photogalleries/greenland-pictures/photo5.html; left) and University of Copenhagen; (http://www.en.agri.life.ku.dk/Aktiviteter/2009/160909_GMB_seminar.aspx, right)

2) The Potato Eaters

Let me move on to another example: This evocative painting by Vincent van Gogh is called 'The Potato Eaters' or 'Aardappeleters' in Dutch (Fig. 7). Vincent painted it in 1882 and it is a classical example of human adaptive capacity. Very skilfully it symbolises multilevel adaptation: while the problem was largely climate induced poverty and famine – caused by natural climate variability – one solution was the growing and eating of potatoes. Books have been written about this issue, even here at our own university but I don't have the time to explore this in depth. My close friend and colleague, Paul Struik, is among these experts. So here are just a few key points:

Potatoes were first introduced into Europe in the mid 16th century, just at the beginning of the 'little ice age' when crop yields generally were declining. The key innovation was that potatoes provided 2-3 times more food per unit land compared to cereals such as wheat. The introduction of potatoes into Estonia in the 1840s put an end to frequently recurring famines that had killed over 75,000 people in Estonia alone (Tannberg et al., 2000).

Fig. 7: 'Aardappeleters' from Vincent van Gogh (1882); reproduced with permission from the Kröller-Müller Museum.

By the mid 19th century potatoes were therefore considered the 'bread of the poor', a staple food and a reliable substitute for wheat. So out of necessity, poor European farmers adapted their cropping systems as well as their eating habits; adaptation is always multi-faceted.

This is risk management in action – risk management defined as *the systematic process of identifying, analysing and responding to risk*. It includes maximising the probabilities and consequences of positive events and minimising those of adverse events. Good risk management seizes opportunities without ideological biases.

The recent pace of global change has added an additional component of urgency for planned risk management and proactive adaptation. It is now time to address this issue more systematically, particularly when it comes to agriculture.

This brings me to the emerging field of 'adaptation science' (Meinke et al., 2009).

Adaptation science is not a new science – it is simply a different way of conducting science. The traditional, reductionist approach to science has a tendency to create *islands of knowledge in a sea of ignorance*. Traditional science conduct focuses much more on analysis of scientific inputs rather than on the synthesis of socially relevant outcomes (Meinke et al., 2006).

Adaptation science, on the other hand, is very much outcome, solution oriented. This new way of scientific inquiry differs from the traditional approach of 'science for adaptation' by attempting to provide societal relevant solutions rather than just more disciplinary based data.

Adaptation science is a problem focused and solution oriented science paradigm that, without prejudice, tries to combine societal relevance with scientific excellence. It has a lot in common with the notion of 'adaptive management', an ecological approach to action increasingly popular within the conservation movement. But more of this later.

Today I focus on climate as a key driver of change. Yet, the principles that I discuss are more broadly applicable. However, given the urgency created by the accelerating pace of climate change, climate risks serve as a good example of how scientific knowledge from many disciplines can contribute to managing our resources more sustainably and profitably. And although we cannot predict with certainty what is going to happen, many of the problems that are in-store for us are very well foreseeable.

The concept of foreseeability is key here – I thank my friend and colleague, Mickey Glantz, for introducing me to this: the best example I can think of that distinguishes foreseeable events from predictions is when you run a red traffic light at a busy intersection. I cannot predict that you will have an accident, but I can foresee that your chances of having an accident will be dramatically increased.

Foreseeability is a legal concept that dictates that if a disaster or an accident is foreseeable, but the operator of the system does not take necessary precautionary action he or she will be liable. Future generations will hold us to it.

Adaptation science takes such risk management principles seriously. Science today offers us the unique opportunity to (a) better understand causes and consequences of our actions and (b) learn from history, by being better prepared and willing to adapt.

Let me give you a final historical example to underline the need to adapt, this time from my home continent, Australia:

3) South Australian settlers in the late 19th century

South Australia's 'Goyder Line' is an icon in Australia's agricultural history. The line was first drawn by George Goyder, a geographer extraordinaire and South Australia's surveyor-general at the time.

