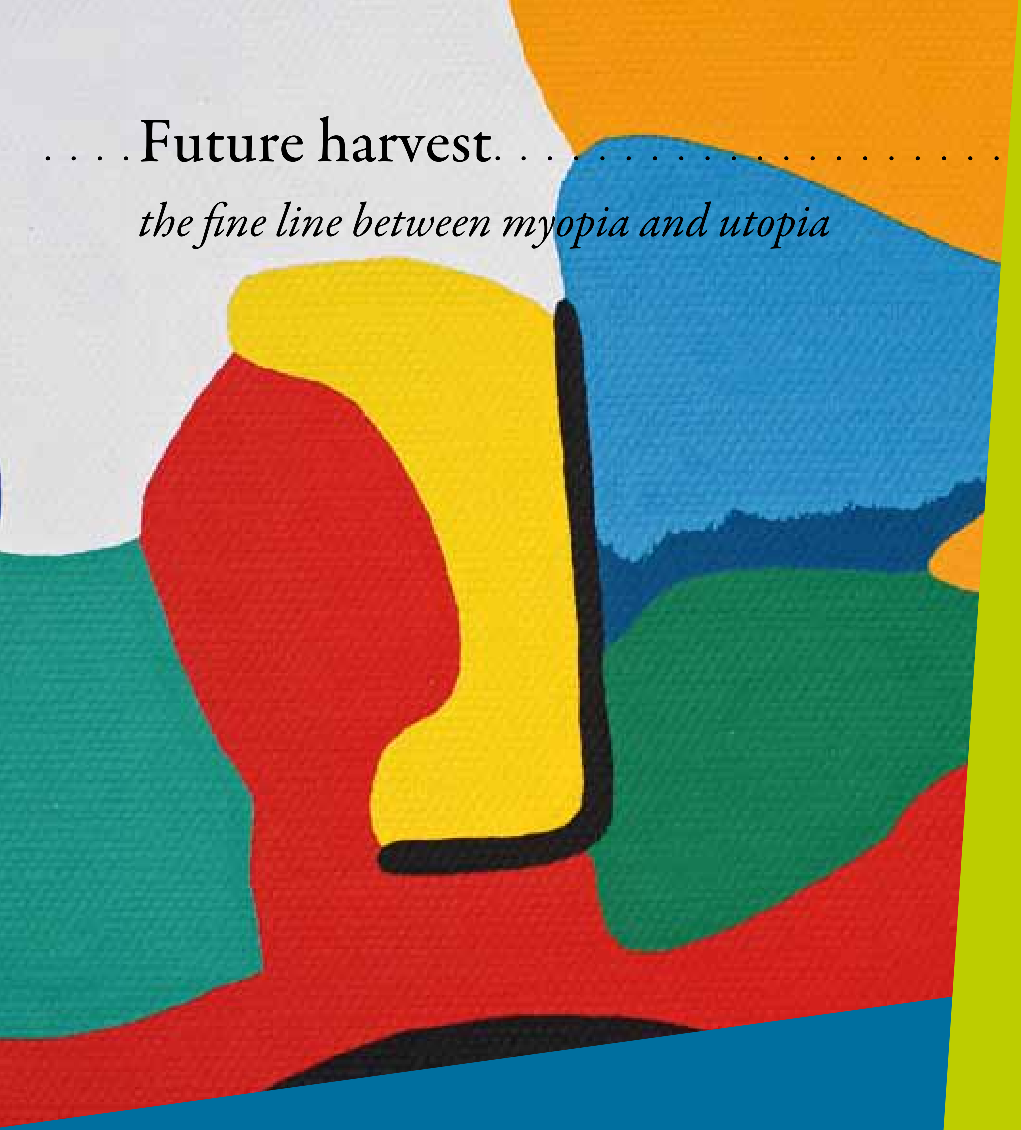

Future harvest

the fine line between myopia and utopia

Prof. dr. ir. M.K. van Ittersum

Inaugural lecture upon taking up the post of Personal Professor of
Plant Production Systems at Wageningen University on 12 May 2011

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Rector Magnificus,
Family, friends, colleagues, ladies and gentlemen,

Let me start this lecture by sharing some old news: the weather forecast for today as provided by the KNMI yesterday. As you can witness, the forecast was not far off. Next, I show the 10 days ensemble forecast of the KNMI, as published on 3 May 2011. Clearly the band around the maximum temperature increased in time, indicating that uncertainty increases in the course of the 10 days forecast and generally the forecasts move towards the long term average. Today we can witness how well the maximum temperature was forecasted ten days ago.

Though the quality of weather forecasts has increased in the past decades, such that now the 10 days forecasts have some reliability, forecasting the longer term weather and a change in the climate is very difficult, as we all know. The various models summarized in the latest IPCC Assessment Report show a substantial variation in possible climate change outcomes for 2050 and 2100 (Pachauri and Reisinger, 2007). Even within a particular SRES development scenario, the forecasted average global increase in surface temperature for 2100 varies up to 4 degrees.

Forecasting the weather or climate change is not the topic of this lecture, but it provides an interesting analogy to forecasting future food production or I should say future agricultural production. Also food production is forecast for the short and longer term. The Food and Agriculture Organization of the United Nations (FAO) publishes its biannual Food Outlooks with short term forecasts for the production, utilization, trade, stocks and prices of the major agricultural commodities. The AGRI4CAST system, also known as the MARS Crop Yield Forecasting

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System, is used by the European Commission to make seasonal forecasts of agricultural production using remote sensing and meteorological observations, agro-meteorological modelling and statistical analysis tools (http://mars.jrc.it/mars). For the longer term, impact assessments of climate change are a good example: crop growth models are used to assess the possible impacts of climate change in for instance 2050 (Parry *et al.*, 2004). Clearly, uncertainty of these forecasts increases with the time horizon: the Food Outlooks have the shortest time horizon and the least uncertainty, followed by the seasonal AGRI4CAST and then the climate change assessment for 2050. There is another difference between these three types of forecasts: whereas the FAO food outlook and the AGRI4CAST give an average forecast with some variation, the long-term climate change assessment does not provide a single outcome with a variation, but provides so-called scenarios: a range of alternative outcomes, each with variations or uncertainty bands. The scenarios stand for a number of external drivers and factors, which are likely to affect climate change but are uncertain in itself. The three example studies move away from predictive to explorative (Van Ittersum *et al.*, 1998).

Forecasting food production is perhaps less difficult than forecasting the weather as yields of crops are the result of cumulative weather during a growing season; the weather of every single day is often not that important. However, the occurrence of extreme events (such as thunderstorms, hail storm, heat, etc.) may clearly complicate this simplification. Soils play a buffering role in agricultural production because they can store water, but they also provide an extra source of variation. Furthermore, crops can suffer from pests and diseases. Finally, human management is typical for agricultural production. This on the one hand provides a degree of control on yield formation, which makes it slightly less dependent of the weather, but on the other hand it also adds complexity and variation to different agricultural systems: farmers within one homogenous region may perform quite differently. In summary, whereas weather and climate are largely physical processes, only in the long term and to some extent influenced by human beings, is agricultural production determined by complex interactions between the weather, soils, pests and diseases and human management. And, agricultural production must be assessed in the context of its natural, economic and institutional environment.

