

Food for all

Sustainable nutrition security

95 years Wageningen University

WAGENINGEN UR
For quality of life

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WAGENINGEN UR
For quality of life


GILA

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"In a world of plenty, no one – not a single person – should go hungry. I invite all of you to join me in working for a future without hunger." With this statement, Ban-Ki Moon launched the Zero Hunger Challenge. His plea touches the heart of Wageningen UR (University & Research centre) and very much reflects our mission 'To explore the potential of nature, to improve the quality of life.' Although hunger is directly related to food security, we are convinced of the need to move beyond that. Not only the production, but also the use and utilisation of food products are decisive for the effect of food on our health. Consumption patterns, determined by cultural, social and economic factors, need to be linked to production and processing systems in order to achieve nutrition security. This book illustrates how the research and education at Wageningen UR contributes to nutrition security, and demonstrates the commitment of our scientists to support the Zero Hunger Challenge with one of the most powerful instruments available: Science.

Wageningen University celebrates its 95th Dies Natalis in 2013. To mark the occasion we selected the theme Food for All: Sustainable nutrition security. This book provides an overview of the theme, followed by a number of illustrations from our research. As the theme is very wide and so many scientists contribute to it, we have made a selection that broadly covers the types of research conducted at Wageningen UR in this domain. A short indication of our education activities is given as well. At the end we give an outlook on future approaches based upon round-table discussions with Wageningen UR scientists.

This book intends to give you a flavour of how our research is addressing a vital challenge. I hope that you will be as inspired by reading it as we were by writing, and invite you all to interact with us and join forces to realise *Food for All: Sustainable nutrition security.*

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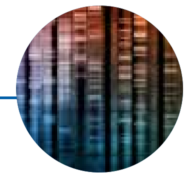

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Food for all

Sustainable nutrition security

The physical infrastructure to transportagricultural products to the market can also be limited.

Food is essential for the functioning of all living organisms. Energy is harvested from sunlight via photosynthesis by organisms such as flowers, crops and algae. The solar energy is stored as chemical energy in organic compounds. Non-photosynthesizing organisms, such as animals and human beings, depend on food for their energy. In addition to energy, food also provides other essential compounds such as the proteins, vitamins and micro-nutrients necessary for life. Livestock farmers decide to a large extent the mix of feed that animals consume, tailored to their requirements. In humans, the food choices made by consumers have a major effect on health and wellbeing, and the importance of a balanced diet is well-known.

Food security involves not only food availability but also food access and use. In other words, it goes beyond the production of sufficient food. This is illustrated by the fact that, while still working on the Hunger Challenge, we are simultaneously facing an obesity epidemic. Nutrition refers to the process involved from the choice and consumption of food up to its effects on health and well-being of individuals. The focus of this book, therefore, is not only on food but also on nutrition, hence the term *nutrition security*.

Apart from providing energy and nutrients for our basic functioning, food is also important in social life, rituals and celebrations. It forms a major component in all cultures and all structures of everyday human life, and plays a key role in the stability and development of societies. Our food supply is strongly linked to environmental issues. Crop production requires inputs like fresh water, fertilizer and pesticides to control weeds and pests. Animal production requires inputs such as fresh water, feed, vaccines to prevent diseases and medicines to cure diseased animals.

Agriculture is at the base of our food supply, but also yields biomass for other purposes like the production of bio-fuel. The total of food and non-food functions of biomass is often referred to as the bio-economy, and to achieve sustainable nutrition security, the food supply needs to be in balance with other functions of the bio-economy. This is not an issue of producing food or fuel but rather of producing food and fuel. Moreover, it is increasingly acknowledged that food production is only one of the many services provided by the ecosystem of planet earth. For instance, the ecosystem plays a role in protecting crops and animals from new emerging diseases.

Realising sustainable nutrition security is a central issue for the coming decades, containing a wide range of related topics. Many questions arise: How can we feed the world population in the future within the carrying capacity of our planet? What are the relations between food and health? How can we ensure sustainable food supply systems in different regions? How do we deal with climate change? How do we balance productivity and animal welfare? How do we share the benefits along the food supply chain? How do we integrate food production with other functions of the ecosystem? How do we implement innovations across the entire food supply system and how do we balance ecological and economic issues? How do we secure the safety of food? How do we ensure equity and equality when it comes to access to food? How do we allow for cultural varieties in food production and consumption now that the food system is homogenising? How do we balance power relations in food chains and networks so as to ensure access for all?

This serves to illustrate that technological solutions alone will not lead to sustainable nutrition security, and that social, cultural and economic dimensions also need to be considered. A number of these questions are addressed in this book. Although not intended to fully cover the activities of Wageningen UR, our hope is that by combining a description of general strategy with practical examples we provide a good picture of the contribution Wageningen UR intends to make to the future of sustainable nutrition security.

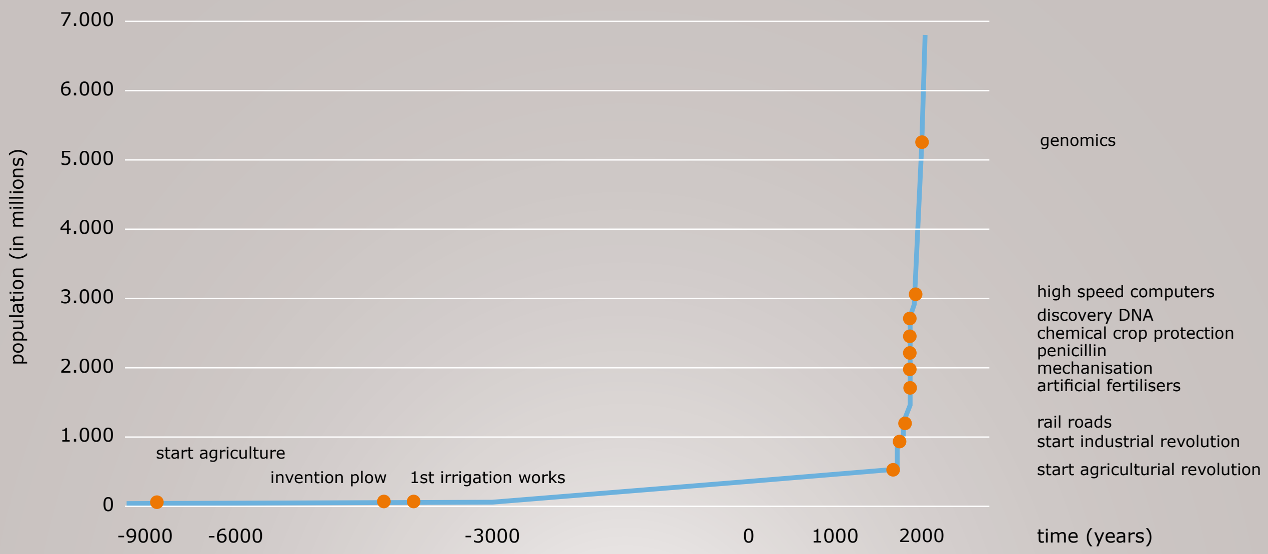
Food Production

From the very first beginning of agriculture, technological improvements and social innovations shifted offering a more effective way of collecting and producing food. Nonetheless, a recurrent question has been whether food production could keep pace with a growing global population. A major step was taken around 10,000 years ago when humans started to move from hunting and gathering to growing crops and keeping livestock. Over the last 150 years, major changes have taken place. Breakthrough technologies made it possible to produce more with less labour, enabling the world population to grow and enabling more and more people to work outside agriculture. During this period, agricultural production in the Netherlands increased by a factor of six to eight while labour productivity (i.e. production per fte) increased by a factor of more than 200. In addition, there have been major developments in processing and preservation which improved the efficiency of the food supply chain and increased its complexity.

At the end of the 18th century, Thomas Malthus warned for a population outgrowing the agricultural production capacity. He pointed out that while the population tends to grow on a logarithmic scale, food supply increases linearly at most, with the inevitable consequence that food supplies will run out. “The most enthusiastic speculator cannot suppose a greater increase than this,” Malthus wrote. Reality proved different, however, and productivity outstripped the population increase over the following century.

Almost hundred years later, the club of Rome commissioned the report ‘Limits of Growth’.

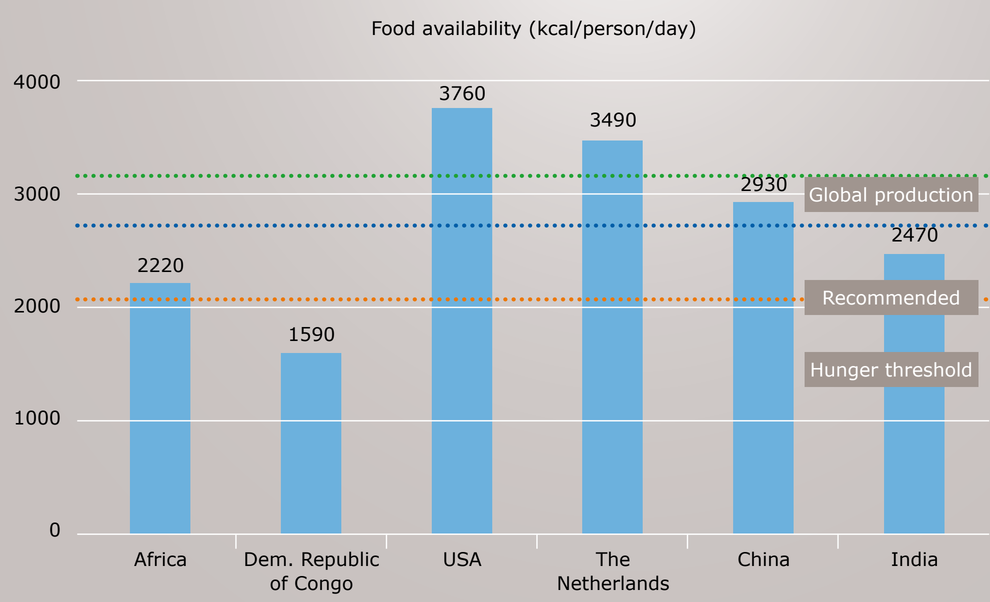
Growth of the world population and some major events in the history of (agricultural) technology



Adapted from: Fogel R. W., The Escape from Hunger and Premature Death (2004)

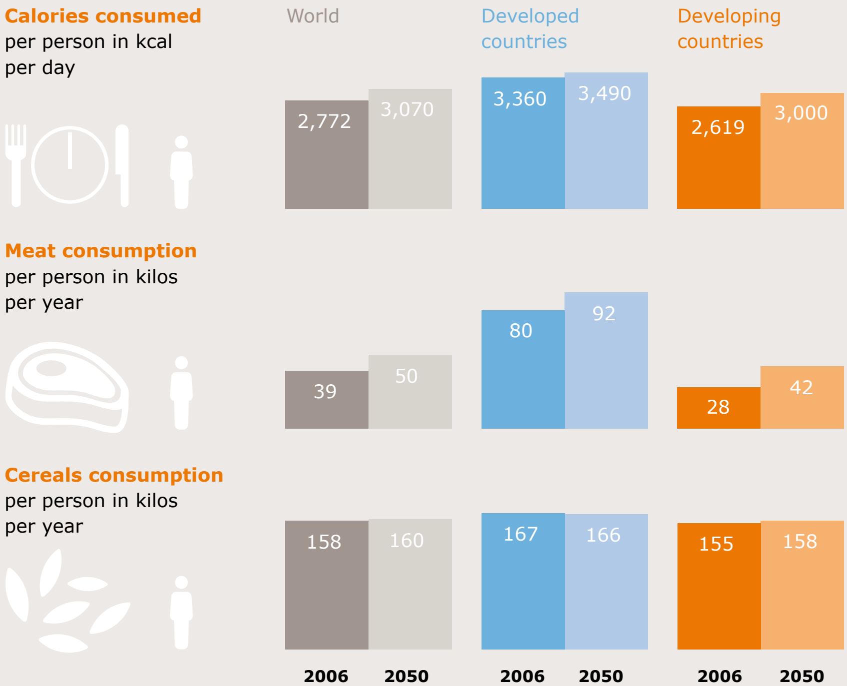
Global food availability

The Dietary Energy Supply (DES) in kilocalories available per person per day in various regions of the world. On average, global food production is enough to supply everybody with 2800 kcal per day, exceeding the average recommended energy supply. However, large regional variation exists.



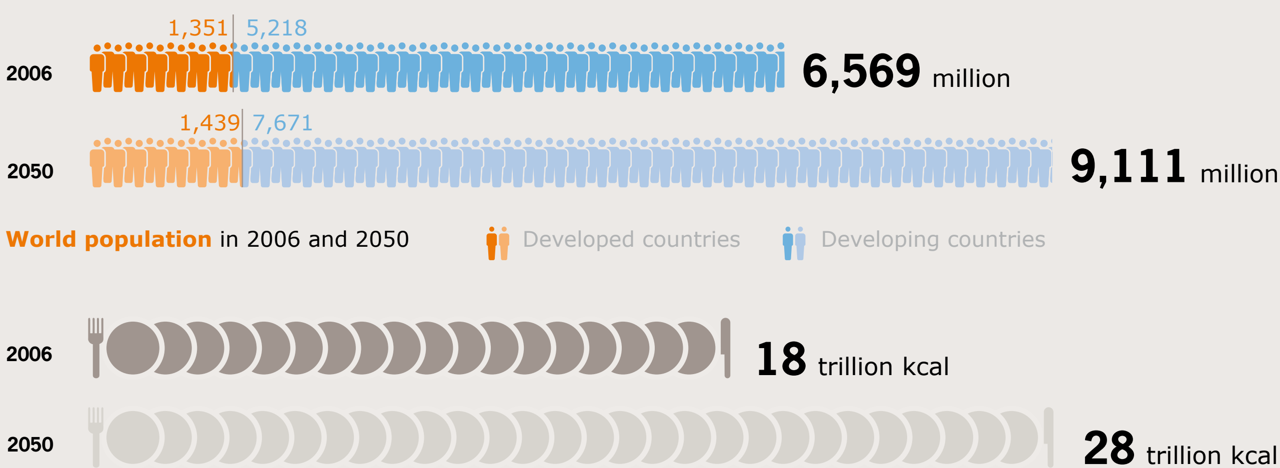
Source: FAOSTAT

Increase in consumption



Source: FAO 2012

Growing demand for food



Food consumption world population in 2006 and 2050, per day

Source: FAO

Published in 1972, it concluded in a neo-Malthusian way that *"If the present growth trends in world population, industrialisation, pollution, food production and resource depletion continues unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years."*
Once again, however, food production grew faster than anticipated by the scenario builders. This increase of productivity was the direct result of major breakthroughs like the invention of fertilisers by Liebig and the principles of genetics discovered by Mendel. The Haber-Bosch process by which atmospheric nitrogen can be transferred to ammonia formed the basis for the fertilisers we know today. The invention of vaccines to protect livestock and the development of pesticides to control pests, diseases and weeds contributed to improved productivity by reducing losses.

Mechanisation led to a considerable reduction of labour, and advanced nutrition for livestock improved feed conversion efficiency, especially in poultry, pigs, and dairy cattle. Effective institutions secured farmers' access to capital for investment, appropriate information for productivity improvements and efficient markets in which to sell their produce. As result, more food is available per person now than a century ago.

These developments may have a flipsite DDT, for example, was welcomed as a very effective insecticide, but turned out to have tremendously negative effects. After the later discoveries of less harmful but still effective compounds, the use of DDT was abandoned. An overuse of fertilisers in some parts of the world led to pollution and degradation of local biodiversity and contributed to the faster depletion of minerals such as phosphate. The use of antibiotics to protect livestock can lead to resistance in micro-organisms, which in turn threatens human health. Meanwhile, not all breakthroughs lived up to expectations. Growing public concern about the (potential) side effects of innovations was expressed through NGOs that aim for greater sustainability in food production.

Nutrition refers to the process involved from the choice and consumption of food up to its effects on health and well-being of individuals

The FAO considers Dietary Energy Supply (DES) to be a good indicator of food availability. DES reflects the food available for human consumption, expressed in kilocalories (kcal) per person per day. At the country level, DES is calculated as the food remaining for human use after the deduction of all non-food consumption such as exports, animal feed, industrial use, seed and wastage. Global DES increased almost linearly over recent decades, although there are considerable regional differences. In Sub Saharan Africa (excluding South Africa), the DES is substantially lower than the global average. Although the DES in Sub Sahara Africa increased over the last decade, this is not the case for regions with more than 35 percent undernourished people. Thus, while the overall food availability in this region tends to improve, the situation worsens in the most vulnerable areas.

DES only reflects energy, and does not take other aspects of nutrition into account. According to the FAO, almost two billion people suffer from some form of malnutrition. Vitamin and mineral deficiencies in children lead to stunted growth, blindness and compromised mental development, with iron-deficiency anaemia contributing to 20 percent of maternal deaths in Africa and Asia. Hungry, unhealthy people cannot be productive workers either, creating a vicious cycle of hunger and poverty. In contrast, overconsumption may also lead to problems. High energy intake and unbalanced diets may lead to chronic problems such as obesity, diabetes and hypertension. Again, it proves that nutrition security is far more complex than the production of food alone. It also concerns access to food, and the consumption of food that is safe and nutritious.

Food production does not solely involve land-based agri-production. The harvesting of seafood has been a major source of nutrition since ancient times and increased from 40 million tons in 1960 to 150 million tons today. Aquaculture is a booming agribusiness, increasing its production volume by 10 percent a year in addition to the limited seafood production capacity from fisheries. The share of seafood in global food production is expected to increase further.