Driven by a deep, intuitive understanding of the role of rainfall variability as a key driver of risk for wheat farming in low rainfall regions, Goyder set out in 1865 to determine '*the line of demarcation between the portion of the country where the rainfall has extended and that where the drought prevails*' (Government of South Australian, 2010).

George Goyder went out on a horse, examined the natural system, particularly plants and soils, and drew inferences from this knowledge. Based on this, he drew a

. . .

line on a map to highlight the areas where, in his opinion, cropping should never be attempted. The line runs roughly west to east across the mid-north of South Australia from the edge of the desert, the Nullarbor Plain, to the Victorian border (between 33° and 34° S; ABC, 2009).

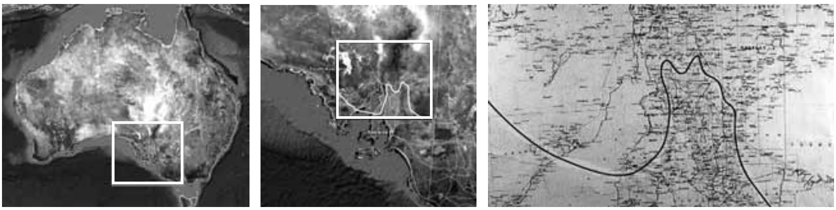


Fig. 8: Maps of (a) Australia (left), (b) parts of South Australia (centre) and (c) a historic map showing the Goyder line (left). Goyder's line is indicated on maps (b) and (c).

Goyder was a visionary and one of the very first people to perceive the degree and impact of Australia's highly variable rainfall. He postulated that north of his line, which equates roughly to the 300mm annual rainfall zone, rainfall was too low and erratic for viable wheat production. These days we use simulation models to arrive at such conclusions. Goyder conducted this systems analysis in his head!

Just a few years later, however, Goyder's line became highly controversial when a series of wet years resulted in farmers establishing properties way north of his line. He was attacked in parliament, ridiculed in the press. At public meetings, people called for Goyder and his line to be thrown out of the colony (ABC, 2009). When more variable and drier conditions returned yet again in the late 1880s nearly all of the new farms were abandoned resulting in considerable hardship.

Goyder's line had an enormous influence on the Australian psyche and rural settlement policies. He was at least one century ahead of his time in understanding rainfall variability and its impact on natural ecosystems and agricultural productivity. Since then generations of Australian farmers have learned at their peril to ignore climate variability and its consequences on farm businesses. As a consequence, Australia has probably one of the most 'climate aware' agricultural sectors in the world.

Lessons learned?

The experience of the Norse, of poor European farmers and the early Australian settlers should be sufficiently convincing that adaptation science – a more formal, transdisciplinary approach to scientific inquiry – is urgently needed. But how will it work? What do we need to do differently when compared to what we already do? And what does this have to do with the chair of Crop and Weed Ecology, which is what this event today is about?

In the examples I provided, everyone would have benefited from the knowledge-generating technologies that are at our disposal today. For agriculture 'creating hindsight in advance' has only become possible based on the scientific breakthroughs in modelling complex systems. This modelling work has its origin here, in Wageningen, where Prof. Cees de Wit first introduced systems theory and simulation modelling in the 1950s and 60s. The global science community continues to build on the foundations de Wit created. Wageningen University has a very proud tradition of this and Crop and Weed Ecology – the chair that I currently hold – has always been a fundamental part of this. And it will continue to do so.

However, this chair is now part of a bigger picture, namely the Centre for Crop Systems Analysis (CSA) that combines the chair of Crop Physiology held by my colleague and friend, Paul Struik, and Crop and Weed Ecology into one functional unit.

At CSA we use models to create a new type of knowledge that is similar to the conventional, empirical knowledge that decision makers usually draw on when managing risks holistically and through intuition. This provides the cornerstones for adaptation science, which draws heavily on modelling as a knowledge-generating technology. The ability to analyse and simulate complex systems is essential for 'creating hindsight in advance'.