In this lecture I will focus on research needed to answer the question 'will mankind have enough to eat', and address this question from long-term and shorter term perspectives, while considering issues at global, regional and local level. And, I will focus on the economic and environmental constraints and consequences of this agricultural production. But first, a long-term perspective on whether the earth can produce enough food for mankind in 2050.

Will mankind have enough to eat?

A major news item over the past months, sometimes underlying other news items such as political unrest in the Middle East, has been the high prices of agricultural commodities. For the second time in just 3 years, prices are peaking and a factor 2-3 more than they were in the first years of this millennium. These price peaks are significant also when correcting for inflation. They are remarkable given the historical trend in deflated prices of wheat, which is shown in Fig. 1. Ever since ca. 1875, when the industrial revolution led to breakthroughs in agriculture, the trend in prices has

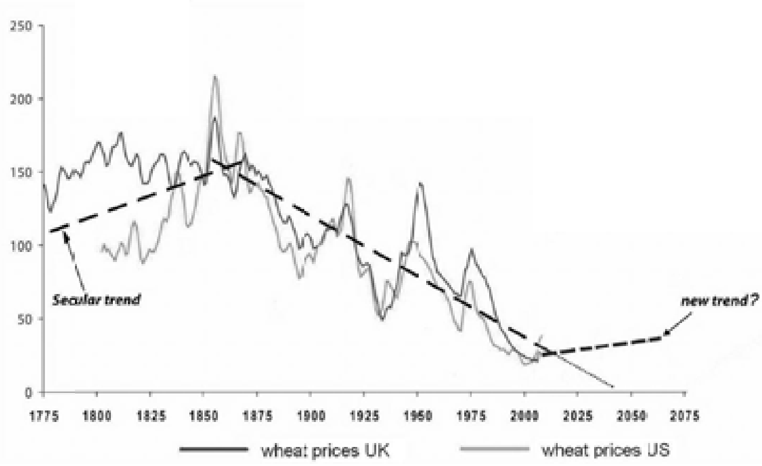

Fig. 1. Indexes of real wheat prices in the US and England and Wales, 1800–2007, and hypothetical evolution after 2007. Prices up to 2005 are five-year moving averages, with 1901–1905 = 100. Prices in 2005–2007 are annual prices with the same base years (Koning et al., 2008).

been downward, only interrupted by temporary peaks due to wars or other global crises. Apart from these crises, since 1875 hunger has been a problem of poverty amidst plenty rather than of absolute scarcity. The question is whether the recent peaks point at a trend break: will the poor suffer even more from rising food prices that suggest an absolute scarcity?

It is well known that the demand for food will increase substantially. By 2050, the number of people will have increased from ca. 6.9 today to 9 billion. Many of these people in emerging economies will eat more meat, as there is a distinct positive relationship between income and meat consumption (Speedy, 2003; Nonhebel and Kastner, in press) Thirdly, a biobased economy is looming. Official policy targets impose a mandatory blending of transport fuels with bio-ethanol or biodiesel, currently often made from food as feedstock. And even if this myopic solution will not continue forever, the amounts of feedstock needed for this and the possible demand for biomass for producing (high value) biochemicals will add substantially to the future demand. To illustrate the enormous amount of feedstock needed in a biobased economy: the global energy consumption in 2008 was estimated 980 EJ (Schiffer, 2008); assuming a favourable conversion rate this equals ca. 55 GT of grain equivalents[1] (GE). Ten percent of this amount comes close to the present total agricultural production. To simplify: the poor countries will require more food because of more people and because current diets are marginal. The middle-income countries will require more feed and feedstock because of increased meat consumption and a biobased economy, and the rich countries will require more feedstock for a biobased economy (see also Nonhebel and Kastner, in press).

Current food production, expressed in grain equivalents, can be estimated at ca. 7 GT GE. Future demand for the 9 billion eating more meat will be ca. 12 GT. If 10% of our present energy consumption comes from agricultural yields than this is another 5 GT and if all people on the globe would consume a European diet the

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[1] Grain Equivalent is a theoretical food unit, referring to the quantity (in kg) of dry grain that would be produced if only one type of crop were grown (a cereal), plus the amount of grain that needs not to be produced because of feed (grass) harvested from land unsuitable for arable farming .

demand would add up to ca. 23 GT GE. It is evident that the world will have to produce substantial amounts of additional food.

The required growth for food and feed is nothing new compared to the challenges in the second half of the 20th century, when yields increased with ca. 2% per year and the food per capita increased despite an increase of the population from 3 to ca. 6 billion (1.8% per year) people (Fig. 2 – after Evans, 1998). Yet, conditions in 2011 are very different from those in 1960. The low hanging fruit has been harvested. Let's explore the possibilities.

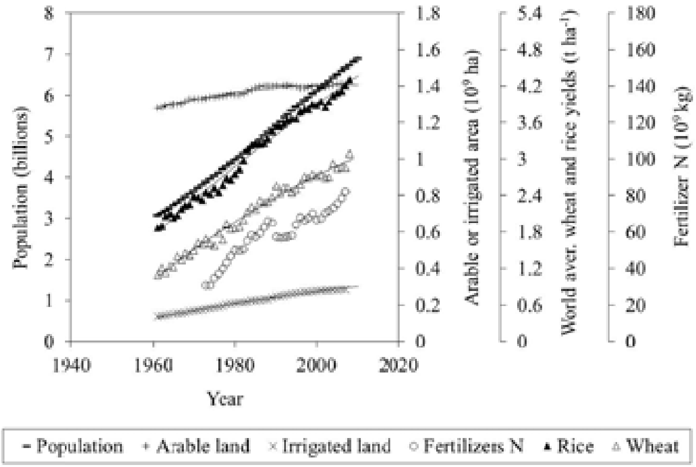

Fig. 2. Evolution of population, arable land area, world average wheat and rice yields, fertilizer N use and irrigated area. Updated from Evans, 1998.

In the past 50 years an increase in agricultural area played only a modest role in increasing agricultural production (Fig. 2). Agricultural area increased by ca. 10%. Potentially there are still vast areas of land available for agriculture: theoretically it could increase by another 60% (Penning de Vries et al., 1995; Young, 1999; Koning *et al.*, 2008). Much of that land is less fertile, much is under natural ecosystems with important values and much land will be needed for urbanisation, transport and recreation. Hence, in reality it is unlikely that total agricultural areas can increase substantially. So, the only way of increasing production is through higher yields per hectare. Just as in the past 50 years, when global yields of rice, for instance, increased from 1.9 t/ha to 4.3 t/ha (Fig. 2).