Although nutrition security is much broader than food production, food security is a prime prerequisite for nutrition security. The FAO estimates that the world needs to increase its food production with 70 percent by 2050 in order to serve a global population of nine billion. Until now, the general picture has been that food production can keep pace with population growth, despite the existing hunger in several parts of the world which is mainly a problem of access. Agricultural productivity is very flexible, and man is creative in finding solutions for immediate threats. Agricultural production increased over the last century beyond expectations. Technological innovations resulted in discontinuities in productivity of wheat in Europe and the US in the 1950s and rice in Asia in the 1970s. But, within this historical perspective, what can we expect from our agricultural systems in the future?

Sustainable intensification

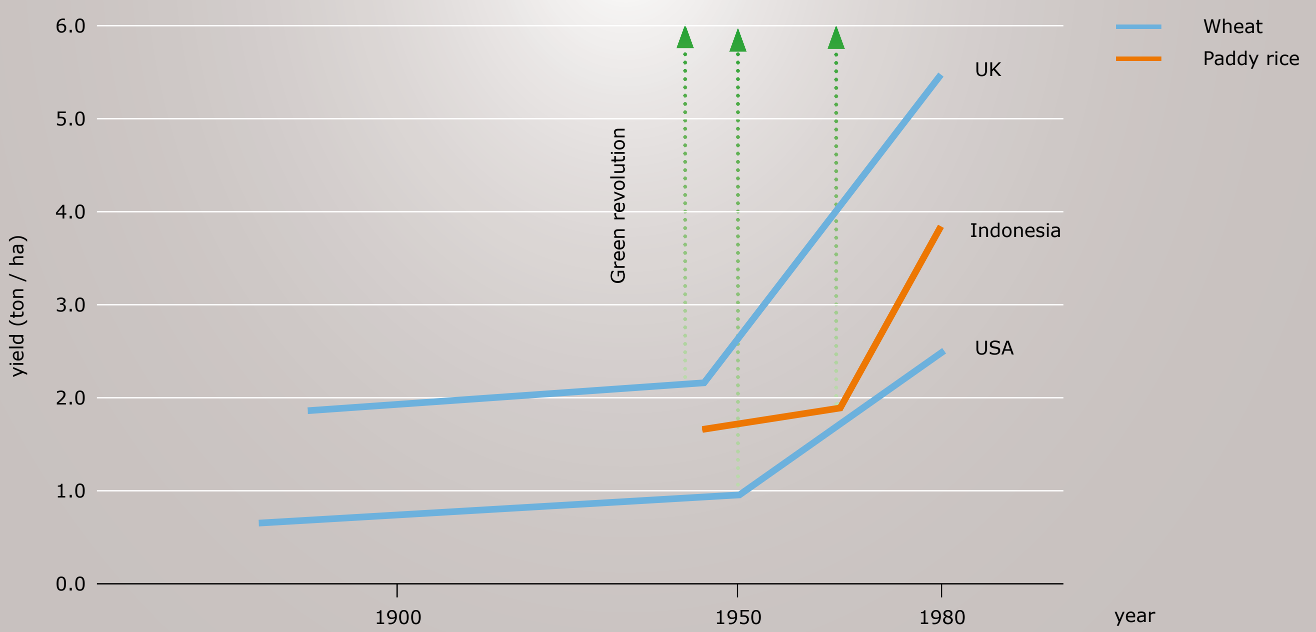
Several pathways can lead to a higher availability of food. Land reclamation for agriculture is an obvious way to go, but has limited potential. In contrast, the amount of available land tends to decrease as a result of urbanisation, desertification and population growth. Extending the agricultural area has only limited potential therefore – a more feasible approach is to increase global production on the same agricultural area: Intensification of our production. The capacity to intensify production varies. In some regions, the actual yield approximates the theoretical maximum, leaving little room for improvement with current technologies, so fundamental breakthroughs would be needed. In other regions, however, much can be gained with existing technologies.

Although beneficial from a productivity point of view, the green revolutions also caused problems. While inputs such as fertilisers and pesticides can boost crop production, they also impact the local environment, contribute to climate change and depend on non-renewable resources of minerals or fossil energy. Fertilisers require much fossil energy for their producion and affect the natural environment, making it necessary to be efficient. In addition, resources like phosphate are limited, necessitating an efficient use and recycling wherever possible. The environmental impact of pesticides should be minimised by using pesticides that break down fast. In several situations, a biological control mechanism has effectively replaced the use of pesticides. Organic farming shows how much can be achieved by using the natural fertilisers and control mechanisms offered by nature. Nitrogen fixing legume plants and manure from animals illustrate how nutrients can be obtained from sources other than fertilisers. Therefore, although productivity is of major importance, the challenge ahead is to increase the sustainability of our food production systems. Not *maximising* yield but *optimising* it in balance with other ecosystems services should be the focus. And that can be achieved by innovative pathways, rooted in science and technology. This book gives examples of ways to contribute to these ambitious goals. It calls for a sustainable intensification of our production systems, which is far more than just a matter of higher production per hectare or per animal or higher feed efficiency.

The relationship between livestock and food security is often portrayed by the media in emotional terms such as 'go vegetarian to save the planet'. It is not that simple. Livestock has positive impacts on 'the planet', not the least in the economy, with trade in live animals and animal products comprising 40 percent of the global value of agricultural output (FAO, 2009). Moreover, a billion poor people in Africa and Asia

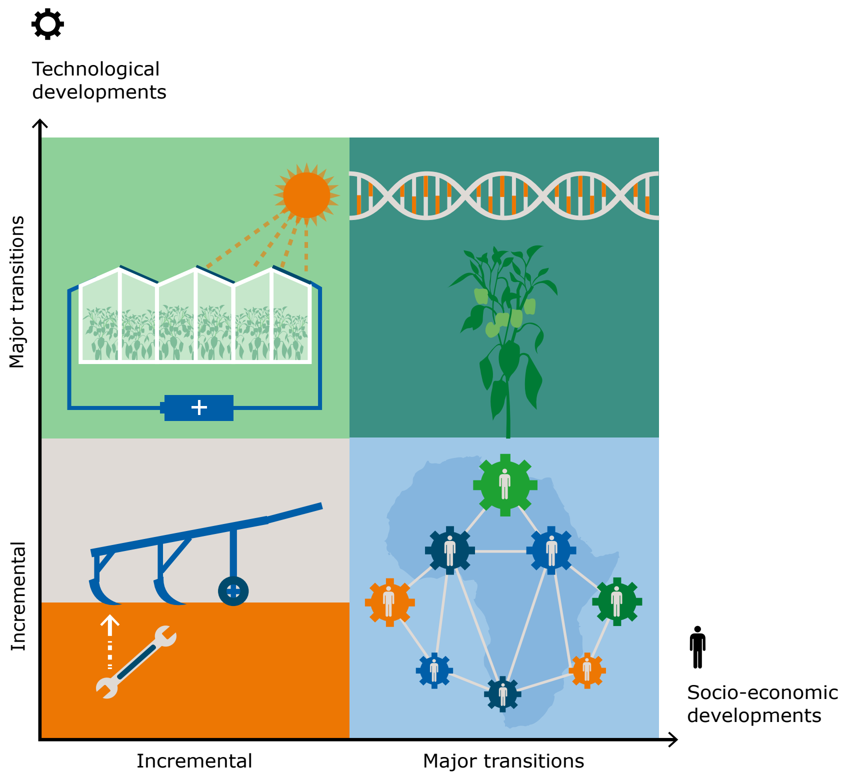
Discontinuities wheat yield (UK & USA) and yield of paddy rice (Indonesia)

Before the Green Revolution, the yield of wheat increased every year with 3-4 kg per ha due to agronomic improvements and the use of improved seeds. The Green Revolution boosted this increase enormously to 50-75 kg per year. This is visualised in the graph as a discontinuity, showing the yearly yield-increase before and after the Green Revolution in the UK and the USA. With some delay, the Green Revolution also affected South-East Asia, as illustrated by the discontinuity of the yield increase of paddy rice in Indonesia.



Adapted from: De Wit, Rabbinge

Successful innovations arise from a combination of technological and socio-economic developments



Considering that innovations may be either incremental or based on major transitions, and that socio-economics and technology need to interact to reach innovations, four quadrants arise. Some innovations call for major technological breakthroughs but easily fit the current socio-economic conditions. New greenhouses acting as power plants, for example, require major technological breakthroughs but are easily accepted by society. Some innovations are characterised by the opposite: The major challenge is socio-economic rather than technical. In Africa, for example, a lot of technology is available, but governance mechanisms and institutions are required for a new green revolution. Some innovations are incremental on both axis. These innovations slowly but steadily improve the food systems, and although not always clearly visible, have a major combined effect. The most visible innovations are those that require transitions on both axis. The use of genetically modified plants belongs to this latter category. Cutting-edge research increased the tool-box of plant breeders enormously, yet implementation relies on the application of and acceptance by society.

depend on livestock for their livelihoods. Animal feed production is increasingly competing for resources (land, water, and fertiliser) with human food and fuel production, urbanisation and nature. Combined with climate change (making production more volatile and harvests more insecure), this will increase feed prices and lead to a demand for livestock that can sustain productivity on diets with a lower nutrient density.

Our vision on the future of animal production is best reflected as 'livestock farming with care'. This involves an integrated approach that can be captured in a set of four principles: Health (healthy and safe for animals and humans), customised (from the individual animals' perspective), nuisance-free (from an environmental and societal perspective) and creditable (from a societal prospect). And this in turn requires research into the 'best ecological means' to reduce the ecological footprint and 'best animal health means' to prevent diseases (human and animal) and enhance animal welfare.

Food Systems

As argued, higher productivity by our agricultural systems is in itself insufficient for nutrition security. Food needs not only to be available, but also accessible and utilised to become effective. This is a matter of food supply systems, logistics and consumer behaviour in addition to production. We need to address food supply systems rather than production systems if we are to nourish a future world. Apart from food production itself, many other factors determine the food system. In the first place, up to 40 percent of our food is lost in post-harvest phases. In developed countries, this is mainly due to food wasted by consumers and retail. In developing countries, this is often a result of ineffective harvesting and storage systems. Another important factor is the existence of food chains that determine the availability for consumers. This may be a simple chain for subsistence farmers and farmers with small cash crops. Or it may be complex chains for farmers who are serving the local or world market in fresh products such as vegetables, cereals and potatoes or processed products such as dough, milk and sugar. These chains often have an international dimension and involve many stakeholders.

Food supply systems are also integrated with other functions of the bio-economy. Biomass will increasingly be used for purposes beyond food, including biofuels and bio-materials. Biofuel is a relatively low-value use of biomass and requires vast amounts of resources, competing with the production of food and feed. This application is therefore the source of much debate, especially where it concerns the direct use of food components for fuel, often referred to as first-generation biofuels. However, biofuels from non-food components may also jeopardise food production, as the production of the required biomass may compete with food production for scarce resources. The best way forward is to combine various applications, using all compounds of biomass in a smart way. This concept is referred to as bio-refinery, analogous topetro-refinery where all the components of crude oil are used in successive refinery steps. The non-food functions of the bio-economy are rapidly developing but highly dependent on technological breakthroughs.

Food chain

Food chain development, governance systems and co-innovation processes, however, need a strong scientific input from the social sciences. Complex trade and governance systems may easily lead to insecure markets, especially for commodities where national trade exceeds international international trade. Globally, for example, 650 megatons of rice is produced yearly, but only 10 percent is traded internationally. This is why food prices go up when shortages occur in some countries. In the recent past we had several peaks in prices that resulted in riots in countries where people spend more than half their income on food products. Particularly in developing countries, effective institutions are lacking to allow producers access to information, capital and markets for inputs and to sell their produce. The physical infrastructure to transport agricultural products to the market can also be limited. Investment in higher productivity will not lead to greater food security without addressing these other dimensions of food systems, including a stable political environment.

We are also witnessing a consumerist shift where decisions by consumers (and retailers) increasingly have consequences throughout the food system. Shifting consumer cultures, changing diets, demands for more sustainability in food and decisions on whether or not to accept particular food products, such as GMOs, cannot be ignored by the other actors in the supply chain. As this trend will only intensify in the future, decisions aimed at nutrition security need to actively take into account consumer viewpoints and their potential impact on the food systems.

The Wageningen Approach

As explained, food systems require concerted interventions in different domains. Interdisciplinarity is increasingly a guiding principle in education and research in our domain. This fits Wageningen UR perfectly and is referred to as the Wageningen Approach: Combining specialisation on the one hand with general knowledge on the other hand in our curricula ('T-shaped' skills). Wageningen therefore delivers academics who are experts in their own field while understanding experts in other areas.

Wageningen UR is a major player in the domain of bio-economy. The developments in this domain are spectacular and offer new opportunities for potential innovations. Our understanding of biology and the functioning of ecosystems also serves as an inspiration not only for the design of novel food supply systems or systems to combat emerging diseases, but also for bringing about changes in consumer behaviour. Inspired by biology and based on the latest scientific insights, scientists at Wageningen UR contribute to the improvement of the earth's ecosystem. Our understanding of socio-economic, cultural and political dynamics in a broad array of agro-food systems around the world serves as an inspiring resource for designing sustainable pathways to future food provision. Natural science approaches are therefore interlinked with social science approaches in these innovation pathways. We collaborate with others to realise our ambition and together open new pathways to solve the global challenges faced by us all. Joining forces will be the adage for the years to come, and Wageningen UR is dedicated to do so in order to meet the most challenging challenge of all: *Sustainable nutrition security*. ■

Education to see the bigger picture

Food and Nutrition Security at Wageningen UR

Food and nutrition security is a multi-faceted topic, many aspects of which can be studied in depth at Wageningen University. These include plant & animal production, agronomy, breeding, soil & water quality, food technology, nutrition, marketing & consumer behaviour, international development studies, and international land & water use. However, as you will read elsewhere in this book, nutrition security is the result of all kinds of actions taking place in complex food systems. This means that studying each aspect separately, while valuable in its own right, is simply insufficient.

The search for innovative food systems that increase food/nutrition security requires graduates who can grasp the complexity of the finer details while also being able to see the bigger picture. How do we achieve that? Tiny van Boekel, managing director of the Education Institute of Wageningen UR: "The so called Wageningen Approach offers a wide-ranging

The Wageningen Approach offers a wide-range solution

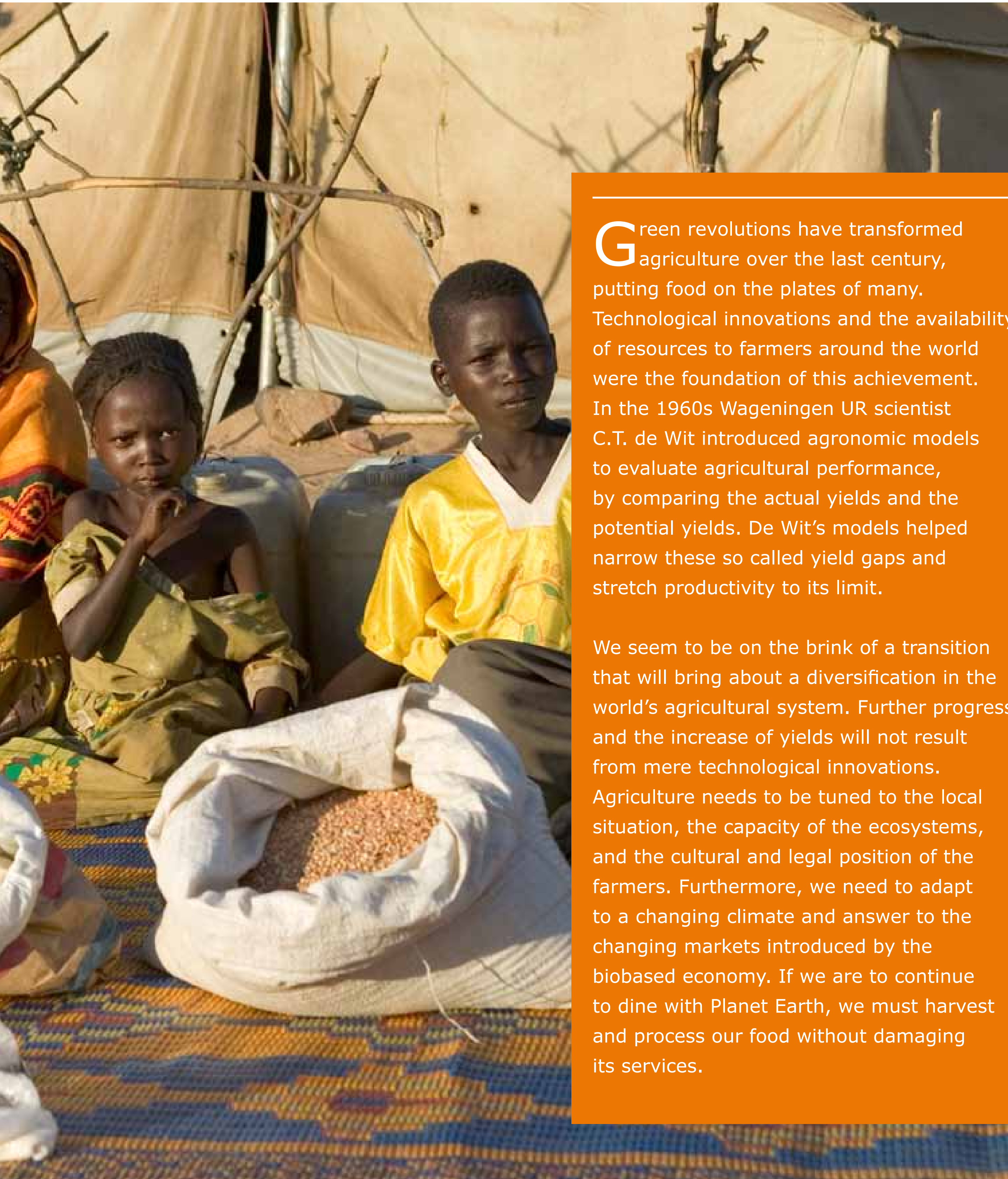
solution. It starts with a basic scientific training inrelevant courses, after which students are required to work together in projects where they look beyond their own specialisation ('T-shaped skills'). The Wageningen Approach is also characterised by a combination of natural and social sciences, both in research as well as in teaching. This is based upon our conviction that innovations have a technological and a social aspect, and both need to be taken into consideration.