I already outlined the **need** for adaptation science; I will now argue that the **form** is highly context-specific and needs to be in itself 'adaptive'. This might even include a requirement for new, different institutions and the way they interact.

...

So how will adaptation science work? For this I propose a 4-step approach (Meinke et al., 2009):

- **agree on the problem domain** such as 'securing food for the poor', 'improve the efficiency of water use' or 'minimise crop losses due to weed infestation', to name just 3 of an unlimited number of examples;
- **agree on the transdisciplinary scientific objectives**, i.e. what mix of disciplinary knowledge is required to make the best possible scientific contribution towards solving the problem;
- **agree on partnerships and governance** of the team that are supposed to develop the solutions; in most cases this will be a community of practice, i.e. a group of people – including scientists – from many different domains who share a common interest in solving specific problems;
- **do the work**.

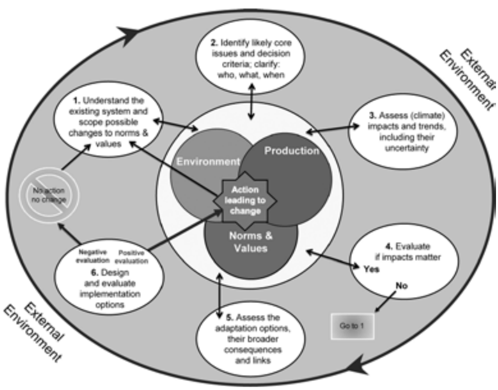


Fig. 9: The adaptation cycle, the 'engine' of adaptation science, is based on a reflective analysis-action continuum (Meinke et al., 2009).

Let us for now assume that we have established such a community of practice around the issue of climate risk in agriculture. One of the first hurdles we have to overcome, even before we turn this into a truly transdisciplinary community, is breaking down the barriers within disciplines. While much of the talk is about climate change, the real issue from a farmer's perspective is managing climate variability.

What we often forget is that climate change will be delivered to the farm gate – free of charge – by climate variability (Meinke and Stone, 2005). As one of my colleagues often quips: 'Who destroyed the sand castle? Was it the wave or was it the tide?'

Fig. 10: Who destroyed the sand castle? Was it the wave or was it the tide?

This is a powerful analogy that stresses how existing climate variability rides on a slowly raising tide of climate change (Fig. 10). Unless we help the rural sectors in both developing and developed countries to proactively adapt to climate variability and change, we fail in our responsibility as scientists.

Today is a very special, a very proud day for me. Being inaugurated as Professor for Crop and Weed Ecology means that I can make a small contribution towards solving some of the world's most pressing problems.

But of course I, as an individual, can do very little about this. However, I have the good fortune of being surrounded by a team of excellent and very dedicated scientists and technical staff. As I already told you, my colleague, Paul Struik and I, have pooled resources and formed the Centre for Crop Systems Analysis – CSA – in order to conduct our research and teaching more effectively.

There is no doubt that plants will remain the single most important objects in the quest to solve the problems of our planet. Without plants there will be no life. CSA is uniquely placed to provide the underpinning science for adaptation actions. We develop and apply the quantitative modelling tools that are needed to assess the value of different adaptation options for agricultural production systems.

The Centre is at the scientific forefront of understanding how plants and plant systems function. To better understand and assess the function of these systems, we use simulation modelling as one of our core technologies. This group of multi-disciplinary scientists comprising plant physiologists, crop physiologists, cropping systems experts, ecologists, modellers and climate scientists – to name just some of the key disciplines – is committed to making a difference.

Of course, in spite of being a multidisciplinary team, often additional expertise is needed to solve real life problems. Hence, global collaboration is the key to the group's success. And our collaborative networks are extensive and reach all corners of the earth.