Production ecological principles enable us to quantify the potentials to increase yields further (Van Ittersum and Rabbinge, 1997). The difference between, on the one hand, the potential production of a crop when it experiences no water or nutrient stress and no yield reducing factors due to pests and diseases, and on the other hand, actual yield is defined as the yield gap. If irrigation is not feasible, then the yield gap can be defined as the difference between the water-limited (or rainfed) yield level and the actual yield. Yield gap closure is defined as the ratio between actual and potential (or water-limited) yields. Assuming current acreages of agricultural land, multiple cropping per year (in large areas of the world 2 to 3 crops per year can be grown), 80% yield gap closure and no negative consequences from climate change nor land degradation, the global food production potential with today's cultivars of crops and grassland can be estimated at ca. 36 GT GE per year (Koning *et al.*, 2008). This requires a vast expansion of the irrigated area; theoretically this is probably possible (Penning de Vries *et al.*, 1995), but in reality competition for sweet water and infrastructural limitations will be constraining. If we assume a maximum of 50% increase in irrigated area, the potential production comes down to ca. 27 GT GE per year. Still enough to meet future demands, but potential production and demand come close.

The calculations above give the potential with current cultivars. Of course, we can breed for new cultivars with a higher yield potential. Potential yields of new cultivars continue to increase, but progress is slowing, in particular for the major crops such as maize, wheat and rice (Fischer and Edmeades, 2010). Progress in productivity has become source limited rather than sink limited and breeding for an enhanced biomass production rather than improved harvest index is complex (Yin and Struik, 2008; Zhu *et al.*, 2010). An international consortium has joined forces to breed C4 rice (Hibberd *et al.*, 2008), but it is hard to predict whether and when this will be successful. Another route of increasing the potential is through improving conversion efficiencies and biorefinement. The first is important in converting plant production into animal production. Here, at global level major progress is still possible also with current animal breeds (Wirsenius, 2003; Wirsenius *et al.*, 2010). However, so far methods that enable benchmarking animal production similar to plant production are largely lacking. I will come back to this later. We can also increase the production potential through increasing food production on water, sea and/or aquaculture, including the production of sea algae (Reith *et al.*, 2008; Subhadra and Grinson, 2011). Finally, an estimated 30 to 40% of the food is lost before it comes to our plate (post-harvest losses) or ends up in the rubbish bin as industrial waste (Godfray *et al.*, 2010); reducing food loss and waste is a necessity. Though each of these options holds some promise, none is easy to achieve and little concrete evidence is available that they will provide substantial contributions within the coming 10 or 20 years.

Much of the productivity increase will have to come from yield gap closure. But will it be possible to realize such yield gap closure? Fig. 3 presents a framework that summarizes biophysical and economic relations in raising food production. Fig. 3a provides the relationship between production level (amount of biomass) and the

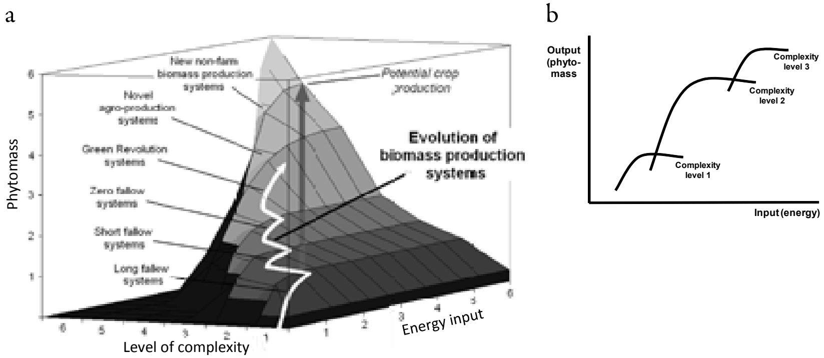

Fig. 3. Conceptual representation of biophysical (a) and economic (b) relations in raising food production. Source: Koning et al. (2008); Koning and van Ittersum (2009).

energy input and degree of complexity of systems. Degree of complexity is defined here as the degree of human control and management of the entire agricultural production system, including the delivery of inputs. In the course of agricultural development the complexity and energy inputs have increased, and as a result of this agricultural productivity per hectare has increased. In case of new cultivars, often the potential production has also increased, i.e. through a more favourable harvest index.

Agricultural production options can be characterised by input-output relationships (Fig. 3b). In economics these are named production functions. Agricultural production uses multiple inputs and several of them cannot be mutually substituted because of their unique role in biological processes. To bring them under a single denominator, inputs can be aggregated into one unit such as energy. For a given state of technology (crop cultivars, combined with inputs, equipment and labour) different input levels may fall on a single production function, but a new technology or complexity level results in a new production function which generally starts at larger input levels and results in greater outputs. Typical for agricultural production is that greater production requires more complex systems. And, under low input conditions less complex systems tend to be more efficient. Profit is maximal when the iso-profit line (with the input-output price ratio as slope) gives the largest intercept with the output axis. With favourable input-output price ratios, developing new systems may become profitable, but the reverse is true as well. Under unfavourable input-output ratios producers can even opt for low-input techniques.

The above economic considerations explain why in many places in the world there is a significant yield gap, now and most likely also in the future. First, farmers maximize profit rather than yield. Second, less favoured areas usually experience unfavourable price ratios, high risks and transactions costs. This may be due to legal (Latin America) or natural and political reasons (Africa).Third, closing yield gaps requires research, particularly because the low hanging fruit has been plucked. Growth in public investments in agricultural research has steadily decreased in the past decades and this is only partly compensated by increases in private investment (and only in developed countries) (Beintema and Elliott, 2009). Fourth, it may be anticipated that depletion of resources such as fossil fuel and phosphate rock will increase input prices and stimulate farmers to stay away from maximum yields.

So, supply of food may become tight long before technical potentials have been exhausted and this may well indicate that we will experience a trend change in food prices (Koning *et al.*, 2008; Koning and van Ittersum, 2009). Not just a temporary peak, but sustained higher prices of agricultural commodities. If this is the case, the transition poses special risks. Both private and public decision-makers have short time horizons. If current prices are high(low), they tend to expect that prices will also be high(low) in the future. This can cause endogenous price fluctuations coupled to an alternating overshooting and undershooting of trend investment. With this reasoning, the rise in food prices in 2007–2008 and currently can be seen at least partly as an effect of the low prices in the 1980s and 1990s which caused an undershooting of trend investment in agricultural research and development. The transition phase (the trend break) is characterised by high price volatility, which is aggravated by the abandonment of price support and price stabilisation and the lowering of food stocks. The low prices have kissed policy and society asleep – policy and society became myopic. Thinking that it can be fixed by just gene and cell research is utopian. Closing the gap between potential and actual yields requires a major, integrative effort. Also because environmental constraints will impose limitations on production practices.

Short and longer term considerations

I have sketched a global and long-term picture. There are of course many nuances to make. These are short and longer-term nuances and considering issues at farm, regional and global level. In the second part of my lecture I will deal with five of such issues which receive attention in my current research projects or for which I plan new activities.