A striking example is the course called Academic Consultancy Training where students from different disciplines work together on a societally relevant project. Many programmes also offer internships where students experience the complexity within real-life situations. In this way, we deliver graduates who are knowledgeable in their chosen specialisation, while also capable of communicating with other specialists and seeing the broader picture.

Wageningen University does not offer a programme called Food/Nutrition Security. Van Boekel: "As we have seen, food/nutrition security is a very complicated phenomenon and it is not possible to address the many different aspects in a single programme. We therefore educate students who become experts in their field and at the same time are able to combine this expertise with that of other experts and see the importance of involving both the social and the natural sciences in bringing about innovations."

Wageningen offers programmes for BSc, MSc and PhD degrees. Students can enter the programmes at all levels. MSc and PhD courses are given in English and contain global topics and intercultural aspects. As a result, some 40% of the MSc students and 60% of the PhD students come from abroad.

1 | Dining with Planet Earth



Green revolutions have transformed agriculture over the last century, putting food on the plates of many. Technological innovations and the availability of resources to farmers around the world were the foundation of this achievement. In the 1960s Wageningen UR scientist C.T. de Wit introduced agronomic models to evaluate agricultural performance, by comparing the actual yields and the potential yields. De Wit's models helped narrow these so called yield gaps and stretch productivity to its limit.

We seem to be on the brink of a transition that will bring about a diversification in the world's agricultural system. Further progress and the increase of yields will not result from mere technological innovations. Agriculture needs to be tuned to the local situation, the capacity of the ecosystems, and the cultural and legal position of the farmers. Furthermore, we need to adapt to a changing climate and answer to the changing markets introduced by the biobased economy. If we are to continue to dine with Planet Earth, we must harvest and process our food without damaging its services.

Innovation involves more than technology alone

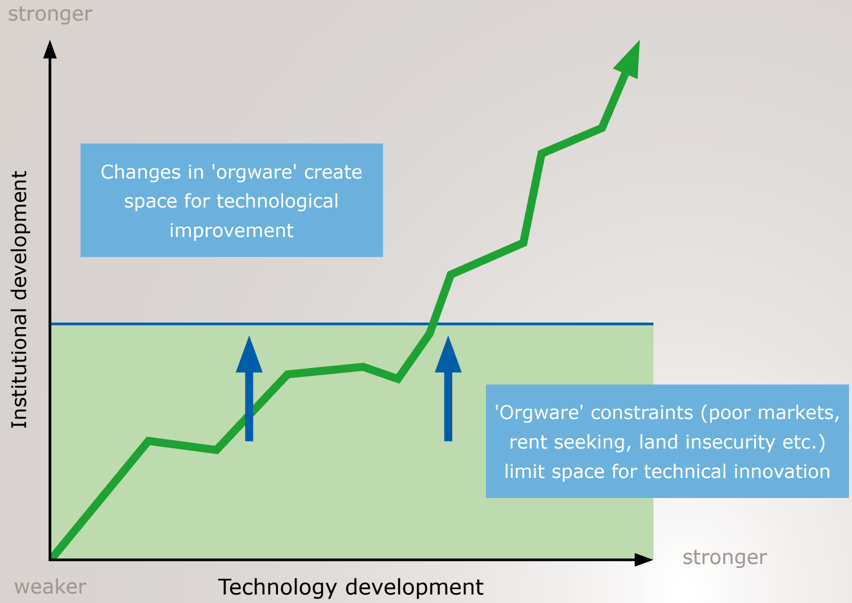
Innovation is often associated with technological improvements. Cees Leeuwis, professor of knowledge technology and innovation looks beyond the *hardware*, and points out that new technology only works when it fits within a shared way of thinking and future vision (*software*) and is supported by new rules and organisational structures (*orgware*). "There will be no innovation if the software and orgware do not co-evolve together. Innovation has to be grounded and rooted in society, where the actual changes take place."

"Problems with food security are often related to orgware issues. Technologies to improve soil fertility – for example by means of artificial fertiliser or crop rotation – assume that farmers can and wish to invest in the land. Poverty always plays a role in preventing investment, as does the way access to the agricultural land is organised. In Africa, for instance, a lot of land is leased via short-term agreements or borrowed from family. The resulting insecurity makes investing in the land a tricky issue. If I didn't know whether I would be able to reap what I'd sown, I wouldn't invest my money either. In this case, yield gaps aren't soil problems but an issue of land rights. Improving soil fertility can only be achieved by experimenting with alternative lease or tenancy contracts that are based on a longer time span, including associated systems for settling disputes. If that is unsuccessful, one could consider optimising production systems in the short term."

"Improving food security therefore not only requires investments in the development of technology, but also in the processes required to develop new shared future visions and orgware. We must remember that our own, much renowned high-productive agriculture was partly developed as a result of far-reaching land reforms, subsidies, import limitations and a strong focus on collaboration within the sector. It is a misconception to think that development can be stimulated by simply

Agricultural innovation

Agricultural innovation as a co-evolution of 'hardware' (technology) development and 'orgware' (institutional) development (adapted by the 'Convergence of Sciences – Strengthening Innovation Systems' programme from A.J. Doward, J. Kydd and C. Poulton (1998). Smallholder Cash Crop Production under Market Liberalisation: a New Institutional Economics Perspective. Wallingford: CABI International).



transferring or exporting our knowledge and technology. It revolves around new ways of organising and coordinating people."

Mouldable world

"Another persistent misconception is the idea that innovation and development can be planned and predicted. The idea that we live in a mouldable world. This is reflected in the way we traditionally organise and evaluate development projects. Most programmes are still characterised by clear-cut goals, detailed step-by-step plans and evaluation protocols that are focused on simple cause-and-effect relations. The reality is far more complex. The world consists of intricate social and biophysical systems and networks that influence each other via countless interactions. This leads to unpredictable dynamics with often unintended consequences."

"Stimulating food security requires organising a process of continuous adaptation to new conditions instead of linear projects. Additionally, history has shown that innovation involves a competitive and evolutionary process in which multiple options and futures compete in a selection environment and the 'best fitting' wins. This is not necessarily the most advanced option technologically. It may also be the option that best suits the socio-economic conditions. Most potato farmers in East Africa, for example, cannot afford new pathogen-free seed potatoes due to the level of investment required. It seems a better option therefore to improve the selection of their own seed potatoes. A simple solution, but one that escaped attention for a long time because it was seen as outdated technology."

In Africa a lot of land is leased via short-term agreements or borrowed from family

Multiple options

"Although existing knowledge and technology can fail to any longer meet a given transitional context, that does not mean we should dismiss them as outdated. From the perspective of adaptation it is often wise to back multiple options. It is important that we organise people around a variety of technical and socio-organisational experiments; not in a laboratory but at various levels in daily practice. This means bringing people and disciplines together, studying the environment, clarifying questions, developing visions and learning what happens in these experiments. Well-trained innovation intermediaries – brokers and links between people and expertise, as it were – can support these processes. Experience has taught us that these professionals can make an important contribution, and luckily this is recognised by many. There are now many experiments with innovation networks and R4D (research for development) platforms, and this creates a wealth of opportunities for scientists to become involved in transition processes and increase the chance of having a positive impact." ■

Due to the level of investment required,it seems a better option for farmers in East Africa to improve the selection of their own seed potatoes.

Smart agriculture as adaptation strategy

Few scientists now doubt the existence of the enhanced greenhouse effect and the fact that human activities affect climate is also rarely disputed. As the consequences on food security and the distribution of these effects around the globe are studied, scientists at Wageningen UR are using their knowledge to develop climate-smart food systems capable of withstanding the most likely climate changes.

The intense social debate about climate change pays little heed to the actual scientific basis. Partly due to the 'disclaimers' in the societal debate, scientists are unable to ensure that the high degree of consensus that exists within the scientific world, plays a dominant role in the political decision-making process. The result is that international measures to mitigate the human production of greenhouse gasses are unlikely to be taken soon. The climatic consequences will soon become clear, especially in countries where the infrastructure and food supply is insufficiently prepared.

A smart strategy for farmers is to adapt to a future with more extreme weather conditions, but these conditions remain uncertain. To build a clearer picture and translate the climate developments into local practice, Rik Leemans, professor of environmental systems analysis and his group are developing various models and scenarios in which global models are linked to specific local conditions such as hydrology, existing agricultural practices, consumption patterns, social structures, local markets, infrastructure and government policy.

Extreme surprises

The interaction between weather extremes and agricultural systems is the main topic of these model studies. Higher temperatures and more CO_2 in the atmosphere appear to have a positive effect on the growth possibilities and, therefore, potential agricultural yields. But what are the effects of other

The interaction between weather extremes and agricultural systems is the main topic of the modelstudies.

stress factors caused by climate change? It is interesting to see how existing agricultural systems respond to extreme conditions. Remarkably, research by Wageningen UR has shown that in an extremely warm and dry year (2003) the negative effect is greater on large-scale, high-tech agricultural regions in Northern France and the Netherlands than on the small-scale and varied Italian landscape. This is not in line with the theory that northern countries could benefit from global warming, while countries closer to the equator would experience mostly negative consequences. It seems that the way agriculture is organised has a substantial impact on its resilience.

Wageningen UR is involved in two major, globally coordinated research programmes into adapted agriculture and food systems: Future Earth, a ten-year programme by the International Council for Science, and Climate Change Agriculture and Food Security (CCAFS) from the Consultative Group on International Agricultural Research. CCAFS has programmes in Vietnam, the Hindu Kush region (India, Bangladesh, Pakistan, Afghanistan, Nepal, Bhutan, Sri Lanka and the Maldives), East and West Africa, and South America. The core of the programme is to acquire local knowledge and achieve concrete improvements by taking specific actions in agricultural practice that will make them more resilient now. This practical knowledge is widely shared to develop new insights and innovative changes that can be made more widely applicable at a later time. An added benefit is that food security and agriculture are now included on the global and climate agenda.

Adaptability is essential

It is important that the vulnerability of the local food systems is recognised. Integrated research into water and carbon (CO_2) management, food production and public health are being performed to build a clear picture of this vulnerability and the influential factors. In this approach food security is a connecting theme. Assuming that climate change will result in more extreme conditions, adaptability is essential to maintain food security. In areas that are expected to experience considerable drought, the system must be made more resistant using crops that require less water. Vice versa, we can develop systems that can cope with a higher risk of precipitation, flooding or saline penetration in the soil.

Although the CCAFS programme is still new, the first experiments have already been set up. In Burkina

Faso and Mali the scientists will visit the villages to experiment with cultivation that is expected to correspond with the local climate. On the often dry and nutrient-deficient fields they will plant millet seed in small holes mixed with animal compost, combined with small trees that can fixate nitrogen from the air. This should result in fields with growth potential, roots that retain more water and shade, making them less vulnerable to drought and heat. To assess whether this local approach can lead to an attractive system that could make Sub-Sahara Africa and other regions more resilient, the scientists will analyse the global results within the CCAFS programme to see how they correspond with the developed climate models.

Local approach

There may not be any standard solutions, but regions can learn from one another. For example, Vietnam, with its specific delta problems (high precipitation, infiltrations, saline penetration) and a food system with fish farms and rice cultivation in flooded fields, requires different solutions than Burkina Faso or the Hindu Kush region. The shared factor is the local approach, and in many countries it has resulted in considerable enthusiasm among locals.

With regard to the scientific aspects, combining the regional studies with climate-change scenarios provides insight into the possibilities of a food system approach. The approach enhances the understanding of the interactions between food security, environmental stress and other local factors. In turn, this provides a clearer insight into the decision-making processes and policy options.Eventually the research is intended to form a basis for local food and agriculture policies that can withstand the various conditions that may result from climate change. ■

It seems that the way agriculture is organised has a substantial impact on its resilience

Vietnam has specific delta problems and a food system with fish farms and rice cultivation in flooded fields.

Food as a service from nature

Nature enables people to produce food. In addition to food, ecosystems provide us with many other 'services' such as fresh water and clean air. These are known as ecosystem services.

Ecosystem services are interconnected. An emphasis on food production can come at the expense of another service. The proper functioning of the entire ecosystem is important for food production. By bringing the food supply in balance with other ecosystem services, we can help enhance the overall sustainability of the system.

Food supply in the ecosystem service approach is a provisioning service, as are fresh water and clean air. Other ecosystem services are needed to ensure the delivery of these essential products in a sustainable way. Supporting services such as soil formation, nutrient cycling and the pollination of crops; regulating services such as the regulation of air & water quality and pest & climate control; and cultural services such as the development and exchange of seeds, varieties and breeds, food cultures and spiritual values that express connectedness with the land.

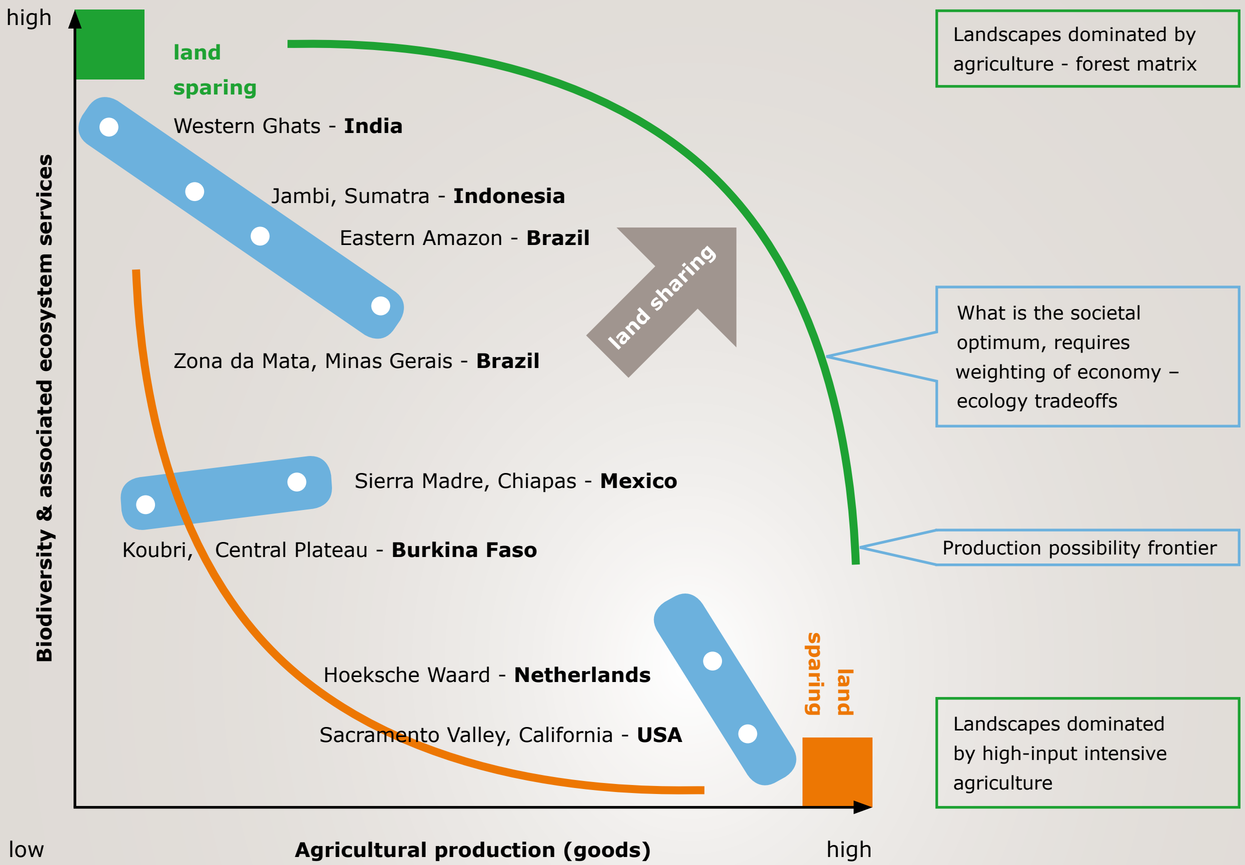
Land sparing

A prevailing view is that concentrating food production on the most fertile lands is a winning strategy, whereby focusing the highest possible production in a limited area would coincide with nature preservation elsewhere – so-called land sparing. To optimally use an area for food production, however, we must also treat other ecosystem services with respect. These services can be overloaded or damaged – they sometimes already are – if increasing food production is the main focus. Maximising the utilisation of an area for food production often goes at the expense of biodiversity , sometimes causes water scarcity or floods, and can leave the pollination of crops at risk. Conversely, if we consider biodiversity and the protection of existing ecosystems as an absolute aim, food production can be endangered. Both forms of specialisation then lead to suboptimal situations.

Pollination of crops is an ecosystem service.

Agricultural landscapes

Eight agricultural landscapes clustered according to level of contributions to agricultural production and biodiversity & ecosystem services, based on the mix of assets of financial, natural, physical, human and social capital.



Modified after Jackson LE, Pulleman MM, Brussaard L et al. (2012) Global Environmental Change 22: 623-639.

Intensive agriculture with border strip sown to a mix of flowers to attract pollinators and natural enemies of crop pests.

For sustainable food production, we must recognise the tradeoffs between services and seek synergies among the wide range of ecosystem services. As part of a global consortium, Lijbert Brussaard, professor of soil biology and biological soil quality has investigated the effect of different combinations of preservation and utilisation (land sharing). The scientists looked at eight different landscapes featuring different types of agricultural production. The study shows that some areas have a relatively high natural quality and marginal food production, whereas others allow high food production with a limited ecological quality. Some areas are a problem because they score low on both scales (under the orange line in the figure). The scientific challenge is to achieve ecological intensification (along the green line in the figure), where areas score as highly as possible on both scales. Developing new and existing agricultural systems in these areas requires much more knowledge about the structure and functioning of natural systems than earlier such initiatives.