We have organised ourselves according to five themes that reflect our expertise and the way we combine this expertise for problem solving. These five themes capture the essence of the team (Fig. 11):

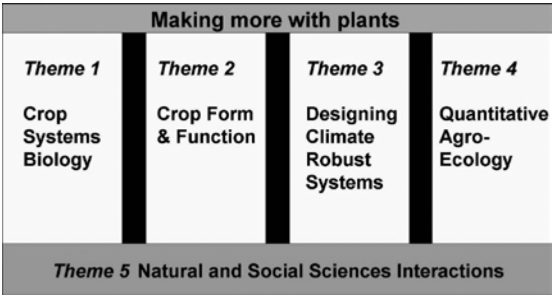


Fig. 11: Current research themes of the Centre for Crop Systems Analysis (CSA).

The aim of this structure is to foster transdisciplinary, solution-oriented research. The operating principles are simple: every CSA scientist has active research responsibilities in at least two of these themes. Most of our scientists are active in more than two themes, indeed some individuals belong to all. Yet, we recognise that in well-functioning teams there also has to be the opportunity to pursue specific research interests in depth. Through this structure, we facilitate and provide all these opportunities.

Let me give you some very brief examples of the research that is conducted under these themes:

Being a 'boundary organisation' we see ourselves at the interface between two worlds: science and society. Hence, our theme **'Natural and Social Science Interaction'** constitutes a core element of the research we conduct. Research includes, for instance, agronomic and social aspects of informal seed systems on several continents (including Africa, Asia and Latin America), gender issues in participatory plant breeding, impacts of HIV/AIDS on agriculture, farmer-managed biodiversity, wild-gathered foods and economic and spatial analysis of plant disease impacts (e.g. Richards et al., 2009).

Crop Systems Biology is concerned with matching molecular biology and biochemistry with agronomic reality and needs. Research includes investigating the possibilities of 'turbo-charging' photosynthesis by better understanding genetic differences in photosynthetic activity through modelling. The approach allows, for instance, assessing the value of molecular plant breeding at the field level (e.g. Yin and Struik, 2008, 2009).

Crop Form and Function investigates how plants respond to their environment by adapting their functions (e.g. light interception, photosynthesis, transpiration, N allocation) and their structure or architecture (e.g. buds either break or remain dormant; size, shape and orientation of organs). This involves complex 3-D modelling techniques to better understand interactions between form and function (e.g. Buck-Sorlin et al., 2008, Evers et al., 2010, Vos et al., 2010).

. . .

Quantitative Agro-Ecology investigates the threats posed by pests, diseases and weeds to crop productivity. It considers, for instance, the use of natural enemies to suppress crop pests and spatial strategies for deployment of crop species and genotypes to help mitigate the impact of diseases. The control of indigenous and exotic weeds will become increasingly important in places like sub-Saharan Africa (e.g. Bastiaans et al., 2008; Landis et al., 2008; Ryan et al., 2010, Zwart et al., 2009).

Although each of these themes deserve a lecture of their own, the focus of today is on what I can and will add to this rich research portfolio. Allow me therefore to elaborate a little on the new theme that I introduced to the group. **Designing Climate Robust Systems** aims to use the group's strengths and apply them to improve agricultural outcomes. The theme investigates better and more relevant ways to create and use scientific knowledge that provides solutions to global problems associated with sustainable agricultural production. It researches agricultural innovations and quantifies their impacts on productivity, product quality and natural resources. It also deals with farm-enterprise issues, in addition to crop and cropping systems issues.

Here is an example:

Rice is the world's most important staple food; 91% of all rice is produced in Asia. There is limited scope to increase production due to competing claims on scarce resources such as water, land and labour. Increasing temperatures, more frequent droughts, anticipated loss of productive estuaries caused by rising sea levels and more frequent and severe storms further compound these problems. This creates urgency for rice-based production systems to produce more rice with less water, less land or less labour; in other words: we need to increase these various efficiencies, which are also referred to as 'eco-efficiencies'.