Yield gaps

In my introduction I have mentioned the concept of yield gaps. Yield gaps are defined by the difference between the potential or water-limited yields and the actual yields as observed on farms or in statistics (and yield gap closure as the ratio of actual over potential or water-limited production). Yield gaps have been estimated in different studies around the globe in the past two decades. Lobell *et al.* (2009) summarized many of these studies, with an emphasis on Asia. They found that yield gap closures vary between 16 and 95%. Table 1 summarizes examples of yield gap studies from other places as well. In Africa yield gaps are generally large. Tittonell *et*

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al. (2008) estimated yield gap closures, relative to water-limited yields, at only 26 % on average for maize in Western Kenya. At the other extreme, in The Netherlands and parts of the US, yield gap closures are often around 80%.

Table 1. Yield gap closures (actual production relative to the potential or (for Kenya) water-limited production).

Location	**Crop(s)**	**Yield gap closure (%)**
Mostly Asia (Lobell *et al.*, 2009)	Various	16-95
Kenya (Tittonell *et al.*, 2008)	Maize	17-33
SE Asia (Laborte *et al.*, in review)	Rice	44-71
The Netherlands (Wolf *et al.*, unpublished)	Various	75-87

The presented data are average data for a region or groups of farms. It is interesting to learn from variation. What do best farmers, for instance, achieve? For four rice growing regions in SE Asia, actual yields were estimated based on farm surveys, for so-called average farmers and for the farmers with the upper 10% percentile yields (Table 2). Average yield gap closure for the dry (sunny) season varies between 45 and 69%; interestingly closure is higher in the rice exporting countries Thailand and Vietnam. Best farmers achieve a yield gap closure which is 12-28% higher. The farmers with largest yields use only slightly more nitrogen fertilizer, in some regions less labour and tend to have more years of schooling in two out of the four regions. Proper understanding of yield gaps and their causes in a farming system and

Table 2. Average and best farmers' yields, yield gap closures and inputs for rice production (dry season) in four regions in SE Asia (Laborte et al., in review).

	Central Luzon (Philippines)		**West Java (Indonesia)**		**Suphan Buri (Thailand)**		**Can Tho (Vietnam)**	
	Average	*Best*	*Average*	*Best*	*Average*	*Best*	*Average*	*Best*
Yield (t/ha)	*4.7*	*7.7*	*4.1*	*5.7*	*5.3*	*6.4*	*6.2*	*7.6*
Yield gap closure (%)	*45*	*73*	*52*	*72*	*59*	*71*	*69*	*84*
N fertilizer (kg/ha)	*122*	*162*	*124*	*142*	*112*	*120*	*89*	*97*
Labour (h/ha)	*55*	*84*	*107*	*89*	*17*	*17*	*61*	*54*
Years in school	*6.7*	*5.7*	*7.3*	*11.0*	*4.7*	*5.0*	*6.8*	*10.5*

socio-economic context provides a meaningful starting point for re-design of practices and for improving agricultural productivity.

Yield gap analyses are currently very fragmented and carried out in a variety of ways. They are only meaningful if the conditions in terms of climate, soil and genotype of the crop have been well specified with local information. My colleague from the US, Ken Cassman, and I organised a symposium in Montpellier during the most recent European Society of Agronomy conference (Wery *et al.*, 2010) and we are now initiating a global project to develop a global yield gap and water productivity atlas. To achieve this, first joint protocols for yield gap analysis and estimating water productivity will be developed. Using these global protocols, the atlas must be realised bottom up, using local knowledge of agricultural management and good weather, soil and experimental data. Wageningen's extensive network of alumni is an excellent starting point for such a project. The atlas will be made available on-line and form a rich source of information for new research and development projects. Donors have expressed sincere interest in this project. In Wageningen this can be a key activity in the strategic theme 'Sustainable and Smart Food Supply'. The approach can be readily extended to benchmarking use efficiency of resources such as water, nitrogen and phosphorus.

Whereas yield gap analyses for crop production are well known, for grassland they have hardly been done and for animal production we largely lack the concepts. The strategic theme that I just mentioned proposes to develop the concepts and methods also for animal production systems to enable yield gap analyses. Initial attempts to translate concepts from plant production to animal production are available (Van de Ven *et al.*, 2003), but this clearly requires more work and I consider this an exciting topic for joint research between animal and plant science groups, within the recently established Wageningen Centre for Agro-ecology and Systems Analysis (WaCASA).

Related to the topic of yield gaps, is the discussion on whether organic production is a viable alternative to current agricultural practices, particularly to lower local impacts on the environment and landscape. In an extensive analysis of the literature describing 400 comparative yield sets we assessed the yield gap between organic and conventional practices (De Ponti *et al.*, in review). Data came from (field or on-farm) experiments and from farms and farm statistics and refer to the difference at crop level (so no upscaling to a rotation, farm or region). The average difference in yields between the two practices was 22% (Fig. 4a). We showed that differences in yields are larger when conventional yields are larger. Demand for nutrients and control of pests and diseases is greater when conventional yields are high, and this may be more difficult to achieve with organic practices. Such relationship was significant for only a few crops and the relationship was not strong (Fig. 4b). This yield gap implies that for producing the same amount of food we will need at least 22% more land under organic agriculture, but most probably significantly more than that. The presented comparative analysis is on a crop basis. However, with organic practices productivity, incl. soil fertility, can only be maintained through inclusion of legumes in the rotation and through the use of substantial amounts of animal manure. Inclusion of green manure crops in the organic system will widen the yield gap between organic and conventional systems and it is questionable whether sufficient amounts of (animal) manure are available to maintain soil fertility and yields of a purely organic agriculture. A comprehensive picture of the yield gap of organic agriculture requires analysis at multiple spatial and temporal scales.

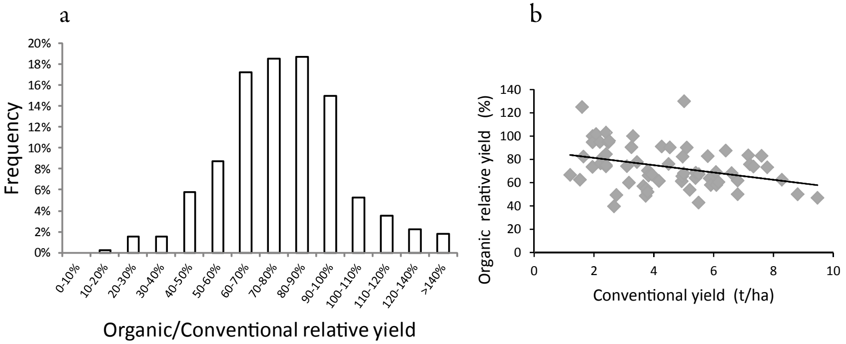

Fig. 4. (a) Relative yield of organic versus conventional agriculture in 400 published results and (b) relative yield of organic practices versus yields of conventional practices for wheat (De Ponti et al., in review).

Resource availability and use efficiency - phosphorus

Whether yield gaps can be closed now, and even more so in the future will depend on a whole range of factors, including availability of resources. One resource which received increasing attention in the last two years is phosphorus. Alarming articles stated that the amount of phosphate rock mined and primarily used for agricultural fertilizers, may peak around 2030 and that soon after we may run out of P-stocks (see e.g. Weekly Time Now, 21 September 2009; http://www.weeklytimesnow.com.au/article/2009/09/21/113681_national-news.html). Since then, just as with fossil fuels the discussion focused on the amount of P available for mining. Stocks appear to be larger and estimations now vary between 40 and 300 years before depletion of phosphate rock reserves, but are still a cause for concern also because new stocks are of lower quality. Long before depletion, prices will drastically increase as was already the case in 2008. The debate has been focusing largely on the availability of P, rather than on the P requirements. But, how much P do we need to feed the world, and, how can we make systems much more efficient and perhaps recycle P?