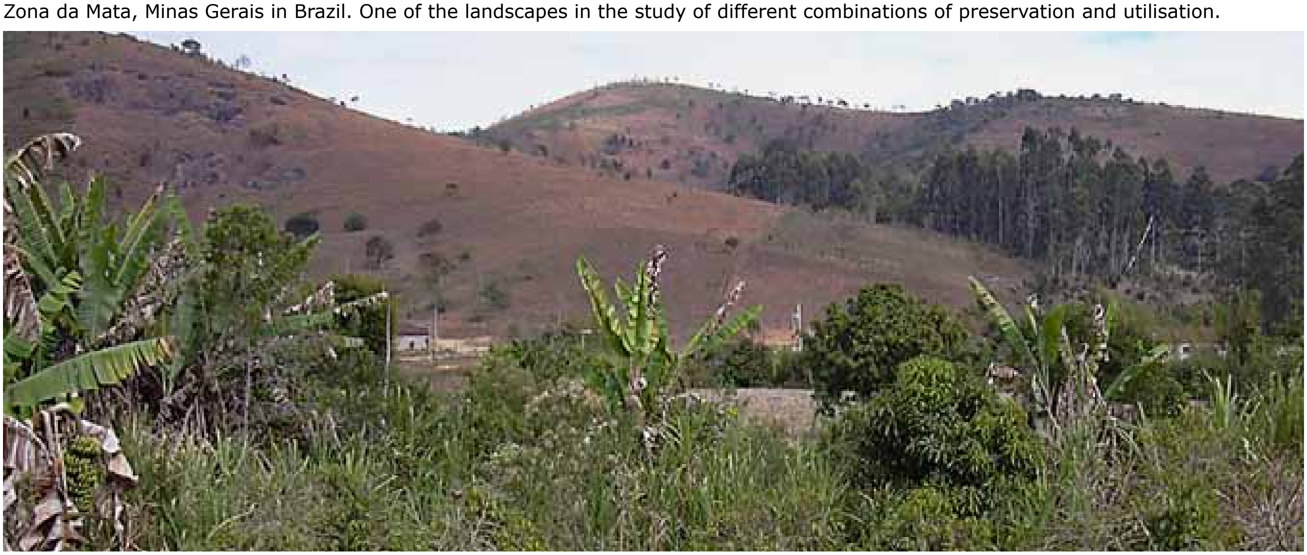
Blending ecosystems?

Ecological intensification does not mean a total blending of natural ecosystems and food production. Protected areas remain essential for the preservation of the majority of organisms on the planet, and introducing production systems which would threaten other ecosystem services must be avoided there. Ecological intensification is a particularly interesting challenge in areas where biodiversity and ecosystem services are degraded.

Maximising the utilisation of an area for food production often goes at the expense of biodiversity

The potential scale of land sharing is highly dependent on the local situation and the input of the stakeholders. Scientifically, we look for those combinations of ecosystem services which offer optimal yield. Armed with this knowledge, and based on their cultural background, local stakeholders can choose their own preferred combination and find a smart way to produce sufficient healthy food in a sustainable manner. ■

Zona da Mata, Minas Gerais in Brazil. One of the landscapes in the study of different combinations of preservation and utilisation.



Agricultural economics and rural policy

Soaring food prices frequently dominate the world news. High prices are often associated with increasing hunger and reduced nutrition security. The relationship between food prices and security varies with time and place, however.

Food prices are determined by supply and demand. Supply and demand, however, hardly react to price changes, both are price inelastic.Conversely, small shifts in demand or supply lead to substantial changes in market prices. As demand increases – through population growth and higher disposable incomes – prices rise very quickly. The same is true if the supply decreases, for example as a result of crop failures.

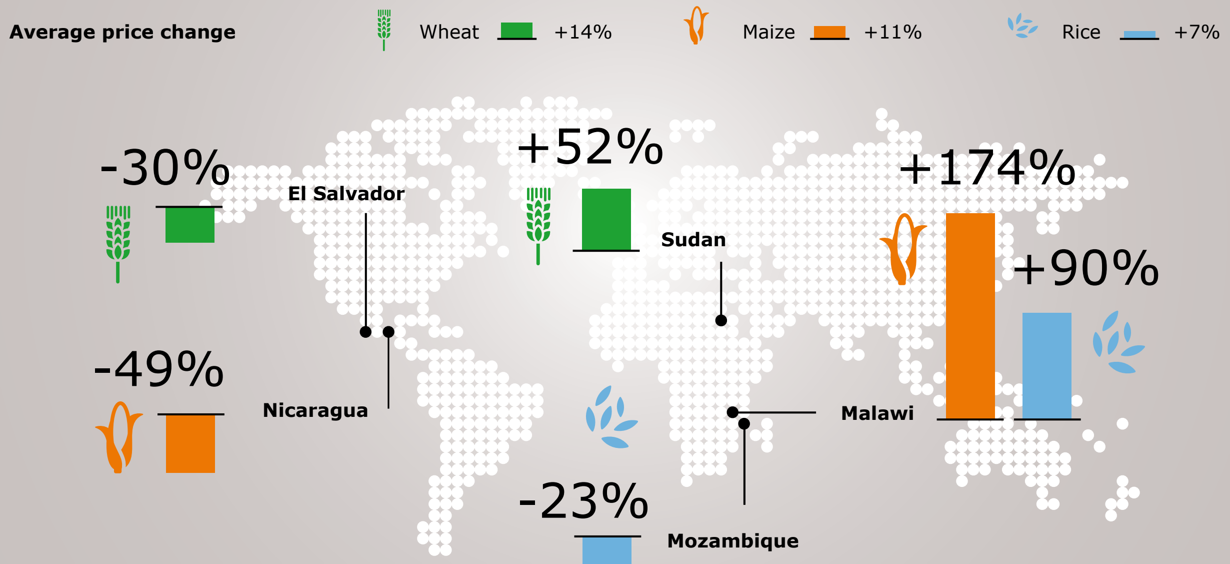
Reversed process

Food production has grown faster than global food demand over the past 50 years, explaining the downward trend in food prices up to 2000. However, since early 2000s this process has reversed. The export price of some conventional crops has approximately doubled between 2003 and 2008, according to figures from the FAO. This is not due to lower production. The FAO and the OECD expect that the increase in food production (2.3 percent per year) will remain ahead of the world's population (1.0%) until 2021. Other drivers of demand growth, such as increases in wealth and demand for biofuels and livestock feed, are therefore important explanations for the observed price increases.

The effects of fluctuating food prices are not the same for every country and individual. When the prices of maize, wheat and rice rose sharply in 2008, there were worldwide protests, leaving several dead and wounded in places such as Cameroon. In Haiti, Egypt, Mauritania and Mozambique, demonstrations against high food prices led to looting and clashes with the police. Thailand and Pakistan deployed the army to monitor food warehouses. High food prices caused hunger and poverty in these low-income countries.

Things remained quiet in our region, as in the rest of the developed world, where the amount that people spend on food is relatively low. In the Netherlands,

Changes in the price of food crops
at various locations around the world between July 2011 and July 2012.



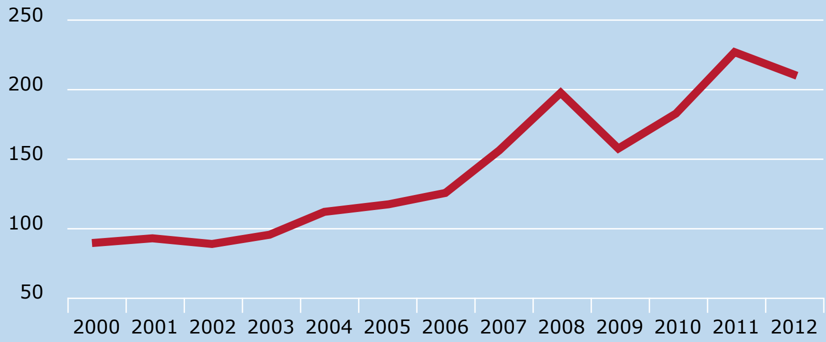
Source: FAO and GIEWS, 2012

Growth food prices

There are several different indicators for world food prices. The FAO and the World Bank both regularly publish statistics, including a food price index based on export prices of a number of commonly traded food crops. Both institutions report for 2012 that food prices are about as high as they were in 2008. That is twice as high as the average between 2002 and 2004. The World Bank reported record prices for maize and soya this summer of 2012.

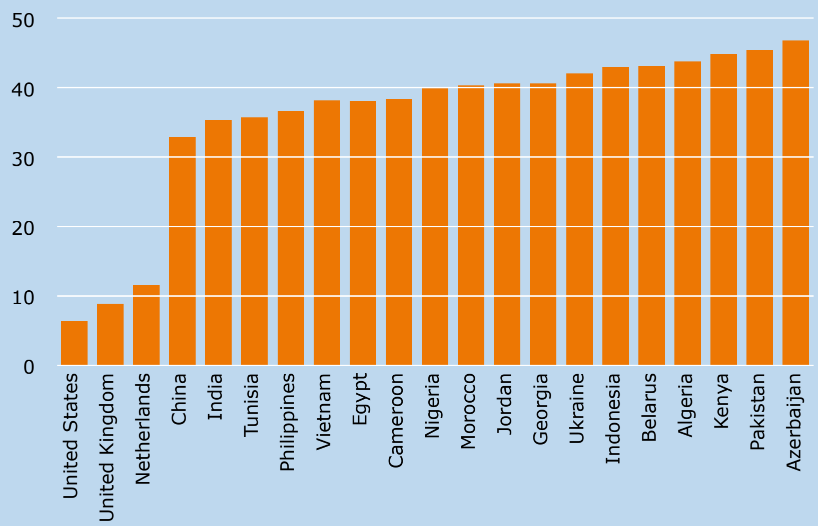
Food Price Index

an indication of relative international world food prices.
2002-2004 = 100



Source: FAO

Percentage of income spent on food



Source: USDA, 2011

about 14 percent of our total household budget is earmarked for food. Moreover, the cost of primary foods – grain, sugar, etc. – only partly determines the price of the final product. Marketing, transportation, processing and trading costs are all important components of the consumer price. All of these elements dampen the impact of prices on the world food market. The increased use of food banks in Western countries is largely the result of other problems, such as a loss of jobs and income, high housing costs and debt.

Consuming less

In developing countries, poor households spend a large part of their income on largely unprocessed food. People thus respond to higher food prices by consuming less food or skipping more expensive and nutritious foods, such as meat and vegetables. They base their diet increasingly on staple crops like grain and sugar. (Food) poverty in these countries varies geographically. Local conditions – harvest, stockpiling, policies – determine the food prices, which are not always in line with the world market and prices. Research of Koos Gardebroek, associate professor of agricultural economics and rural policy, shows that, even within a region, prices may react differently to global price fluctuations. The further a place is from major commercial centres, the greater the impact of local conditions. This may mean prices rise or even fall less rapidly. However, it can also cause the price shock to be that much greater.

The magnitude of the differences in price fluctuations was established in research by the FAO. While the price of rice, maize and wheat on the world market increased by 7, 11 and 14 percent respectively between 2011 and 2012, the price of rice increased by 90 percent in Malawi and fell by 23 percent in Mozambique. Wheat was 52 percent more expensive in Sudan and 30 percent cheaper in El Salvador. Maize costs 174 percent more than a year earlier in Malawi, while its price fell by 49 percent in Nicaragua. The overall impact of the global price on the prevention of hunger appeared limited, partly because local prices barely changed in China, India and Indonesia.

Price effect biofuels

In addition to supply, demand is also relevant. In this regard economists do not just look at the current situation in the food market. Although the exact effect is difficult to determine, speculation – i.e., the trader and the farmer agreeing on a price before the harvest, giving the farmer security and the trader an opportunity for higher profit – can have an impact on food prices as well. A minor part of the increase in demand is currently driven by biofuels. Food crops such as maize and sugar are used for the first generation of biofuels (the proportion of the food crops being converted into energy is relatively small, however). Since this market is growing – due among other things to compulsory requirements by governments in Europe, the US and Brazil – it creates an upward pressure on prices.

The negative effects of high food prices – poverty, hunger, political unrest – have a flipside. Medium-term nutrition security may benefit from relatively high food prices, as they encourage farmers to increase production. Furthermore, as farmers profit from higher yields, they can invest in fertiliser and other inputs to increase production. It also becomes more attractive to use fallow land. In the long term, high food prices can lead to increased spending on R&D in agriculture as it is expected to be recouped quickly. ■

In the Netherlands, about 14 percent of our total household budget is earmarked for food

Biobased economy: getting more out of biomass

Agriculture and nature management are increasingly linked to other economic sectors through the development of the biobased economy. Deploying green raw materials (biomass) as components in chemical products and in energy production opens a whole new world of possibilities for the use of biomass and the gradual replacement of fossil fuels (coal, oil, natural gas). But how do we guarantee food safety in such a biobased economy?

The new biobased production-consumption chains start with plant production of biomass in agriculture, horticulture and forestry, and with the organic waste released during agricultural production and nature management and in household waste. These green raw materials can be processed into components for food, feed and biobased products (chemicals, materials and energy) through biorefinery. The attraction of this approach is that it makes use of as much of the plant as possible. Naturally, this requires that sufficient plant material always be available as green manure in order to maintain the quality of the soil.

New biorefinery

Using biorefinery technology currently in development, the rich complex composition of biomass can be con- verted into a wide range of products. New biorefinery processes strive to use the complex (molecular) structures of biomass in the best possible way. The available functional compounds can then serve as chemical building blocks for semi-manufactured and end products. The main difference with petrochemical refinery is that molecular structures are not completely broken down to the simplest small molecules, which then need to be made functional again. In biorefinery, however, the functional groups remain intact, which saves energy and power consumption across the production process.

Wageningen UR provides an important contribution to the development of the biobased economy in an integrated manner. In this context, Wageningen UR cooperates with knowledge users, work on new custom crops, and develop new biorefinery process technologies together with industry. We also generate knowledge for use by policymakers and support the public debate with factual information. Our knowledge users are both governments and international companies in the chemical industry, materials production & processing, electricity & fuel production, and the agricultural, food and horticulture sectors.

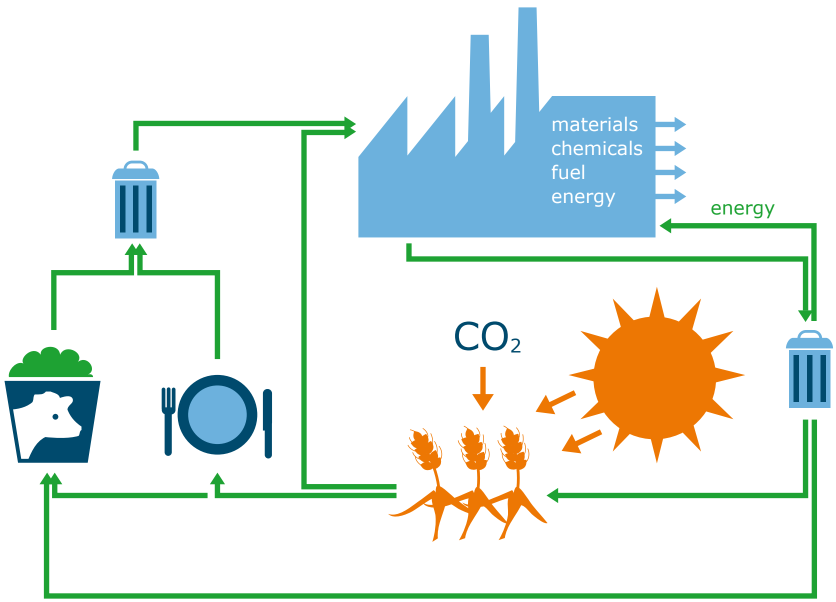
Within the Biobased Economy research programme of Wageningen UR, the biorefinery concept connects the various biomass sources, conversion processes and chain development to the various applications. Biorefinery and biobased value chains are developed and applied at a local, regional, national and global scale. Wageningen UR charts the opportunities and barriers on each level and develops the technological knowledge required to achieve new biobased value chains. This knowledge development and the related opportunities and restrictions, are relevant to technology, logistics, process-related product development and the economy, as well as in the field of social embedding. Sustainability issues always play an important role and there is a necessity for extensive cycle closure in all cases.

New biorefinery processes strive to use the complex (molecular) structures of biomass in the best possible way

Optimised cooperation

The development of the biobased economy will be finalised through the production and sale of biobased products. This will ultimately occur via optimised cooperation between the production of food, feed, biobased chemicals, materials, biofuels and energy. This is why Wageningen UR's R&D programme is focused on innovation and market implementation. Many scientific questions involving biorefinery, bio-based chemicals, materials & energy, specific crops and soil quality are relevant within this R&D programme. There are also issues related to economic knowledge: Economic feasibility and development of business cases, competing claims, changes in land use, and environmental issues such as the development of sustainability indicators, related greenhouse gas emissions and risk assessment for new biobased chains. In terms of food production, economic development constitutes an important issue. While food and feed have a high value in the sustainable biobased value chain, there is also a large and growing market for other biobased applications. It is necessary to ensure that sufficient biomass is produced and available for food. The task for agricultural and horticultural producers is to realise a level of production of a sufficiently sustainable and high quality to satisfy current and future food needs. At the same time, the sector faces the challenge of optimising the production of biomass to allow the greening of the fossil fuel economy. Wageningen UR supports this process, among other things as a co-developer of production in integrated biorefinery concepts, where non-edible components and residues are processed into quality products in chemicals, materials and energy production.