In his classic paper on "Resource Use Efficiency in Agriculture", Cees de Wit (1992) explored these eco-efficiencies. His paper sparked intense scientific debate, which, unfortunately, I don't have time to detail here. There is agreement, however, that eco-efficiencies are highly contextual. To understand these complexities, we need formal, quantitative methods that help us to decide, which efficiency improvement to target for maximum gain. For this, an efficiency frontier framework can provide valuable guidance when making research investment decisions (Keating et al., 2010):

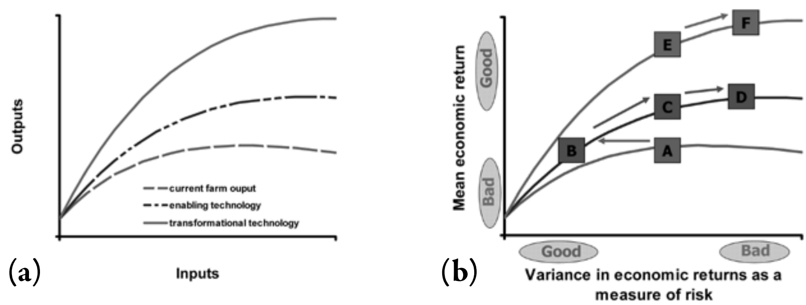


Fig. 12: Agricultural input / output relations as efficiency frontiers (a); using efficiency frontiers as risk management tools (b), reproduced from Keating et al. (2010)

The diagrams in Fig. 12 are stylised presentations of input / output relations for agricultural production. They describe general responses to inputs at various levels of intensity and co-limitations. Particularly under severely limited conditions, this approach can help to determine the most appropriate starting point in order to increase productivity and efficiency of production. How do we know which type of technology might be best suited for such improvements? To answer this question, we consider 3 different levels of input / output relationships in a developing country context:

a) current farm output – usually under severe resource limitation; here we often find that increasing the amount of a single production factor does not significantly raise production outputs;

b) enabling technologies – technologies that are readily available and could at least theoretically be supplied, such as fertiliser combined with better management of pest and diseases; and

c) transformational technologies – cutting edge science, such as 'turbo charging' the photosynthetic process or completely new management practices.

Let us explore how we can use this framework operationally:

Increasing inputs can increase outputs, but it usually also increases output variability, particularly when the climate is highly variable. Therefore, the variance in economic returns can be used as a surrogate measure for risk. On the x-axis of Fig. 12b we replaced inputs with a measure of risk, namely the variance in economic returns of a certain action. The y-axis shows the longterm or mean economic return of a certain action. I will now briefly demonstrate how such efficiency frontiers can be used as risk management tools:

(i) We can use enabling technologies to either maintain current productivity but reduce risk by moving from A to B;
(ii) We can also use enabling technologies to address systems inefficiencies at 'constant risk' by moving from A to C; extra income generated through these improvements can now be re-invested.
(iii) Once we have achieved this, we can move along the new efficiency frontier and make use of the increased responsiveness to inputs by moving from C to D;
(iv) and finally we can lifting productivity to a new level through transformational technologies (C to E and E to F).

With the help of models, the necessary data for such response functions can be derived and foreseeable events can be probabilistically described (Maia and Meinke, 2009).

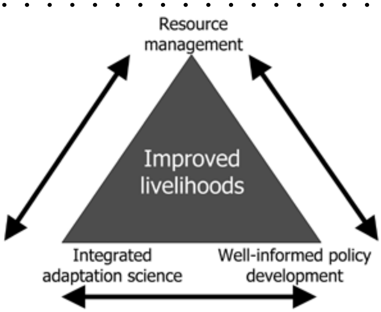


Fig. 13: The role of integrated adaptation science as a communication tool to inform policy as well as practice and to facilitate co-learning of all partners (Meinke et al., 2009).

Once this is achieved, the framework can be used to diagnose the most promising pathways for intervention into agricultural systems to improve their performance – either incrementally or via fundamental changes to the system. Used in this way, integrated adaptation science can really help to improve the livelihoods of the most vulnerable people (Fig. 13).