In a PhD project jointly with Netherlands Environmental Assessment Agency (PBL) and Plant Research International, we estimated the relationship between P harvested in crop products and the fertilizer P use on croplands from the 1960s onwards, also taking into account the use of manure (Sattari et al., to be submitted). Results demonstrate that for major parts of Europe and several other continents, P fertilizer use per hectare has stabilized or decreased in the past two decades, whereas P uptake by crops continued to increase (Fig. 5). In other words the recovery fraction, defined as the annual uptake in harvested product divided by the annual P fertilizer, has increased quite significantly in these parts of the world. Latin America, still increases its application per hectare while the uptake is fairly stable resulting in a slightly decreasing recovery. Africa, on the other extreme, has been using very little P ever since the 1960s. Yields are the result of extraction of native soil P and re-allocating soil fertility from grassland to cropland through manure. We hypothesize that the differences in recovery in time and between the continents must be explained by the effect of residual P of fertilizers. Normally only 20% or less of applied P fertilizer is taken up by the crop and much of the remainder is added to the soil pools. This so-called residual P then can contribute to plant available P for many years to come. In Europe and some other

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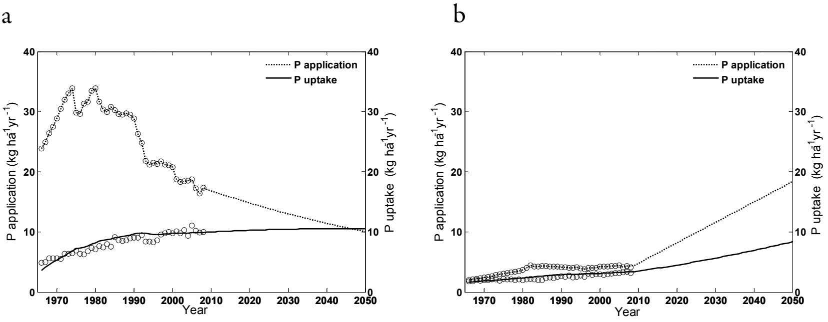

Fig. 5. Observed (until 2007; FAO statistics) and simulated P application and uptake in crop production for (a) Europe (West, North and South); (b) Africa. Simulations are production targets derived from the Millennium Assessment scenario. Source: Sattari et al., in preparation.

continents large amounts of P have been applied in the past and agriculture now benefits from the huge residual stocks of P leading to apparently high recoveries of current P applications. The same phenomenon can be expected for other continents once P status of the soil has been built up. We used this assumption in a two-pool P model (Wolf *et al.*, 1987) and simulated the required amounts of P fertilizer to produce the amount of food needed in 2050 according to the Millennium Assessment scenarios. Estimated relative increase in P requirements for crops is lower than the relative increase in crop production. This does not mean that P scarcity is not an issue to care about and also not that we do not need to develop systems which are more efficient in P use for environmental reasons. And, we would also have to repeat this analysis for grasslands. However, it does illustrate the scope for improving resource use efficiency and the fact that trend extrapolations can be myopic!

Climate change

Another factor which may hinder future food production is climate change. It can affect yield gaps in two ways: it may affect potential (or water-limited) and actual yields. Evidently, climate change is likely to have very different effects in different parts of the world. Climate change may be a serious phenomenon in already warm and dry areas of the world such as dry areas in Australia and Africa

(Parry *et al.*, 2004; Wang *et al.*, 2010), whereas for regions such as The Netherlands or Northern Europe in general the higher CO_2 concentrations and higher temperatures may have neutral or largely positive effects (Bindi and Olesen, 2010).

So, it seems for The Netherlands climate change is not a predominant concern for agriculture, certainly not if farmers can adapt to climate change such that they might benefit from higher temperatures. Or is this a too quickly drawn conclusion? In a recent project of Plant Research International jointly with Grontmij and LTO Noord-Nederland emphasis was on extreme weather events rather than changes in average temperature or rainfall. Thunderstorms, periods of extreme high temperatures or wet and late springs may more negatively affect agriculture than changes in average weather (Schaap *et al.*, 2011). We analysed yield anomalies for potato production in The Netherlands and found out that all recent ones could be explained by late planting due to extreme wet conditions in spring or an extremely wet autumn hindering the harvest in large parts of the country (Van Oort *et al.*, in review) (Fig. 6). Van Oort and colleagues were also able to quantify these extreme events. We are now analysing possible adaptation measures for different farm types. However, a challenge will remain to forecast how often such events may occur in future, and where they will occur, as extreme events are often very location-specific.

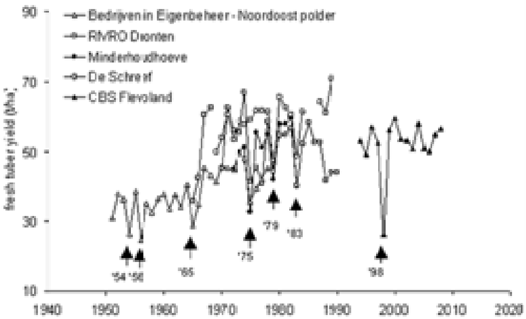

Fig. 6. Time series of potato yields (fresh weight in ton ha^{-1}) in the eastern part of Flevoland, The Netherlands. Arrows indicate years with the largest negative yield anomalies (Van Oort et al., in review).

Climate change is one of the factors that may affect future agriculture, but policy development, markets and technology are equally or sometimes more important than climate change for the average farmer. This was confirmed by farmers and other stakeholders in recent workshops we held on this topic, in the North of the Netherlands. Yet, in almost all today's studies climate change is projected on current crops, management and farms, and then sometimes management adaptations are studied. But by the time climate change will manifest itself profoundly, agriculture will have changed: farms will have increased in size, yields and technologies will have changed, markets and policies will have evolved. So, climate change must be studied in interaction with other changes that take place. In that context we assessed farms of the future in Flevoland under two scenarios of change, i.e. the so-called 'Global market' and' Regional care' scenarios (Mandryk *et al.*, in review). In the past 30 years the number of arable farms in Flevoland has decreased from 1600 to 1100, the average size has increased from 47 to 56 ha, and national wheat yields increased from 6.4 t/ha to 9.7 t/ha (data from CBS). By relating changes in policies, markets, technology and climate, which are distinct in the two scenarios, to changes in aspects of farm structure, i.e. orientation, size, intensity and specialisation, future farm structure in Flevoland was assessed. Fig. 7 shows how shares of orientations and size classes may drastically change in time and differ between the scenarios. This provides a context for further studying climate change impact and adaptation in 2050.