Biobased economy

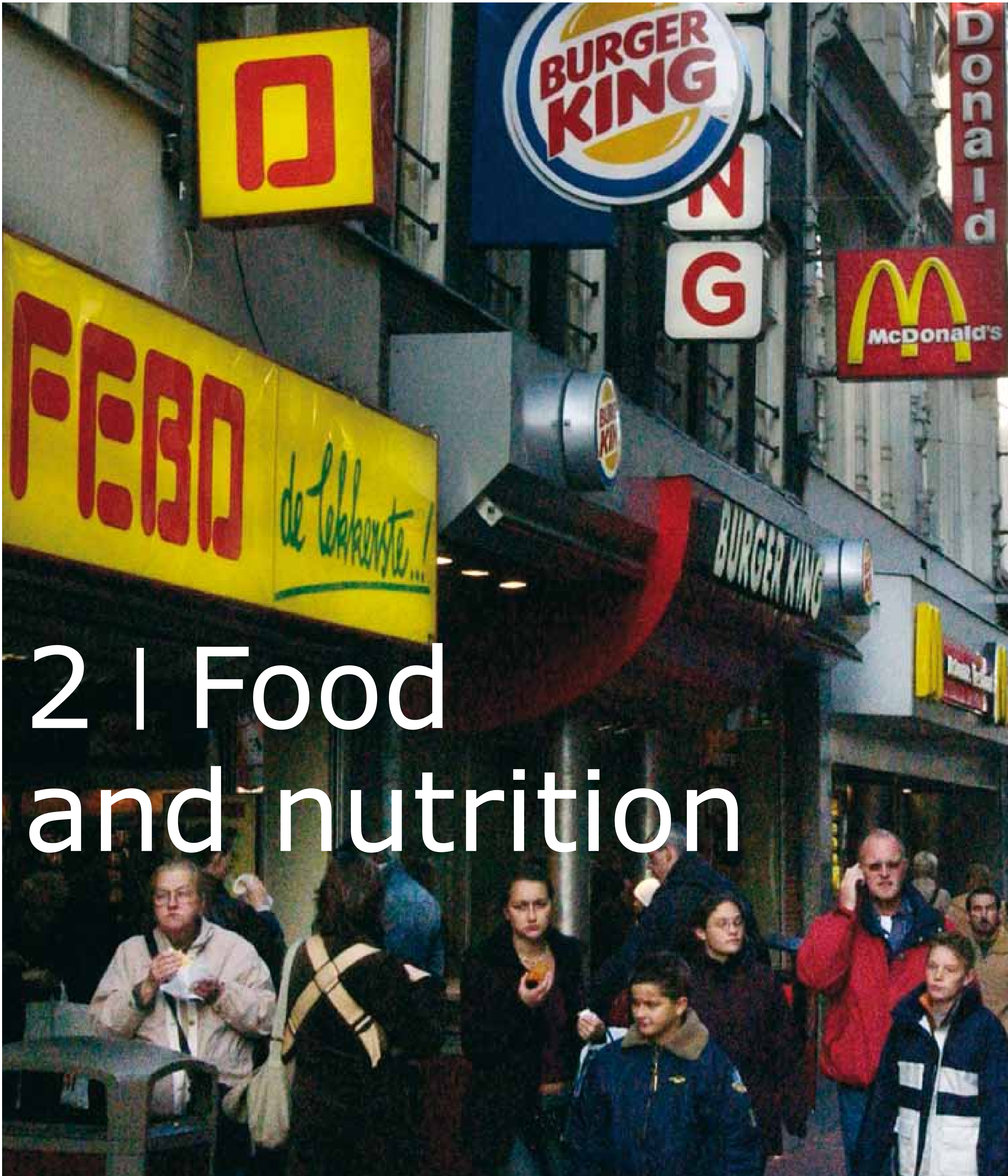


The Biobased Economy is an economy in which food, feed, chemicals, materials, transport fuels, electricity and heat are produced economically and sustainably from green resources: resources that are renewable.

Biofuel production

Lignocellulose-rich crops, such as the fast growing miscanthus, produce biomass suitable for refinery processes.

2 | Food and nutrition



Not everyone on Planet Earth has a well filled plate. Malnourishment comes in three forms: Hunger, hidden hunger and overweight. Some people consume enough calories yet lack essential nutrition. This hidden hunger makes it necessary to improve agriculture and processing to add minerals and vitamins to daily diets. On the other hand, some people who do have access to top-quality food develop diseases such as obesity. They eat too much fast food or have distorted digestive systems. This requires an improvement of food processing, the composition of our diets and our knowledge of the human digestive system. We already know that enough is not always enough. How can we make people eat good food and give them the guts to digest it?

Unravelling dietary patterns

It's the intake that matters

Availability of and access to sufficient and healthy food is often considered the foundation of nutrition security. Ultimately, however, it is the use and utilisation of this food that is decisive for our health and well-being. In other words, consumption is a major element of nutrition security.

We eat on average more than 80,000 meals during our lifetime. Without any conscious effort, this habit ensures that our body functions well: The nutrients make sure that body components can be made, that our body has sufficient fuel and that it can defend itself against diseases.

Knowledge about which nutrients and other food substances we need, and in what quantities, is provided by human nutrition science. This discipline is rooted in several other scientific domains, including biology, biochemistry and physiology, and more recently also studies at the cellular level such as molecular biology, genomics and genetics. This latest development has introduced a new scientific field, which we now call nutrigenomics.

The nutrition science started off about 100 years ago with the discovery of several vitamins. These compounds are vital, and lack of them causes deficiency diseases. Interestingly, we are now not only worried about deficiencies and undernutrition but even more about overnutrition. The excessive intake of energy, sugars, fats and salt was recently found to be an important determinant of various diseases. Our obesity epidemic and chronic diseases which occur with ageing such as cancer, cardiovascular disease and diabetes mellitus are associated with overnutrition. In addition, high intakes of, for example, fat-soluble vitamins can be toxic. Good nutrition, therefore, means optimal nutrition – not too little intakes but also not too many – by a balanced diet.

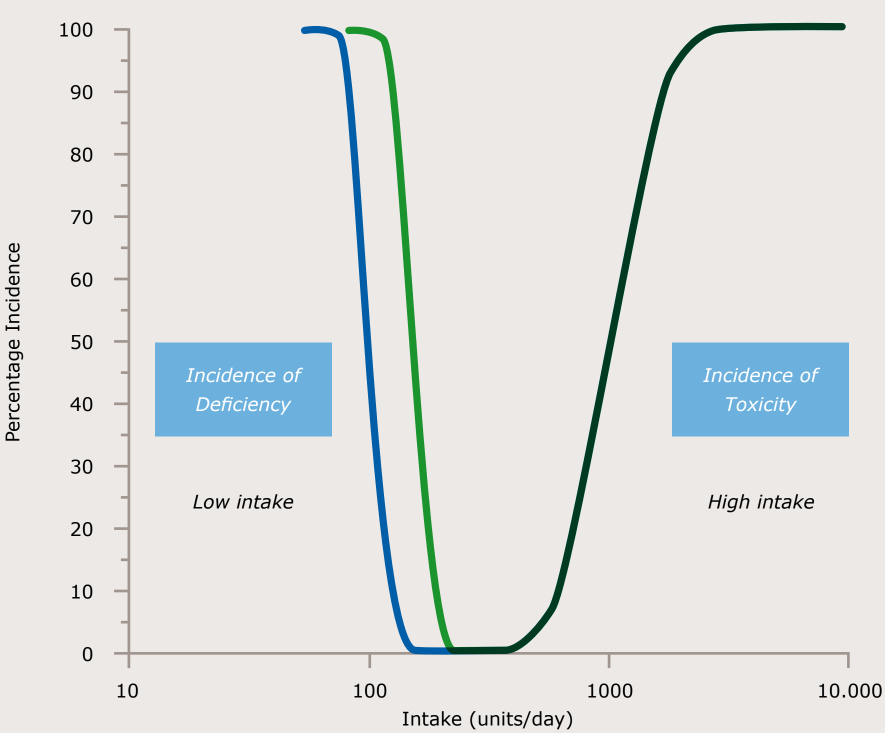
Quackery

But what is a balanced diet? Everybody who reads a ladies magazine, or is an active sports person, is aware of the various components, guidelines and advice related to nutrition. Unfortunately, the media

These food labels are used by a Dutch supermarket chain to help consumers choose healthy products.

Eet Meet Weet

Intake-incidence relationships



Relationship between daily intake of a nutrient and potential adverse health effects. Adverse health effects may arise at very low intake because of nutrient deficiency (blue line), for example anemia due to folate deficiency, at low intake because of absence of a health benefit (light-green line), for example more neural-tube defects due to sub-optimal folic acid intake in pregnant women, and at high intake because of toxicity or other unwanted health effects at high dose (dark-green line), for example masking of vitamin B12 deficiency and its neurological consequences due to very high intake of folate. So, the optimum nutrient intake is between the light- and dark-green line, and is higher than intake needed for avoiding deficiency.

often reports as many fables as facts, even descending into outright quackery. This situation is confusing to many people for two main reasons. Firstly, as eating is a habit we all do, the results of even the smallest studies are of interest to a large group of consumers and health-conscious people. Secondly, nutrition and health is a difficult field to study compared, say, to medication research. Nutrition is dealing with many components eaten at the same time, while pharma usually deals with one specific component at a time. Furthermore, the health effects of single dietary compounds are generally subtle and often only become clear in the long term. This makes controlled dietary trials difficult.

Edith Feskens, professor of nutrition and the metabolic syndrome, and her team therefore need to rely to a large extent on observational studies. An example is cohorts of participants in which we examine dietary habits, and then follow them for at least 10 years to see what diseases develop. A drawback of this approach is that dietary habits are correlated with other habits (for instance, coffee drinkers tend to drink more alcohol and smoke more) and thus these other habits, which we call confounders, need to be accounted for in statistical analyses. But the risk of residual confounding always remains as we cannot measure all relevant health habits. And the dietary assessment, and assessment of the other relevant habits, is not easy. Do you remember what you had for dinner yesterday? How many grams of rice, pasta or pota-toes? Cooked with how much salt? Did you have meat, how much and which kind? And do you remember your mid-afternoon snack?

EetMeetWeet

In 2011 Fesken's group started with a unique observational study in Wageningen and the surrounding towns. Joining forces with all chair groups of the Division of Human Nutrition at Wageningen UR, the goal is to tackle the difficulties in nutrition sciences from three angles: Improve the methodology for dietary assessment, gain insight into the human body with imaging techniques, and use functional tests, biochemical markers and nutrigenomics to obtain more insight into the health status of individuals. The study is called in Dutch 'EetMeetWeet' (eating, measuring and knowing). Wageningen UR collaborates with the municipal health services as well as the local hospital, Gelderse Vallei in Ede. It is a rewarding effort as both very much appreciate the cooperation and everyone recognises the added value.

About 2000 men and women aged between 20 and 70 years are participating in the study by providing extensive information on dietary intake and eating habits, completing health questionnaires and providing blood and urine samples. Height, weight and waist circumference are measured to indicate the presence of overweight or abdominal obesity. A body scan gives information on the overall percentage of body fat and of bone mineral density, an important indicator of osteoporosis. Vascular function is measured, as arterial stiffness is a risk factor for subsequent cardiovascular disease. A cognition test is also taken as we suspect that specific dietary factors such as B-vitamins and certain fatty acids affect mental functioning. All participants are asked to return to the university for similar measurements after one and two years in order to study the natural history of diet and health.

Excessive intake of energy, sugars, fats and salt was recently found to be an important determinant of various diseases

Dietary patterns are the new kids on the block in our research field.

Many interesting scientific questions can be answered by this data collection. For example, questions on dietary habits are also included: Where do you eat, at what time, with whom? How fast do you eat? How mindful are you of what you are eating? These are important determinants of overeating, such as mindlessly snacking in front of the TV. Adding this information to the detailed nutrient intakes gives us a better view of the dietary patterns that give rise to obesity and its metabolic consequences.

Subtle effects

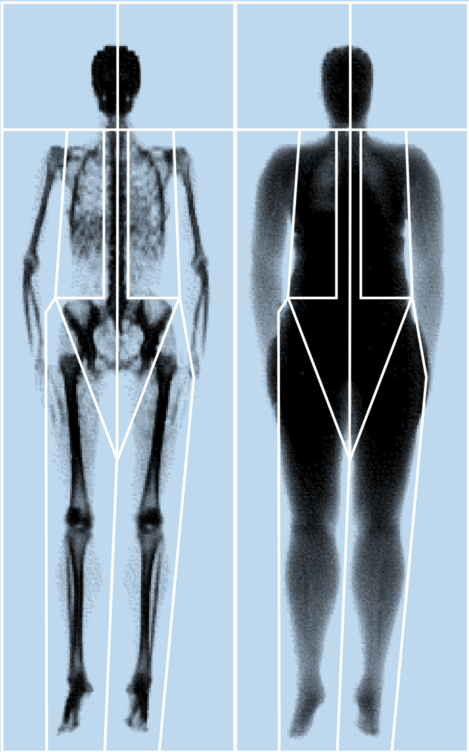
Dietary patterns are the new kids on the block in this field. People choose foods and eat them in certain combinations; they do not go to the supermarket to buy folic acid or potassium. We are increasingly realising that the subtle effect of each nutrient can play a role and may add up, or counteract, the potential beneficial effect of another. An example of this are whole grain foods, which may be healthy as long as they do not contain too many simple sugars. We know that dietary fibre enhances intestinal passage and prohibits constipation, and may have other beneficial metabolic effects. On the other hand, fibres contain phytates, which inhibit the uptake of minerals such as iron and zinc. We know that this prohibiting effect is less than the beneficial effect, so whole grains are generally regarded as healthy. But this example also shows that it is really impossible, and even dangerous, to label foods as healthy or non-healthy. It is really about the amount and variation of intake. You won't get very far by consuming cucumbers alone. ■

Use of DXA scans

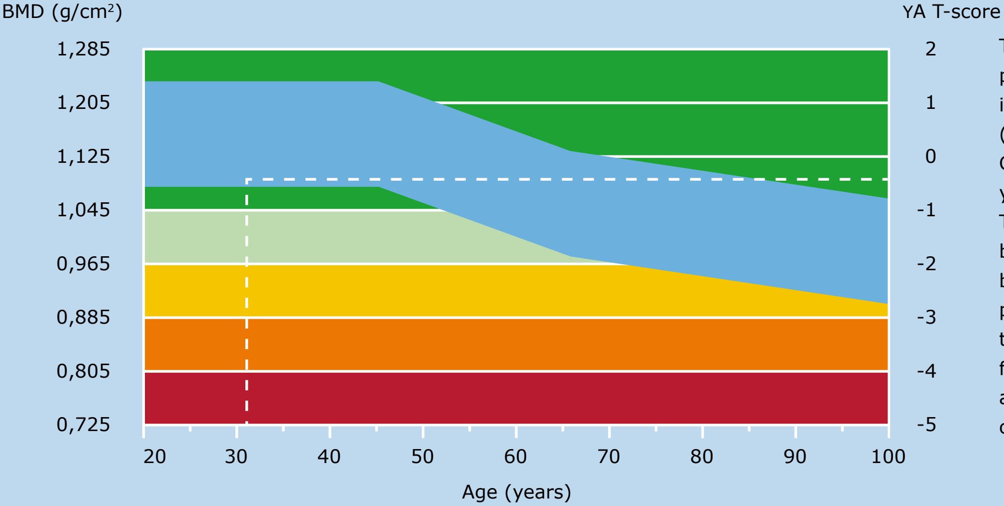
DXA (Dual-energy X-ray absorptiometry) scans are used primarily to evaluate bone mineral density. DXA scans can also be used to measure total body composition and fat content with a high degree of accuracy.

Age	30,9 years
Height	173 cm
Weight	74 kg
Sex	Female
Ethnic	White

Total Body Bone Density



Densiometry Ref: Total (Bone Mineral Density)



The result of the study participant (female, 31 yrs) is Total Bone Mineral Density (BMD) of 1.091 g/cm³. Compared to the general young-adult population (yA Tscore) the score is -0.4, a bit below the mean of 0. As can be seen from the graph this participant's BMD is classified in the blue area, indicating 'normal for age' and optimal (green area). There is no indication of osteoporosis (red area).

Adapted from: Renwick AG, Flynn A, Fletcher RJ, Müller DJ, Tuijtelaars S, Verhagen H. Risk-benefit analysis of micronutrients. Food Chem Toxicol. 2004 Dec;42(12):1903-22.

Quantity isn’t everything

Over the past few decades an increasing number of people have had access to sufficient food. But having enough food does not necessarily equate with it having balanced food. Many people in developing countries may get their calories, but proteins, vitamins and minerals are a different story altogether. Due to a lack of variety and the monotonous diet, between one and two billion people suffer from deficiencies of essential nutrients such as vitamin A, iron and zinc. These deficiencies affect the immune system and restrict growth and cognitive development.