So to improve the productivity of rice-based systems, we need to explore all options, incremental improvements and revolutionary change. What works best will depend on the context. We need incremental improvements, for instance better water management based on seasonal climate forecasts, improved infrastructure and adapted varieties. This moves us along or onto the existing efficiency frontier. We also need the transformational changes in places where there is simply not enough irrigation water left.

For rice-based systems in water-scarce environments, this is where aerobic rice – that is rice that is not grown under flooded conditions – comes into play. While production per unit area will not increase or possibly even slightly decrease under aerobic conditions, water use efficiency gains of more than 100% are clearly achievable. In terms of water use, this will move us onto a new efficiency frontier (Fig. 14).

Fig. 14: Traditional, flooded rice production (left) versus aerobic rice production (right).

This is 'adaptation by design' – a careful analysis of all the options before implementing the most promising ones. Clearly, this requires good modelling skills at all scales, so the theme 'Designing climate robust systems' will draw strongly on expertise from across CSA and beyond.

This was just a very brief example of how our research will continue to contribute to solving the big adaptation questions in agriculture. More information about CSA is publicaly available (http://www.csa.wur.nl/UK/). We are keen to engage in solution-oriented research using our model-based technology platforms.

So rather than bragging about the scientific achievements of the group – which are significant, I might add – I would rather like to briefly touch on two more points:

Firstly, the importance of teaching and education:

The success of a university depends very much on a strong commitment to diversity and true inclusiveness. We must see educating all young people as our civic duty rather than a privilege that is only accessible to some. The importance of equity and inclusiveness cannot be overrated. For a university like Wageningen, there are two key outcomes:

(i) we need to use science to ensure equitable access to food, fibre and other scarce resources such as water and
(ii) we need to fight for access to knowledge by all humans - after all, knowledge is a inexhaustible resource. I know that all staff at the Centre for Crop Systems Analysis are committed to these principles and they are proud of it.

The importance of flexibility

The second and final point I would like to stress is the importance of flexibility, tolerance and self-reflection:

We can't talk about adaptation without adapting ourselves. In fact, this is one of the principles of adaptive governance of which adaptation science is a logical extension. In our group, rather than fixing our structure and our strategic direction, we constantly reflect and review. In a world where the pace of change is rapidly increasing, we must remain responsive to these changing demands.

True to the principle of life-long learning, we endeavour to be a responsive and proactive group that constantly re-invents itself rather than defending our past. Following the principles put forward by Hamel and Välikangas (2003), we aim to achieve revolutionary change in lightning-quick, evolutionary steps, but with no calamitous surprises, no convulsive reorganisations, no across-the-board staff changes. *In a truly resilient organisation, there should be plenty of excitement, but no trauma.*

We want to create such a work environment where great ideas and innovation can thrive, but where the direction is clear and shared by all.

I showed you the diagram of our five themes. We believe that these themes best align our skills with societal needs today. This might not be true tomorrow, so don't expect these themes to remain static. Over the last year we have already re-adjusted these themes a couple of times. This is how we ensure that we remain relevant. We are committed to scientific innovation. This means we also need on-going organisational innovation and renewal.

Our Centre, the Centre for Crop Systems Analysis, wants to lead by example. Together with other groups and, in fact, the whole university, we want to achieve the most important goal of all: to distil the best science has to offer for the task of highest priority - scientific solutions that improve livelihoods and make the world a better place.