We will continue this type of integrated assessment in different projects, including the CARE and ITERATE projects, in which we also look at relationships between agriculture and nature in several regions in the Netherlands. In a European and global context the Agricultural Model Intercomparsion and improvement Project (AgMIP) has been launched by American colleagues. The variety of crop and economic models that are available must be tested for their consistent application in studying climate change impacts. Agricultural scientists need to get their act together and perform a more profound analysis of climate change impact and adaptation, such that comprehensive analyses can be presented in future summits. Here, Wageningen has to play its role and we are currently drafting proposals for a European leg of this initiative.

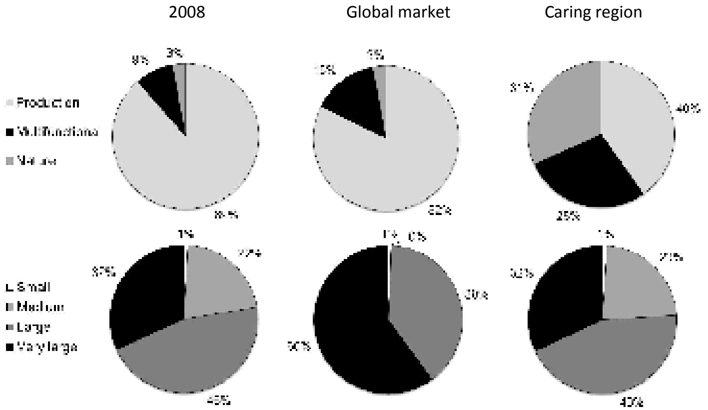

Fig. 7. Farm type distribution of arable farms in Flevoland in 2008 and in two different scenarios for 2050 (Mandryk et al., in review).

Food-feed-fuel

Competition between food, feed and fuel is regarded as one of the factors behind the recent price peaks and a potential food scarcity. Indeed, the projections on future use of some agricultural commodities to fuel our cars are alarming (Fig. 8) (OECD-FAO, 2010). Thirty-five percent of the sugar cane and 10-15% of

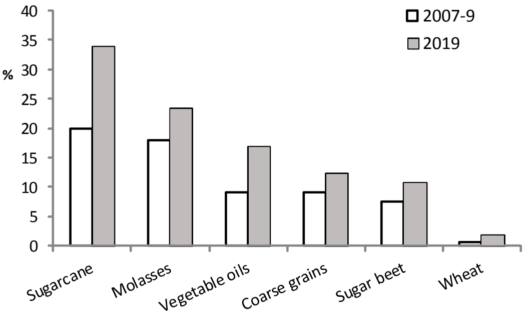

Fig. 8. Share of feedstocks (% of global production) used for biofuel production, currently and projected for 2019. Source: OECD-FAO (2010).

the coarse grains may be used for bio-ethanol by 2019. Perhaps the current debate about nuclear power will provide another push to biofuels. The political targets with respect to biofuel look much like a myopic solution and research must assess impacts and limitations from an integrated perspective, and of course seek alternatives.

Various projects currently focus on food-feed-fuel interactions. In one of them the production ecological sustainability of a range of first generation feedstock sources was estimated (de Vries *et al.*, 2010). Without considering land use change effects and assuming good management, sugarcane and oilpalm are the best performing feedstocks for, respectively, first generation bio-ethanol and biodiesel production (Fig. 9). Under temperate conditions sugarbeet and rapeseed perform better than wheat and maize for a range of agronomic and environmental criteria. But in all cases feedstock production for biofuel may interact with feed and food availability, either on farms or in the region. And, the characteristics of farms, cultural background and possibilities to connect to a biofuel industry determine whether and how different types of family farms can benefit from feedstock for biofuel production and related social inclusion policies. These issues are at the core of a Wotro integrated programme which we carry out in Mozambique and Brazil together with partners in these countries and the groups Management Studies and Animal Production Systems of Wageningen University. Dairy smallholder Sr. André in Montes Claros has sufficient land, but is not mechanised and his crops are targeted at providing feed to the dairy cows. The small arable farm of Sra. Juliana is non-mechanised; currently she is testing castor bean (*Ricinus communis*) because in theory the beans can be plucked manually and are rich in oil that can be used for biodiesel production. However, it competes with food production, its yields are low and the farmer is not connected to a cooperative. Farmer Sr. Neguinho manages close to 2000 hectares of land. Soybean and Brachiaria grass seed are his two crops. Until ca. 10 years ago he grew soybean as a monocrop, but since the inclusion of grass seed in the rotation the yields of soybean have responded positively. The soybean is sold through the cooperative to Petrobras to produce biodiesel and Petrobras is currently considering to build a new plant in the region. This may increase pressure on Sr. Neguinho to supply more feedstock, but at the same time there are good reasons to widen the rotations to enhance agro-ecological sustainabi-

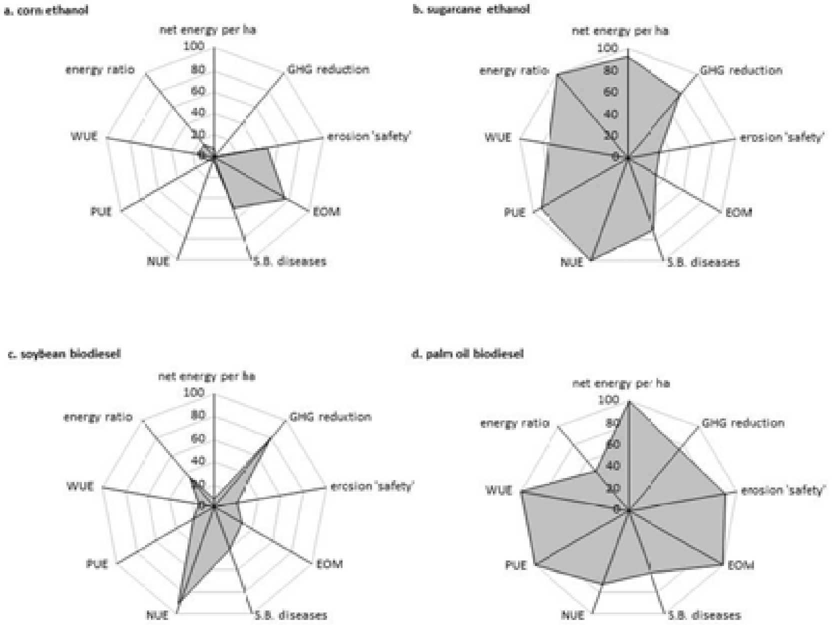

Fig. 9. Relative sustainability of corn and sugarcane ethanol and soybean and palm oil biodiesel, based on nine indicators. Values are indexed in percentages relative to the best (i.e. most sustainable) indicator value found for that indicator across nine systems. 'GHG reduction' is emission reduction relative to replaced fossil fuels. 'Soil erosion' and 'soil borne diseases' (S.B.) indicators have been ranked. WUE = water use efficiency; PUE = pesticide use efficiency; NUE = nitrogen use efficiency; EOM =effective organic matter. Source: De Vries et al. (2010).

lity. Through the use of context-specific farm models we try to estimate different options for these smallholders to benefit from biofuel production, without sacrificing food and feed security and agro-ecological sustainability at farm and regional level.