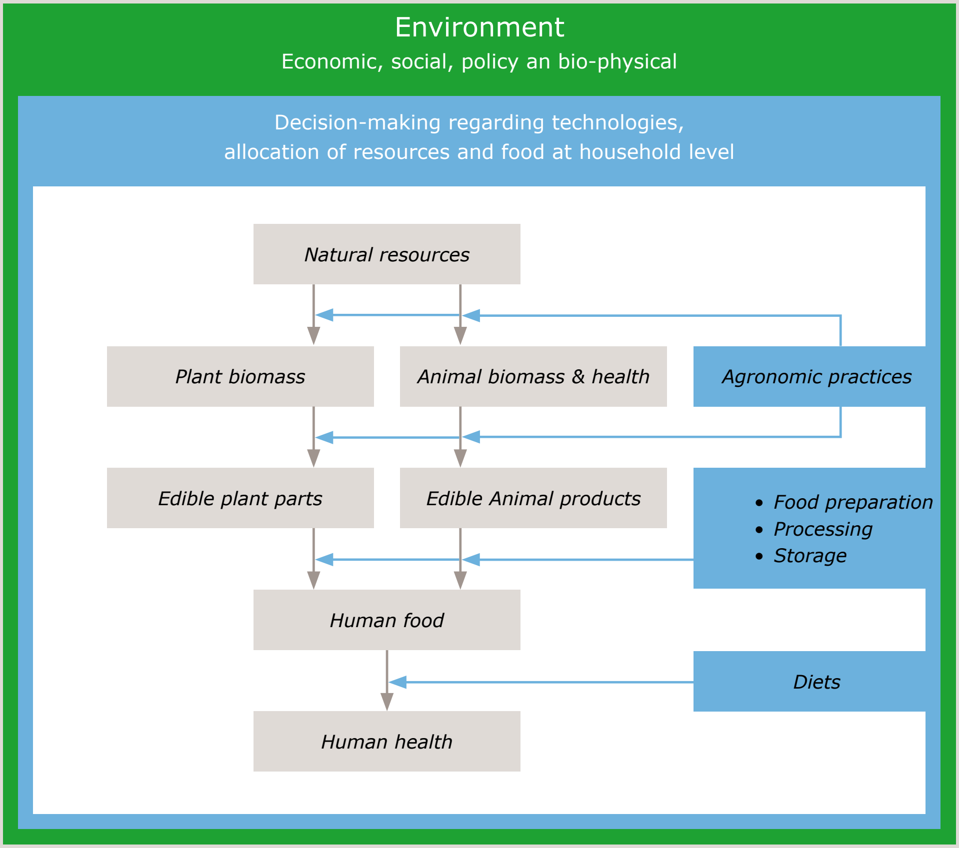
This *hidden hunger* is often combatted by using pills and capsules (supplements) that have a direct effect in the short term, or by fortifying centrally processed foodstuffs such as salt, sugar and oil. Diversification of food, for instance by stimulating the development of vegetable plots or livestock ownership, could also help. However, this is not an option for most farming families who only eat their own-grown crops and have insufficient financial means to purchase new crops or basic food products. Poor city dwellers (or others without land) are even more commonly left to a monotonous unbalanced diet.

A good solution would be to build the required mine- rals into the food crops that these people eat in large portions on a daily basis. This process, calledbiofortification, is a combination of (classic) breeding and cultivation techniques that result in the required quality.

Iron and zinc deficiencies

Ellis Hoffland, personal professor at the subdepartment of soil quality is one of the scientists involved in soil science, crop physiology, food microbiology and food & health who have formed an alliance to find ways to solve iron and zinc deficiencies along the trajectory

Integrated chain approach



All the minerals in our bodies ultimately come from the soil. This process comprises various steps via plants, animals and the food which can be processed in varying degrees before entering our stomach and intestines. These successive steps can be used to analyse the effectiveness of the input into our bodies. For each of the steps we can also indicate which measures can be taken to improve the process. Essential prerequisites for any application of this knowledge are the social environment in which decisions are made and whether or not the interventions actually take place.

from soil to mouth. Although iron and zinc is almost always present in the soil (with the exception of a few regions in Australia), crops often have difficulty absorbing these minerals as they cannot extract it given the form in which it is bound to the soil particles. This situation affects a third of the global agriculture acreage.

So which crops perform best in such unfavourable conditions? The Wageningen scientists discovered that one rice variety was able to absorb 1.5 times more minerals from the soil than another. Choosing the right rice variety can therefore make an enormous difference. At the same time it was shown that only a small percentage of the extra absorbed zinc, even if it was further increased by means of fertilisation, ended up in the rice grain. In other words, the yields and mineral absorption from the soil increased, but the nutritional value of the rice grain showed only marginal improvement. This is the opposite of the findings in sorghum or wheat. Breeding is therefore only useful if it improves the internal distribution of the available minerals.

The solution can also be sought further down the chain; for instance by reducing the extent to which the rice grains are polished so as to maintain the iron in the germ. The husking and polishing of rice in particular is often centralised. The industry in China, however, seems reluctant to switch to better polishing methods as it requires a considerable investment in new equipment. This would make the rice more expensive and thus unattainable for people who need the minerals most. The people who can afford it generally do not suffer from deficiencies as they have a more varied diet. Food quality is unfortunately difficult to market, even if less polishing would result in effectively more saleable rice that could partially cover the costs.

Phytate

In Africa, scientists achieved promising results with fertilising sorghum. The availability of Zn-enriched fertilisers is still a major issue in these regions, however. The new challenge is to make the minerals absorbed by the crop better available to people – the positively charged minerals in all grain crops are linked to phytate and stored as a mineral supply for after germination. In the germination process, the seeds use an enzyme to provide access to the required nutrients. This enzyme is unfortunately not present in the human stomach, and we can absorb much less iron and zinc from seeds than they actually contain.

One of the solutions for neutralising the phytate blockage is allowing the grain to germinate or ferment. This looks to be a good option for sorghum in West Africa, as the locals are used to ferment their food. In sorghum, iron and zinc molecules also form a compound with tannins. This effect can be undone by means of fermentation, but if the fermentation is followed by heating for a different part of the preparation process, the minerals are locked up once again. This therefore requires the selection of tannin-deficient varieties.

Food quality is unfortunately difficult to market

Biofortification

To test whether rice breeding is actually useful, scientists determined the bio-availability of zinc from rice that was enriched through biofortification in a natural way. In cooperation with a Chinese institute and the Swiss ETH, it was found that with higher concentrations of zinc in polished white rice the human body absorbs the same percentage as from non polished standard rice.

But even if these results stand up, it is unwise to place all one's egg in a single basket and bet solely on breeding, according to crop physiologist

Tjeerd Jan Stomph, who is part of the research team: "Biofortification by means of genetics may be the solution in some regions and for the long term. In others – and in the much shorter term – fertilisation may have much better results. Sometimes food technology may be the way to achieve our goals. An optimal effect can be reached by improving conditions at all parts of the chain. For the same reason it is ineffective to be fixated on a deficiency of a single mineral as the function of nutrients is connected by means of numerous interactions. Adding zinc also improves iron retention."

"There is still much to discover about the exact functioning of minerals. It is important that – in fighting hunger – we do not only focus on the quest for 'more' but also strive for 'better' food. Quality is at least as important as quantity." ■

Dry land rice

Wageningen PhD's compared the mineral levels of wet land and dry land rice on Chinese paddies, and determined that under the latter conditions rice has more trouble absorbing zinc. This is a concern as more sustainable water use is a global issue and China is seeing a substantial transition to dry rice farming. This could therefore lead to increased zinc deficiencies.

The role of fibres in satiety

How do we reverse the obesity epidemic?

In addition to undernutrition, overnutrition is a major cause of malnutrition The Global Burden of Disease report established in late 2012 that obesity is now, for the first time in history, a bigger health problem, in terms of number of people, than malnutrition.

Wageningen scientists are looking for solutions to tackle increasing obesity. The *Satiety and Satisfaction* programme focussed on the reasons behind excessive eating and the foods and ingredients that can be used to combat it.

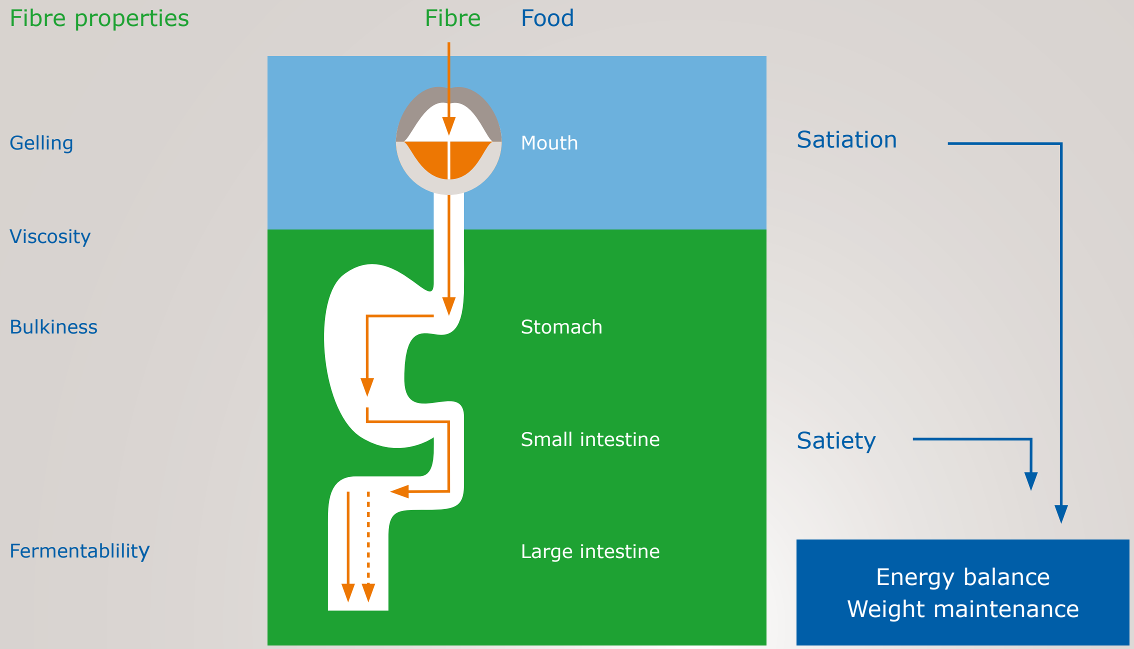
One of the keys in the fight against obesity is satiation. Those who stop eating sooner, or are less quickly tempted to grab a snack after a meal, are less likely to become overweight. There was an increased focus on this internal control on people’s appetite in the 1990s after it was discovered that mice insensitive to the hormone leptin kept eating indefinitely. It seemed that the trigger for a brake on overeating was discovered. And although it is now clear that there are other possible inhibitors for appetite, this has not removed the focus on the mechanisms of meal termination. A high protein diet, for example, seems to result in a feeling of satiety sooner than a diet rich in sugars and fats.

Fibres to prolong satiety

In 2008, research was initiated at Wageningen UR into another candidate for weight manage-ment: use dietary fibres to prolong satiety. This was logical, as some types of fibre absorb a lot of water, thereby literally filling the stomach without providing a lot of calories. Fibres are also an energy source for various intestinal bacteria, and the intestine, too, provides signals to the brains on the extent to which energy requirements are met.

“Hunger is one of the strongest stimuli people experience,” says Charon Zondervan of Wageningen UR Food & Biobased Research, who coordinated the programme. “It is very hard to ignore. People who want to lose weight have to go through a period of increased hunger. It would be useful if they could be helped through this somehow.”

"Depending on their chemical structure food fibres exert different physiological effects in the body."



Adapted from: Monica Mars and Guido Bosch

Satiety and Satisfaction

Satiety and Satisfaction consisted of four projects, in which eight PhD students, three postdocs and scientists from Wageningen UR worked together. The PhD students hope to complete their projects with a doctoral degree in 2013. The four projects were:

- Plant derived foods: Mum, can I have Brussels sprouts again?
- Food patterns: The effects of the introduction of satiety enhancing foods on consumer purchase, consumption and nutrient intake levels.
- Health effect: Food, fibre and health.
- Regulation: Fermentation to prolong satiety.

In addition to fundamental knowledge, the research also focused on practical applications in the food industry. Different products are lined up in Zondervan's office: Chocolate sprinkles with reduced sugar, pasta with built-in courgette and cookies with fewer calories. "You can tell consumers that it is better not to eat cookies, but people are creatures of habit," Zondervan points out. "If, however you put more fibre and less calories in cookies, and they're still tasty, there is a much greater chance that people will maintain a healthier diet."

The Wageningen *Satiety and Satisfaction* programme seemed to provide a useful contribution to this, with experiments showing how high-fibre food does indeed provide a full feeling for longer. This is why high-fibre food appears to reduce snacking behaviour. In practice, however, measuring the total calories that people ingest shows that there is not much difference with people who eat less fibre. "This is a common problem for nutrition research," adds Zondervan. "We can usually show a short-term effect in small groups or under controlled conditions. But demonstrating a long-term effect such as weight loss in practice is often difficult."

Mum, can I have Brussels sprouts again?

Soluble and insoluble

Is the study a failure then? "No – while it's true that we didn't get the results we were hoping for, these things happen. Only carrying out research where the results are known in advance gets you nowhere by definition. Moreover, a lot of what we found remains useful." The study has, for example, shown that not all types of fibre are the same. In older textbooks, nutritionists make a distinction between soluble and insoluble fibres, and stop there. "Today, we have a much more accurate picture of the relationship between the physical-chemical properties of dietary fibres and their physiological properties. This allows us to better predict the types of fibre that companies should use to ensure that their food has healthy properties. We developed design rules for products: if producers want a certain satiating effect of their foods, such and such fibre should be added to it. If you want a given type of fibre to have a certain effect, such and such properties should be given to it."

Furthermore, investigation into marketing and health claims yielded new insights into the way consumers read labels. While companies would like to advertise the strongest possible claims on their product, there are authorities who check whether such claims are justified. "Of course manufacturers would very much like to put 'helps with weight loss' on their product," Zondervan explains. "They would have to be able to prove this, however. If they cannot, then what else can they do?"

This question was investigated by market experts at Wageningen UR, who looked at how consumers interpret claims, among other things. "We assumed that most consumers would interpret a claim more generously than its literal meaning," Zondervan says. "Our research showed that the opposite is true, however." People assume that the claims on product packaging are exaggerated and in practice they remain quite sceptical.

Research into fibres and satiety has also opened doors in Brussels. Thanks to this programme, Wageningen is participating in the European research programme Full4Health, in which scientists from 19 universities and companies look at communication channels between brains and intestines. ■

Healthy intestines

Understanding bacterial consortia

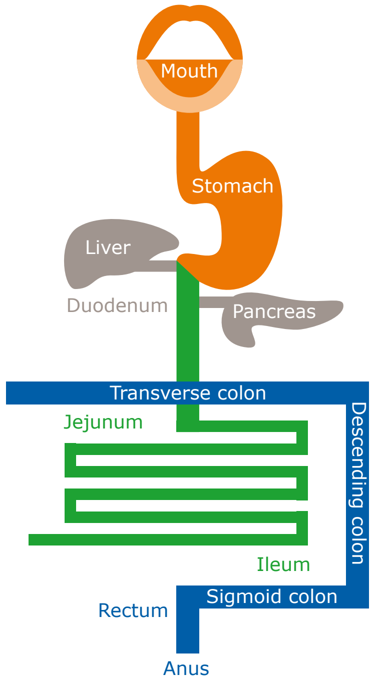
Although we try to side-line bacteria throughout the entire food chain, they do in fact play an important part in the final few metres. In the human intestine, thousands of different types of bacteria that form our intestinal microbiota (previously called intestinal flora) release carefully cultivated, harvested and processed nutrients into our body. This complex ecosystem is gradually revealing its secrets.

Why does one person falls ill from a *Salmonella* infection while another feels fine? What are the chances that someone will become obese? The answers to these and many other questions can be found by understanding the system that organises human resistance and food intake. This system is the intestinal system; a complex ecosystem comprised almost entirely of bacteria. An estimated 90 percent of cells in the human body is bacterial and lives in the intestine. They are the object of a study by a team of biotechnologists, micro-biologists, biochemists, bacteriologists, geneticists and medical biologists at the department of Agrotechnology and Food Sciences at Wageningen UR headed by Willem de Vos, professor of microbiology.

The discovery that the ecosystem of intestinal bacteria determines the (non-)development of diseases is relatively recent. In the past, physicians have regarded many diseases as an infection by certain pathogens such as *Salmonella* or *E. coli* bacteria. Treating the disease starts with removing the infection. Now there is a growing realisation that it is the level of disturbance of the existing intestinal system by the intruder that determines whether someone will or will not suffer permanent discomfort. Sometimes the pathogen is able to disrupt the system, but often the system stands firm or recovers quickly. By getting to know the interaction between the intruder and the existing system, we will be able to control a number of diseases in a more effective, and possibly less expensive way.