I have come to the end of my oration, and probably the end of your patience. All that remains is for me to thank the people who have made this event possible:

I thank

- my family, particularly my wife Julie and my son Nic, for their ongoing support and love under often difficult and challenging circumstances;
- my friends for their tolerance and sound advice;
- some individual scientists who have shaped my career fundamentally, such as my PhD supervisors, Graeme Hammer and Herman van Keulen (who unfortunately can't be with us today), and Rudy Rabbinge; my predecessor Martin Kropff and

. . .

someone whom I was unfortunately not privileged to meet, but whom I greatly admire for his vision and sharp intellect, Prof Cees de Wit;

- the Board of the university for their confidence in my abilities;
- my extensive international professional network for the fruitful and enjoyable collaboration and stimulating scientific discussions we had over the years; many of these collaborations have resulted in lasting friendships;
- all the funding agencies which have generously supported me over the years;
- my adopted home country, Australia, for awakening my scientific interest in climate risks and for supporting me in acquiring the necessary formal qualifications;
- Jet and Sjanie for all the logistics – without them none of us would be here today;
- The entire staff of CSA and PPS for their professional support;
- And finally all the students who maintain a keen interest in our science and who keep us on our toes with challenging questions. Keep it up!

I thank you for your attention. Ik heb gezegd.

References

ABC (Australian Broadcasting Corporation), 2009. http://www.abc.net.au/rn/hindsight/stories/2009/2540163.htm

Australian Bureau of Meteorology, 2010. Annual Australian Climate Statement 2010. http://www.bom.gov.au/announcements/media_releases/climate/change/20100105.shtm

Bastiaans, L., Paolini, R. and Baumann, D.T., 2008. Focus on ecological weed management: what is hindering adoption? Weed Research 48, 491-491.

Buck-Sorlin, G.H., Hemmerling, R., Kniemeyer, O., Burema, B.S. and Kurth, W., 2008. A rule-based model of barley morphogenesis, with special respect to shading and gibberellic acid signal transduction. Annals of Botany 101, 1109-1123.

Carlson, M., 2006. History of Medieval Greenland; http://www.personal.utulsa.edu/~marc-carlson/history/grontimebible.html

Evers, J.B., Vos, J., Yin, X., Romero, P., van der Putten, P.E.L., Struik, P.C., 2010. Simulation of wheat growth and development based on organ-level photosynthesis and assimilate allocation. Journal of Experimental Botany, in press.

Fricke, H.C., O'Neil, J.R. and Lynnerup, N., 1995. Oxygen isotope composition of human tooth enamel from medieval Greenland: Linking climate and society. Geology 23, 869-872.

Government of South Australian, 2010. State records of South Australia. http://www.archives.sa.gov.au/exhibits/saonmap/gwgtimeline.html

Hamel, G. and Välikangas, L., 2003. The Quest for Resilience, Harvard Business Review, September 2003, 1-13.

Howden, S.M., Soussana, J-F., Tubiello, F.N., Chhetri, N., Dunlop, M. and Meinke, H., 2007. Adapting agriculture to climate change. Proceedings of the National Academy of Sciences of the United States of America (PNAS) 104(5), 19691–19696. doi:10.1073/pnas.0701890104.

Jensen, C., Munk, L., de Neergaard, E., Høegh, K. and Stougaard, P., 2009. Biocontrol bacteria isolated from potato fields in Greenland. Climate Change: Global Risks, Challenges and Decisions. IOP Publishing IOP Conf. Series, Earth and Environmental Science 6; doi:10.1088/1755-1307/6/7/372041.

Keating, B.A., Carberry, P.S., Bindraban, P., Asseng, S., Meinke, H. and Dixon, J., 2010. Eco-efficient agriculture: concepts, challenges and opportunities. Crop