High prices

I started my lecture with high commodity prices. High commodity prices can be a consequence of scarcity on markets, but can also be a cause of changes in agriculture.

This is a relevant question for policy makers, for instance at European or national level, also in the context of reforms of the Common Agricultural Policy. We hypothesized that higher prices may lead to intensification and specialisation. Four different scenarios with shocks in supply and/or demand were simulated with the agricultural sector model CAPRI, developed by the University of Bonn (Britz *et al.*, 2010). Interestingly, these so-called (partial) equilibrium models need very drastic shocks until they respond with new equilibrium prices that are similar to high prices that we experienced in 2008 and today. They are not designed to capture short term dynamics. Fig. 10a shows the relative price changes as simulated with two scenarios for the year 2013, of which 'the supply and demand change' scenario is extreme. We took these simulated prices as the starting point of an analysis how different farm types in the EU may respond, using a bio-economic farm model (Janssen and van Ittersum, 2007; Louhichi *et al.*, 2010) for 14 regions for which we had detailed data available in the database developed in the SEAMLESS project. In the more extreme scenario incomes increased with 60 to over 100% relative to the baseline. N surplus increased in several regions with 10 up to 50%, particularly due to a specialisation into crops with relatively large price increases and that also have higher N surplus. But regions and farm types show very different responses (Fig. 10). For two regions in France, i.e. Champagne-Ardennes and Midi-Pyrenees effects on income were drastic but similar. However, Champagne-Ardennes showed only minor responses in terms of environmental indicators whereas Midi-Pyrenees showed drastic increases in N leaching and energy use, but also, positively, in carbon sequestration. The difference is due to the fact that farming in Champagne-Ardennes is already specialised into the crops of which prices increased most, whereas for Midi-Pyrenees we simulated a specialisation of farms into winter wheat at the expense of sunflower, fallow and peas. I present this example because of the topic of high prices and its consequences, but also because it is an example of a multi-level integrated assessment using economic and agronomic models.

Vision

I started my lecture with the analogy between forecasting the weather and forecasting food production. For the long term, both are extremely difficult – the future is uncertain. I have given indications of what is possible in terms of future harvest. With the potentials of our current cultivars, it may be feasible to meet the future demands of the 9 billion inhabitants of our planet. The yield gaps of crops

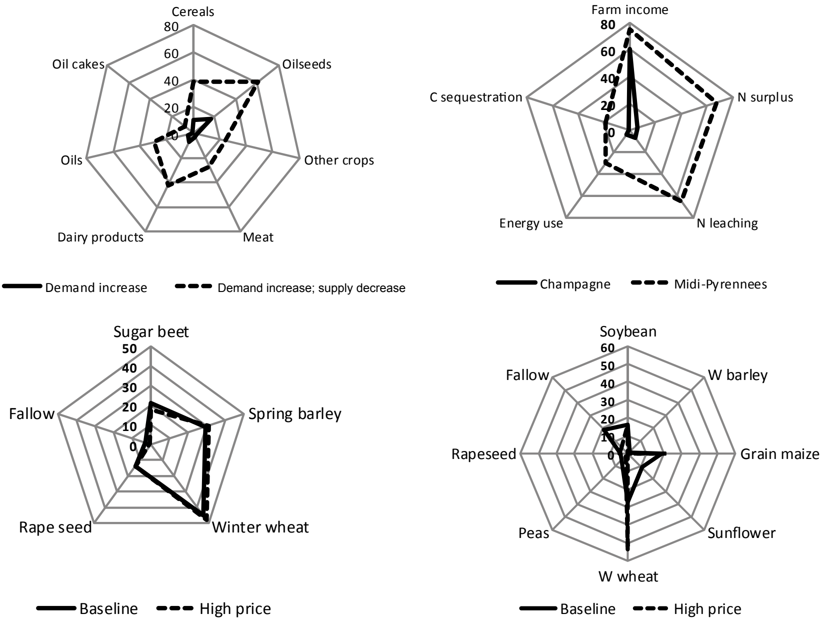

Fig. 10. (a) Relative price increase (% versus baseline) in two scenarios (increase in demand versus increase in demand and decrease in supply); (b) effects of the extreme high price scenario on 5 indicators in Champagne-Ardennes and Midi-Pyrenees in France; values are increases relative to the baseline scenario; (c) Champagne-Ardennes: cropping areas (ha) in the baseline and extreme high price scenarios, and (d) Midi-Pyrenees: idem. Source: (Wolf et al., to be submitted).

and grasslands are still enormous and offer clear possibilities. It will require proper benchmarking of crop and animal production *and* use efficiency of resources to know where and how to change agricultural systems. But, it will be a tremendous challenge to get the economic and institutional conditions right to realize the potentials and to maintain the quality of our environment - it requires a huge investment. I have also shown research and effects of complicating factors such as phosphorus scarcity, climate change and food-feed-fuel interactions.

It will be the role of modern agronomists, and I consider myself one of them, to persistently seek and assess options that are neither myopic nor utopian. We must learn from the past and not extrapolate as that leads to myopic solutions. We must be future-oriented, but use process knowledge and base our solutions on interdisciplinary and multiple level assessments to avoid utopian thinking.

In the European integrated project SEAMLESS, we developed a method for integrated and multiple level assessment (van Ittersum *et al.*, 2008). SEAMLESS was policy-oriented, but we can broaden the same conceptual framework to tackle the wide range of questions that agriculture is facing. These questions are decomposed such that they can be analysed, be it with predictive or explorative purposes, using a nested hierarchical framework (Ewert *et al.*, 2009). In this framework, European (or any other type of) agriculture is part of the global agriculture and economy (Fig. 11). European agriculture, in turn consists of different regions, each with specific farm types that are characterised by their crops and livestock. State-of-the-art scientific models that capture the relevant processes at each of these levels are available and must be further developed in the years to come. To address a particular question, selected models can be linked and assess relevant indicators in tables, maps and diagrams. I have given examples of such indicators, e.g. in the high price scenario. In linking these models scaling methods are extremely important. In the SEAMLESS project various of these methods have been developed, as we recently have summarized (Ewert *et al.*, in press), but many unresolved scaling questions remain. In particular consistency between the micro (farm, region) and macro (market, continent) level remains a challenge. Other key topics that require further scientific attention are uncertainty analysis and the interface between science and its users, i.e. policy, agri-business, development organisations and farmers, to make sure that what science develops is targeted and useful.