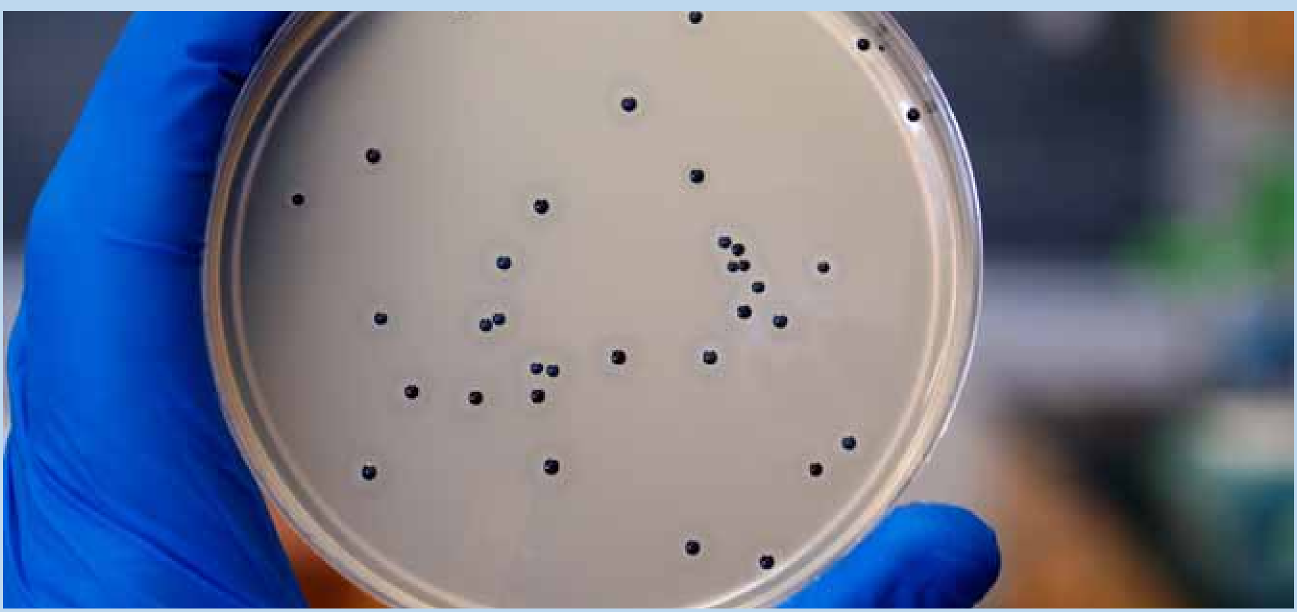
Escherichia coli bacteria

Schematic overview of the architecture of the human intestinal tract, the average food passage time and the density of the microbiota



Source: Mirjana Rajilic-Stojanovic & Willem M. de Vos

Gastrointestinal segment	Length cm	Passage time hours	Density of microbiota cells/ml (g)
Stomach	12	2-6	10^0-10^4
Duodenum	25		10^4-10^5
Jejunum	160	3-5	10^5-10^7
Ileum	215		10^7-10^8
Cecum	6		
Ascending colon	15		
Transverse colon	50	10-20	10^{10}-10^{11}
Descending colon	25		
Sigmmoid colon	40		
Rectum	18	1	10^{10}-10^{11}



Connected in consortia

The intestinal microbiota do not simply consist of a collection of individual bacteria. The bacteria are connected in consortia that are jointly responsible for the complex process of converting food into fatty acids, vitamins and other useful substances, transportation through the intestinal wall to the cells, the discharge of waste products, and resistance to foreign and toxic substances. Researchers of Wageningen UR recently discovered that they play a role in a number of diseases. Intestinal microbiota work together in various ways and have countless signal transduction systems with which they exchange information with each other and their environment. Part of this environment are the host cells that allow communication with the human body. The communication between bacteria makes the collective stronger than the sum of its parts.

Intestinal microbiota work together in various ways and have countless signal transduction systems with which they exchange information with each other and their environment

In their research the scientists approach the consortium as if it were a single organism. They used meta-genomics to map the total genetic functionality of the intestinal microbiota without having to unravel the genome of all individual bacteria. The European research programme MetaHit, in which Wageningen UR is a participant, served as a precursor. In addition, the Wageningen scientists worked with systems analysts from Helsinki University to realise a meta-analysis of the intestinal microbiota in over five thousand human subjects. The resulting data was collected in a large databank and subjected to extensive analyses. This offered a clear picture of unique compositions of intestinal microbiota (not two single persons have an identical collection of bacteria) with recognisable patterns. These patterns provide insight into the functioning of the consortia and help predict the effects of changes to the bacterial composition.

The analysis supports the hypothesis that people inherit two things from their mother at birth. In addition to the DNA as a genetic unchangeable code, a baby inherits intestinal bacteria from the person who has most contacts in early life; usually the mother. Other research has shown that this collection of bacteria generally remains stable throughout a person's life. If the hypothesis is correct, metabolic diseases like diabetes and obesity can be predicted by means of the intestinal microbiota. Moreover, the knowledge that the healthy intestinal microbiota is relatively stable over at least a decade makes it possible to recognise and repair disruptions and imbalances at an early stage. We might be able to tackle the major disruptions that currently still lead to chronic diseases, such as inflammatory bowel disease (Crohn's disease and colitis ulcerosa), by supplementing the shortage of bacteria with a so-called faecal transplant. Researchers in Wageningen and Amsterdam have shown this to work efficiently in *Clostridium difficile* infections as recently published in the medical leading journal the New England Journal of Medicine.

Recovery intestinal system

Supplementing bacteria may seem like drinking over-the-counter probiotics with lactobacilli. But, whereas probiotics can at most provide healthy people

The first impression is that the diatery pattern, especially in the early years, can affect the intake of nutrients and possibly even the development or intensification of obesity.

with a boost, faecal transplants involve a medical procedure for sick people with an extreme imbalance. An example of such a disease is obesity. Obese people consume more calories from food than they require and store it as fat reserves. As with people who don't absorb enough calories, this is related to a disruption of their insulin resistance. A faecal transplant could result in a durable recovery of the intestinal system for both groups and could complement programmes based on changing dietary or exercise patterns.

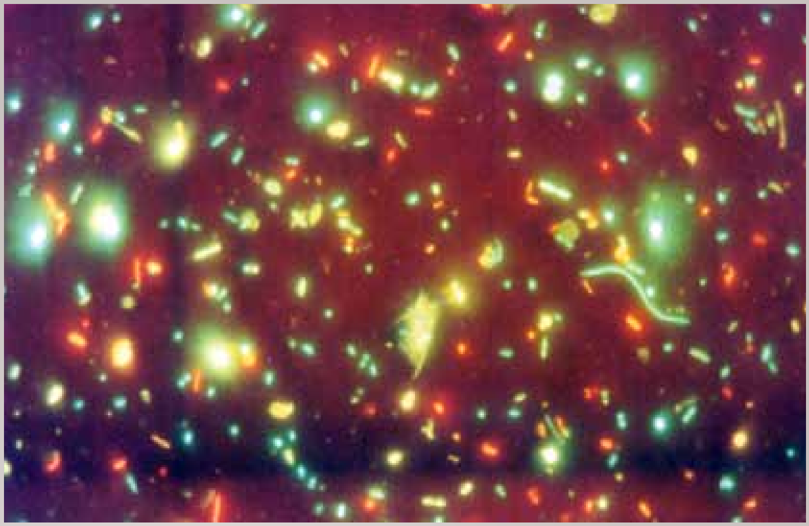
Research is also currently being performed into the functioning of the intestinal microbiota in relation to dietary patterns and medicinal use. The first impression is that the dietary pattern, especially in the early years, can affect the intake of nutrients and possibly even the development or intensification of obesity. The repeated use of antibiotics may also be an important factor. The exact relations are not yet entirely clear, however.

The knowledge of intestinal microbiota is currently rapidly developing and has unprecedented potential. It can possibly help people grow older in a healthier way, and limit obesity, inflammatory bowel disease, or irritable bowel syndrome. The knowledge may also be used to develop alternative nutrients. The general concepts that are being developed could also help improve nutrient intake and general health outside of the wealthy Western world, but the technology is yet too expensive to apply on a global level. In addition, knowledge is being collected on the intestinal microbiota of production animals with an eye on using the resulting insights in breeding to improve the health of pigs, cattle and poultry. A major project was recently established in partnership with TI Food & Nutrition, for example, looking into reducing methane production from cattle and thus increasing the food conversion efficiency in the cows themselves.

A larger understanding of intestinal microbiota in animals and humans can result in a better intake of food and thus limit the primary food demand. At least as important is the possible effect of the research on our health and quality of life.

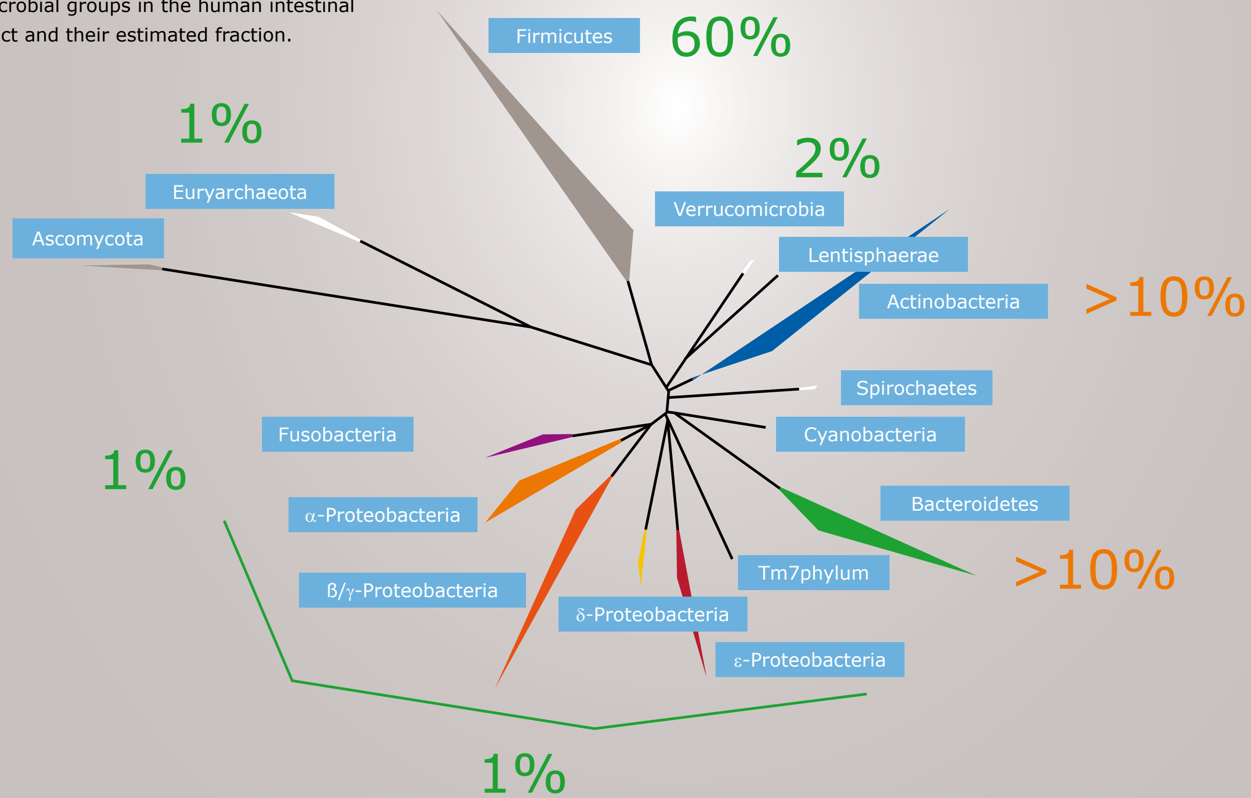
Microbes in the human intestinal tract – visualised by Fluorescent In Situ Hybridisation

Source: Kaouther Ben Amor & Willem M. de Vos



Phylogenetic tree

Showing the inferred evolutionary relationships among the predominant microbial groups in the human intestinal tract and their estimated fraction.



Adapted from: Nutr Rev. 2012 Aug;70 Suppl 1:S45-56. doi: 10.1111/j.1753-4887.2012.00505.x.
Role of the intestinal microbiome in health and disease: from correlation to causation, W.M. de Vos, E.A. de Vos.

3 | Protecting our crops

To close yield gaps we need to tackle pests, diseases and weeds. These reducing factors are especially powerful under tropical conditions and in situations where control options are not available, where they thrive at the expense of agricultural products. This in turn causes losses during the production and post-harvest handling. Better protection of our crops and livestock is a major intervention that directly affects agricultural productivity. The innovations can be characterised by a switch from chemical protection to a more ecological protection, partly by enhancing the power of plants and animals to protect themselves. This can help to feed millions of people.

Eat and be eaten

While plagues of insects pests can be a problem for agriculture, other insects can literally munch on the pests and in doing so protect crops. We are gradually starting to realise the potential value of this gluttony for our own food supply. And so an important new option arises: Insects as human food.

Marcel Dicke's study office is infested by insects: Scale models, posters, toy spiders, art objects and jewellery. It illustrates the fascination of this professor of entomology for his profession, which has had a place at Wageningen UR for long. The scientific attention was initially focused on the damage caused by insects in agriculture. Many different types of insects partake in the rich harvest of agriculture: Caterpillars, aphids, grasshoppers, beetles, you name it. Scientists are constantly developing new methods to contain their gluttony and prevent pests. And they are receiving help from an unexpected source: Other insects.

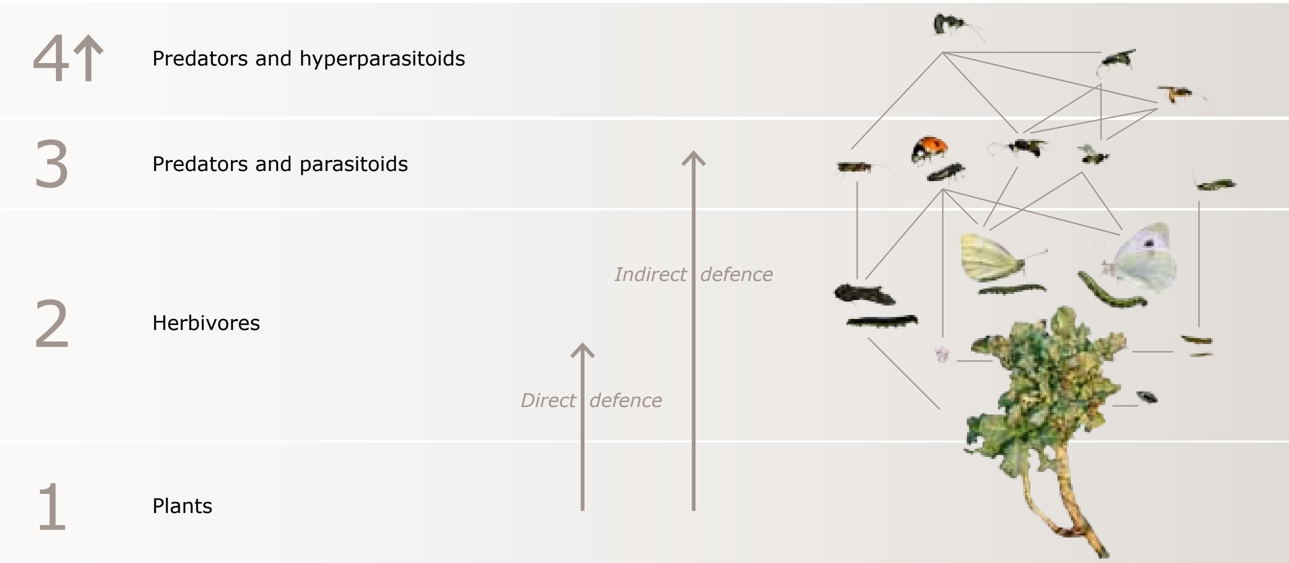
Certain insects are in fact able to selectively control another species. Biological pest control of insects by insects has made great leaps forward. We know the successes: Parasitic wasps, which lay their eggs in caterpillars or on the larvae of, aphids and whiteflies, are extensively used for insect control in greenhouses. In open cultivation, too, insects can do wonders, the best example being the suppression of a scale insect in citrus cultivation with ladybirds. This solution dates back to the late 19th century and is still effective today.

The Wageningen research has shown that plants themselves play an important role in the effectiveness of the biological pest control. Plants attacked by herbivorous insects can use parasitic wasps and predatory insects for protection as a kind of bodyguard, for example responding to an attack by producing odours that attract the bodyguards. Such tritrophic relationships appear to be common in plant-insect interactions. Plant varieties that cooperate more closely with bodyguard insects can be selected, and this can lead to crops on which biological pest control is more successful.

Hyposoter ebininus laying eggs in a *Pieris rapae* caterpillar

Plants interact with a community of insects at different trophic levels

Plants harbour a community of herbivores and their natural enemies that form a complex of interacting associations. Plant defensive traits directly or indirectly interact with each of these organisms and thereby affect the composition of the insect community. Plant direct defense is exploited as plant resistance, plant can have an indirect defense by stimulating the effectiveness of biological control agents.



source: Poelman et al. 2008, Trends in Plant Science

Roasted insects

From incident-based to system

Until recently, both farmers and scientists were lagging behind the facts. To solve this, Dicke and his research team promote taking a systems approach instead. What do biological control agents require from their environment in order to combat pests as efficiently as possible? Based on scientific knowledge and extensive experiences by growers and biological control companies, a pest management system has been developed for greenhouse-grown vegetables which – thanks to biological control – is largely pest-free. The system is pretty well understood and the control of new pests can therefore be quickly included.

In open cultivation, things are somewhat trickier. The biological control agents can fly or crawl away, and are more likely to fall prey to their own natural enemies. The quality of an effective biological control system revolves around accessibility and balance. Leaving field margins intact and growing flowers, for instance, creates a favourable habitat for the bodyguards from which they can invade the crops to be protected. At the same time, it is important to ensure that the introduction of new insects does not disturb the existing system. If a beneficial insect protecting one plant attacks the bodyguard of another plant, the problem may be worse than the solution. Biological control is always a search for balance. And this requires a systems approach.

A systems approach connects fundamental and applied science. This results in the design of intelligent farming systems in which growers know exactly what is needed at any given time. Dicke expects that agriculture without chemical insect control will be possible in the long term. It will be achieved via a systems approach which effectively integrates biological control and breeding and cultivation measures so that they reinforce each other. In the protection of, for instance, cabbage against certain insects, such an approach can even be the only way – the diamondback moth, for instance, is resistant to almost all pesticides.

An obstacle for many forms of insect control is that not every farmer knows enough about the mechanisms behind this systems approach. For instance, the time that insects need to do their job properly can be relatively long. The pest does not disappear overnight when the bodyguards are introduced, as is the case with chemical control. The perception is then often one of ineffectiveness or an insufficient impact, especially among farmers who cannot afford a bad harvest. When implemented in time, however, biological pest control lasts much longer than chemical control. If farmers can move beyond the reflex of quickly spraying with chemical pesticides, more chemicals could be removed from agriculture than we currently think possible.