Science, accepted 50, in press.
KNMI (Koninklijk Nederlands Meteorologisch Instituut), 2010. http://www.knmi.nl/klimatologie/maand_en_seizoensoverzichten/index.html
Landis, D.A., Gardiner, M.M., Werf, W. van der and Swinton, S.M., 2008. Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. Proceedings of the National Academy of Sciences of the United States of America (PNAS) 105, 20552 - 20557.
Lundberg, M., 1999. The history of Greenland. http://explorenorth.com/library/weekly/aa121799.htm
Maia, A.H.N. and Meinke, H., 2009. Probabilistic methods for seasonal forecasting in a changing climate: Cox-type regression models. Int. J. Climatology., in press, doi:10.1002/joc.2042.
Meinke, H. and Stone, R.C., 2005. Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. Climatic Change 70, 221-253.
Meinke, H., Nelson, R., Kokic, P., Stone, R., Selvaraju, R. and Baethgen, W., 2006. Actionable climate knowledge – from analysis to synthesis. Climate Research, 33, 101-110.
Meinke, H., Howden, S.M., Struik, P.C., Nelson, R., Rodriguez, D. and Chapman, S.C., 2009. Adaptation science for agricultural and natural resource management – Urgency and theoretical basis. Current Opinion in Environmental Sustainability 1, 69–76. doi:10.1016/j.cosust.2009.07.007.
Nelson, R., Kokic, P., Crimp, S, Meinke, H. and Howden, S.M., 2010. The vulnerability of Australian rural communities to climate variability and change: Part I – Conceptualising and measuring vulnerability. Environmental Science and Policy 13, 8-17. doi:10.1016/j.envsci.2009.09.006.
Panagiotakopulu, E. and Buckland, P., 2007. Fossil insect evidence for the end of the Western Settlement in Norse Greenland. Naturwissenschaften 94, 300–306; DOI 10.1007/s00114-006-0199-6
Rahmstorf, S., Cazenave, A., Church, J.A., Hansen, J.E., Keeling, R.F., Parker, D.E. and Somerville, R.C.J., 2007. Recent climate observations compared to projections. Science 316, 709.
Richards, P., Bruin-Hoekzema, M. de, Hughes, S.G., Kudadjie, C.Y., Offei, S.K. and Struik, P.C., 2009. Seed systems for African food security: linking

molecular genetic analysis and cultivator knowledge in West Africa. International Journal of Technology Management 45, 196-214.
Ryan, M.R., Mortensen, D.A., Bastiaans, L., Teasdale, J.R., Mirsky, S.B., Curran, W.S., Seidel, R., Wilson, D.O. and Hepperly, P.R., 2010. Elucidating the apparent maize tolerance to weed competition in long-term organically managed systems. Weed Research 50, 25-36.
Tannberg, T., Mäesalu, A., Lukas, T., Laur, M. and Pajur, A., 2000. History of Estonia. Avita, Tallinn, 335 p.
Vos, J., Evers, J.B., Buck-Sorlin, G.H., Andrieu, B., Chelle, M. and Visser de, P.H.B., 2010. Functional-structural plant modelling: a new versatile tool in crop science. Journal of Experimental Botany, in press doi: 10.1093/jxb/erp345.
Wit, C.T. de, 1992. Resource use efficiency in agriculture. Agric. Systems, 40, 125-151.
Yin, X and Struik, P.C., 2008. Applying modelling experiences from the past to shape crop systems biology: the need to converge crop physiology and functional genomics. New Phytologist 179, 629-642.
Yin, X. and Struik, P.C., 2009. Theoretical reconsiderations when estimating the mesophyll conductance to CO2 diffusion in leaves of C3 plants by analysis of combined gas exchange and chlorophyll fluorescence measurements. Plant, Cell and Environment 32, 1513–1524.
Zwart, M.P., Hemerik, L., Cory, J.S., Visser, J.A.G.M. de, Bianchi, F.J.J.A., Oers, M.M. van, Vlak, J.M., Hoekstra, R.F., Werf, W. van der, 2009. An experimental test of the independent action hypothesis in virus-insect pathosystems. Proceedings of the Royal Society. B: Biological Sciences 276, 2233-2242.

Change creates risks and opportunities. We can try to prevent it, resist it or adapt to it. The recent rate of environmental change has created urgency for well-planned adaptation action. Hence I propose 'adaptation science' as the process that generates the insights needed to affect changes in agricultural systems towards increased adaptive capacity and performance. This requires quantitative assessments of threats, risks and opportunities. For adaptation science to have high social impact it needs to be salient, credible and legitimate.

ISBN 987-90-8585-271-1