The IA framework in SEAMLESS was developed by a team of over 100 scientists from many disciplines. The role of the agronomist is to bring in his or her knowledge about agricultural production and interactions with the environment, and to integrate this knowledge with the other, relevant disciplines, such as soil science, economy, ecology and social science. Agronomists must claim a role in local but also in global studies. Global studies using economic models generally use extrapolations to estimate

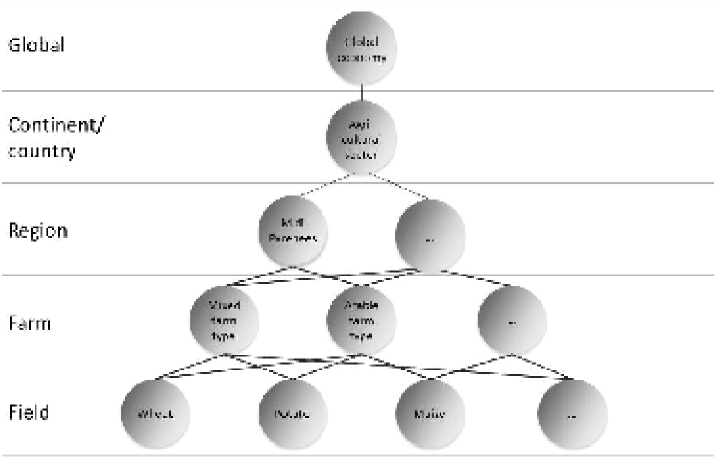

Fig. 11. Nested hierarchical framework as used for integrated assessment. After: Van Ittersum et al. (2008); Ewert et al. (2009).

future production. Foresight studies on agriculture require informed assessments of technological progress. The various examples in this lecture of benchmarking agricultural production, hopefully in the near future also for animal production, indicate what we can provide. Genetic advances are part of technological change. Here I invite my colleagues from plant breeding and molecular sciences to join forces and give fair estimations of what may be achieved and when with new cultivars, such that this can be included in assessments.

Integrative science is demanding. It is generally much easier to do a monodisciplinary study, i.e. a PhD supervised by just one individual chairgroup. Having two (or more) groups involved does not mean half of the work for each group – it involves inefficiencies and extra effort is needed to build interdisciplinarity. That should not be used as an excuse to become myopic: we need integrative solutions to tackle today's problems. However, proper incentives, also financial, for integrative research and PhDs are needed to avoid that interdisciplinarity becomes utopian.

Modern agronomists require or better deserve a thorough background in production ecology and systems analysis. And they need to learn highly integrative skills. I am looking forward to intensify contacts with students. Teaching in production- and agro-ecology has become scattered; in my view there is a need to improve this and make it more quantitative. The first course that I developed from scratch after finishing my PhD was the course QUASI, nowadays called QUALUS (Quantitative Analysis of Land Use Systems). Together with my colleague Nico de Ridder we developed this course in 1992 and it was further developed with several other groups to a truly interdisciplinary course. New insights obtained in the Plant Production Systems group's large research projects can enrich such courses and continue to form a rich source for postgraduate courses. Further, in the context of the new IPOP programme 'Smart and Sustainable Food Supply' and the increasing relevance of Global Food Security it seems very timely to develop a BSc minor in the domain of Global Food Security.

Finally, I would like to propose a novel action, in the context of the IPOP 'Smart and Sustainable Food Supply', with in my view good potential for both research and education. Similar to 'weather seminars', I propose to set up a bi-monthly 'Future harvest' meeting in which the main current issues on global food production are summarized (e.g. global rice and wheat production forecasts), but in which we can also present specific analyses of production issues of short or longer term relevance (e.g. analysis of yield gaps, climate change and variability) and report back on trips to various parts of the world with more detail about production of specific commodities in different parts of the world. So, the event would start with a concise overview (Wageningen Food outlook) and then take a more specific subject for further elaboration. Scientists, students, development agencies, agri-business and other stakeholders can participate and thus contribute to Wageningen's role in society to build a food secure world.

Words of gratitude

At the end of this address I would like to thank a number of people without whom it would have been impossible to stand here. The main title of my presentation, Future harvest, does not only point at future harvest of cereals and potatoes. It also points at future harvest in science and daily work, because of seeds sown by others. Only through standing on the shoulders of our predecessors, and making use of our talents we can make progress. I realize that I can continue in a rich tradition in Wageningen, where I can benefit from huge investments of world famous scientists that have enormously contributed to research methods that we are using today. Five of them have influenced me in particular. First, I'd like to thank Professor Paul Struik, my promotor, and my PhD thesis supervisors Dr. Klaas Scholte and Dr. Jan Vos. Paul, you have learned me a critical scientific and ambitious attitude with an open eye for detail. I admire your versatility. Klaas, Jan and Paul, from each of you I have learned different things and I am very grateful for the nice start of my academic career that you have co-shaped.

My second academic job was at the group Theoretical Production Ecology under the leadership of Prof. Rudy Rabbinge. Rudy, I thank you for teaching me to think strategically and sometimes utopian, to think beyond today's constraints and to work at higher levels of integration. You have always offered me new opportunities in the eight years I worked with you. Sometimes perhaps more opportunities than I aspired to, at that very moment. But also that you respected.

During the last 10 years I worked in the Plant Production Systems group, led by Prof. Ken Giller. Ken, you colour yet another part of the spectrum of scientists that I have worked with. I admire the way you can motivate and unite people based on respect and based on science. We are different, but we also share very important, in my view, values: we both highly enjoy the human aspect behind agriculture, the farmers and their professionalism. And we share our search for the middle ground in agricultural development, the search between myopia and utopia. I thank you for the support and friendship and I am hoping for more years to come.

I thank my colleagues in the Plant Production Systems group for the team spirit and pleasure in the work. Something we have shared in the past period and something we must cherish in the years to come. I owe you my gratitude for the fellowship and dedication: staff members, assistants, secretaries, PhD candidates and post-docs alike. I have presented work of a team.

I am looking forward to continue and intensify collaboration with colleagues from many other groups in Wageningen, in particular the chairgroups Organic Farming

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Systems and Animal Production Systems with whom we have recently started WaCASA, as well as with the Centre for Crop System Analysis, the Agrosystems unit of Plant Research International, Alterra and Social Sciences groups.

Ik ben heel dankbaar dat ik deze dag kan vieren met mijn ouders en die van Jody. Dank jullie wel Pa en Ma, voor de vrijheid en mogelijkheden die jullie me gaven om mijn eigen keuzes te maken en voor het meegeven van belangrijke waarden in het leven. Verder ben ik in de gelukkige positie dat zowel mijn broer als zus bijdragen aan de oogst van vandaag.

Jeanne, Nienke en Birte: ondanks jullie jonge leeftijd zijn jullie zeer betrokken bij de toekomst van onze planeet en wereld en jullie maken je eigen keuzes, met veel passie. Ik ben daar trots op en op de vele andere dingen die jullie drie fantastische jonge mensen maken. Jody, dank je wel voor jouw rol en je onvoorwaardelijke steun. Sommige relaties beginnen met een gemeenschappelijke interesse beroepshalve; de onze kwam wat dat betreft dichter bij elkaar in recente jaren, nu je werkt voor een hulp- en ontwikkelingsorganisatie die zich inzet voor de allerarmsten van onze wereld.

Ik heb gezegd

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Will mankind have enough to eat? And can this be realised with acceptable impact on natural resources and the environment? These questions require quantitative and integrated assessment at multiple levels: from field, to farm, region and globe. And they must be addressed for both short and longer time horizons. The role of a modern agronomy is to identify and quantitatively assess options and to integrate this knowledge with other disciplines. Options for future harvest must neither be myopic nor utopian.

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