Stress

We have long known that insects play an important role in nature and agriculture. It is no coincidence that a fierce debate is raging about the apparent disappearance of the honeybee, one of the most important pollinators. Seventy percent of crops cultivated for human consumption depends on pollination by bees. Dicke's team would like to start research on the mechanisms that cause stress to the honeybee. Why do some honeybee colonies have such high mortality rates today? The answers range from chemical pesticides, the Varroa mite and a fungal disease to the uniformity of cultivation and intensification of land use, which may make bees hungry and vulnerable. The relative contributions of these possible causes require a critical analysis of the underlying mechanisms.

When implemented in time, biological pest control lasts longer than chemical control

A meal prepared with crickets

Alternative proteins

Insects are increasingly considered for another benefit they offer – as a source of animal protein. With an average of 80 kg of meat per year, Dutch consumers eat an amount that is between the Americans (120 kg/year) and Chinese (50 kg/year). Seventy percent of the world's agricultural land is already directly or indirectly dedicated to meat production. As a source of animal protein, insects require ten times less space than cows. This could be a solution not just for producing meat for human consumption; insect protein could also, for example, replace fishmeal in animal feed.

Assuming that there is a need for animal protein – whether physically or socially – the Wageningen researchers look at insect species in terms of effective farming, scaling, hygiene and disease-free cultivation. With insects, too, diseases can be a problem, although transmission to humans is less likely than in the case of diseases from mammals and chickens.

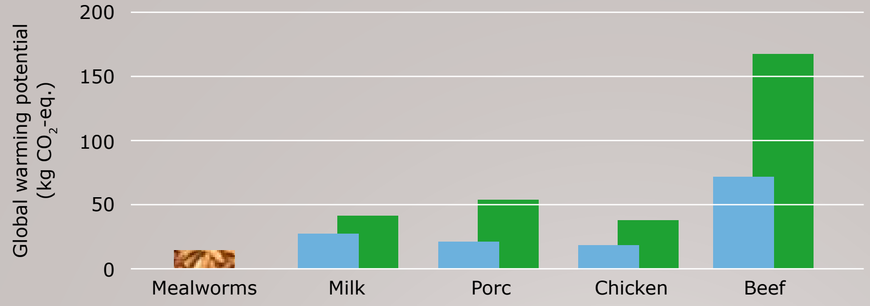
The Wageningen UR approach is unique in that it is a collaboration between academic, industrial and government partners. The subject was put on the agenda in 1997 by Wageningen UR entomologist Professor Arnold van Huis, and received verbal support from the Dutch government in 2005. After the City of Insects festival in 2006, the government provided financial support and cooperation began with insect rearing companies.

The research focuses on environmental issues – greenhouse gases, land use – and the possibility to use residues from other food industries (spent grain, leftovers from biscuit production) as insect feed. Life cycle analysis by the Laboratory of Entomology is already showing that the production of mealworms as a protein source requires less land and produces lower amounts of greenhouse gases than the production of traditional animal protein sources. Energy consumption is still a concern (it is lower than for the production of beef and higher than for the production of milk or chicken). All aspects included, however, the conclusion is that rearing insects as a source of animal protein is much more sustainable than meat production. Further cooperation with food scientists and nutritionists is needed to shed light on the exact composition.

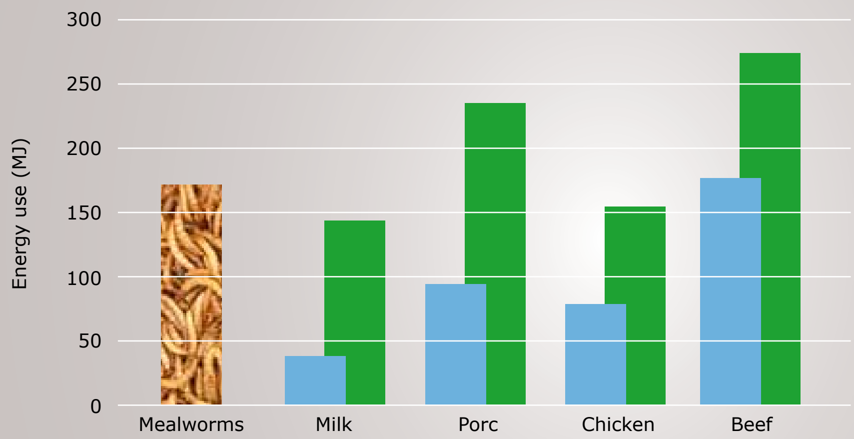
The use of insects as animal feed could prepare the market for the concept of insects as a protein source, and the presence of chitin – which probably promotes health – can promote the acceptance of insect farming. Several Dutch companies are already producing insects for human consumption. To interest the public, Dicke and his colleagues Arnold van Huis and Henk van Gurp wrote *Het Insectenkookboek* ('*The Insect Cookbook*'), which will soon also be available in English as well. ■

Environmental impact of mealworms compared to other animal products

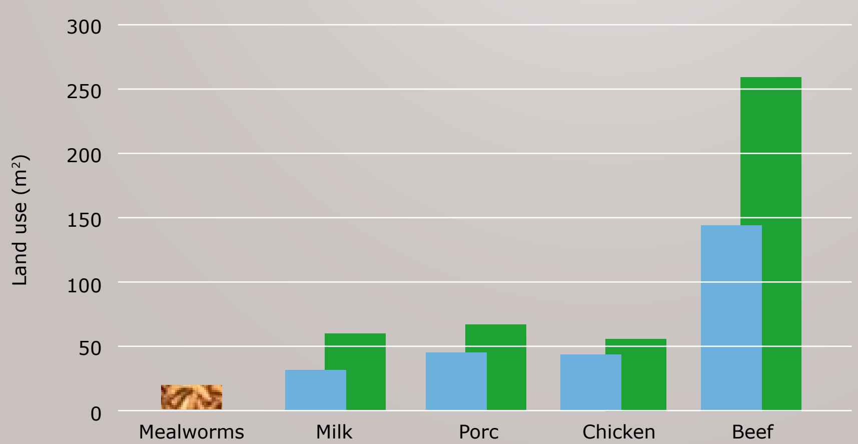
Global warming potential due to the production of one kg of edible protein



Energy use due to the production of one kg of edible protein



Land use due to the production of one kg of edible protein



Results from this study
Minimum literature data*
Maximum literature data*

*Adapted from Environmental Impact of the Production of Mealworms as a Protein Source for Humans – A Life Cycle Assessment, De Vries & De Boer (2010).

SOS sorghum

Parasitic witchweed threatens food crops

There is a subterranean war occurring in Africa with a parasite gnawing at the very roots of the existence of countless farmers. Striga – also known as witchweed – may look like a pretty flower, but wherever it casts its spell harvests are lost.

Harro Bouwmeester, Professor of Plant Physiology has been investigating the cause of the striga plague for many years. Some 40 percent of all agricultural land in Africa is infected with the seed of this parasitic weed today, resulting in huge losses in the production of sorghum, millet, maize and upland rice. The total damage is estimated to be between 7 and 13 billion dollars, while striga also threatens the food supply of around 300 million Africans.

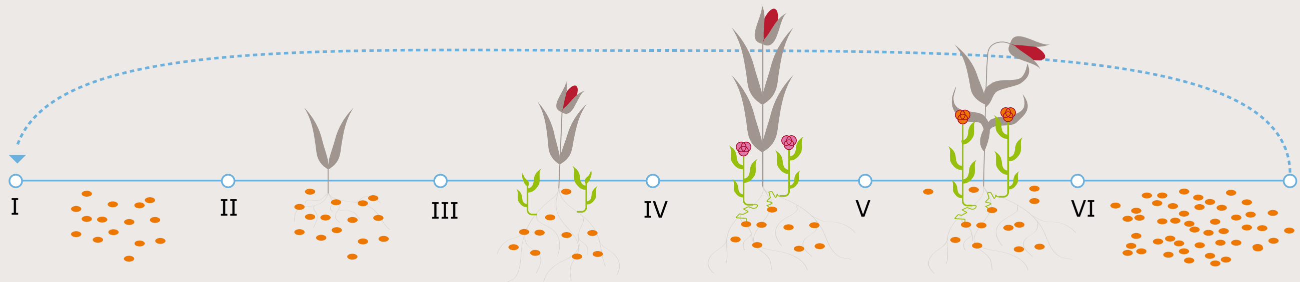
Controlling the weed is difficult. Seeds lay in the soil for long periods waiting to attach to crop roots, during which time the plague remains invisible. Although the seed does not start germinating until a crop is nearby, the striga is a very patient parasite that can even strike after years of inactivity.

The advance of striga is occurring at the same pace as the depletion of the soil. Many African fields are used for cultivation year after year without being left fallow and often without the addition of artificial fertiliser. Striga is in its element in such conditions, which is the easy explanation for the parasite's success. Interestingly, however, it seems that the host also causes its own demise, as Bouwmeester discovered while focusing on the so-called strigolactones; the signal substance that the crops exude into the soil via their roots. These signal substances betray crops like sorghum to the striga seed. The relation between the amount of strigolactones produced by a crop and the size of the plague is clear: More strigolactones equals more witchweed.

Masochistically

So what moves the host plant to behave so masochistically? For a long time, Bouwmeester and his colleagues did not understand the evolutionary logic behind it. Until a new fan of the strigolactone signals

The life cycle of parasitic weeds



Steps in the lifecycle are: (I) parasitic weed seeds are buried in the soil and become sensitive to the germination stimulating signals from host roots; (II) after a crop is planted, the crop roots produce germination stimulants and induce germination of part of the parasitic weed seed population; (III) the radicle of the parasite grows to the host root and a haustorium is formed through the action of haustorium inducing factors produced by the host root, a xylem connection is established and the parasitic plant emerges; a large part of the damage to the host is already inflicted before emergence of the parasite (IV) the parasitic plant reaches maturity and flowers (V) and produces seeds (VI) which end up in the soil seed bank where they again gradually become sensitive to germination signals.

Maize parasitised bij striga

Striga hermonthica emergence in some rice cultivars

Striga hermonthica emergence in some representative low- and high tillering rice cultivars as determined 12 weeks after sowing. The average number of S. hermonthica shoots emerged (between brackets) were: IAC 165 (34), IAC 1246 (29) (both lowtillering), Agee (1), Anakila (1), TN 1 (4) and Super Basmati (4) (high tillering).

IAC 165

IAC 1246

Agee

Anakila

TN 1

Super Basmati

Source: Genetic variation in strigolactone production and tillering in rice and its effect on Striga hermonthica infection Muhammad Jamil et.al. Planta (2012) 235:473–484

Broomrapes

Root parasitism is not exclusively an African problem. In Europe it are mainly members of the parasitic broomrape family that can threaten harvests, with tomato, potato, cabbage, sunflower, pea and beans being favourite targets. Although not not frequently, considerable economic damage can occur in this regions as well. Bouwmeester advocates a long-term strategy. Although the development of a new variety based on the one plant in the field that withstands the parasite may seem attractive, it is an easy task for the average parasite to adapt to changes in a single characteristic of its host. For sustainable resistance it is important to erect multiple barriers, which requires joint research and efforts from scientists and breeders.

was found in 2005: arbuscular mycorrhizal fungi that settle in the root system of the host just like the parasite. Unlike striga, however, this symbiotic fungus is beneficial to the host. In return for photosynthetic sucrose, the fungus uses its deep and widely branched fibres to extract nutrients from the soil that the host cannot reach itself. The fungus is especially skilful in extracting phosphate. When a host has a phosphate shortage, it increases its strigolactone production to attract the fungus. In the African soil, however, this leads to a disastrous version of a Trojan horse – in addition to the beneficial fungus, striga seeds also respond to the SOS, resulting in an unequal battle with calamitous consequences for the host.

A primitive way to control a striga plague is to weed all the stems of the striga. Although not a cure-all, this can save part of the harvest. African farmers who see the parasite blossom, however, know where they stand and leave the field behind in the knowledge that the harvest is lost. Unfortunately, this only worsens the striga. The blossoming parasite produces many thousands of new seeds that patiently wait in the soil for the strigolactones to tell them where to go to benefit from a new host.

Bouwmeester had previously shown that the strigolactones in the plant are produced from carotenes. A logical next question was how one can reduce the production of carotenes without affecting the growth of the plant. There are herbicides available that inhibit carotene production and therefore limit the production of strigolactones. This results in a 60 to 75 percent reduction in the germination of striga seeds. If African farmers would use these herbicides on their crops in very small concentrations, it would be an easy way to combat the parasite. However, herbicides are not a perfect solution and are often unattainable or unaffordable for the majority of Africans.

Phosphate bath

A more expensive and even more unattainable option so far in many parts of Africa is adding the required phosphate to the soil via artificial fertiliser. The fertiliser solution cuts both ways: It increases yield (which is only ten percent of the maximum possible production in some places, even without striga) and eliminates the parasite by stopping the production of strigolactones. In the research some success was achieved with a more precise application of phosphate, such as giving the seeds a phosphate bath prior to sowing or putting phosphate in the soil near planted seeds. Another method is to provide seeds with a mycorrhizal fungus coating to ensure a good start.

An encouraging aspect of Bouwmeester's research is his finding that not all varieties of rice and sorghum are equally sensitive to striga. The signal substances also play a key role in the process as he demonstrated by studying the strigolactone production of collections of rice and sorghum varieties. An important aspect here was replacing the classic bio-assays for determining the strigolactones with a quantitative analysis of the signal substances using sensitive analysis equipment (LC-MS), bought using finance from the Netherlands Organisation for Scientific Research (NWO). Of the many rice varieties studied, several produced very low amounts of signal substances and showed considerable striga resistance. Plants with many tillers produce few strigolactones and are less affected by the parasite so breeders can use this to develop resistant varieties. Cooperation with World Food Prize winner Gebisa Ejeta brought to light sorghum varieties that also produce strigolactones while being far less attractive to striga. According to Bouwmeester this proves that the signal substances can change their tune. ■

Breeders can use the number of tillers to develop resistant varieties

The biological arms race

Harvests face a constant barrage of plagues. Over time, crops have lost a large proportion of their natural defence arsenal as breeders have long focused mainly on increasing yield. This has made them far more vulnerable to attack and it is now urgent to equip plants with advanced weaponry to protect them against the wide variety of pathogenic organisms.

These war-like analogies are used by Pierre de Wit, Professor of Phytopathology, who even speaks of an arms race. Triggered by Rachel Carson's book 'Silent Spring', he has been working on improving the natural resistance of plants against pathogens since starting his studies in Wageningen in 1968. These pathogens – fungi, bacteria and viruses – attack plants and affect their growth physiology, sometimes leading to death. Over recent decades most plant pathogens have been controlled by means of chemicals. Wouldn't it be better if the plants were able to protect themselves against plagues and disease?

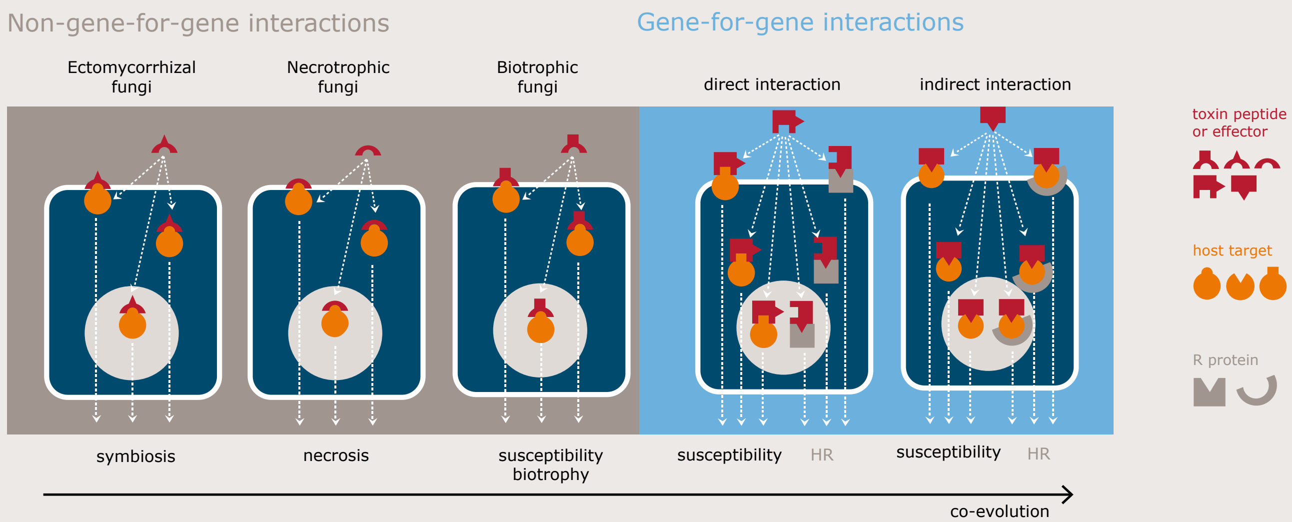
Natural resistance has often been a secondary consideration in plant breeding compared to increasing crop production, especially after it was discovered that many plagues and diseases could easily be controlled by means of chemicals. The downside of this increasing viability has been a loss of genetic variation relevant for protection. Genetic deterioration often affects resistance, allowing pathogens to strike without mercy. The highly aggressive stem rust fungus Uganda 99, for example, is a major threat to the wheat fields in East Africa because the crops are not sufficiently armed against the weapons of their attackers.

Gene-for-gene interaction

De Wit and his research group are studying the interaction between tomato and the *Cladosporium fulvum* fungus at the genetic and molecular level; the so-called gene-for-gene interaction. A tomato plant recognises the products of specific effector genes from the fungus causing the leaf mould disease. It does so by means of receptor proteins which are coded in its

Interactions of fungi with plants

A mould that comes into contact with a plant can create a symbiotic, necrotrophic or biotrophic relationship with it. In many plants, no gene-for-gene interaction is possible, and the plant is defenceless against the attack of the fungus. If the plant has built up a natural defence through gene-for-gene complementarity, an R-protein can neutralise the harmful effect of the fungus.



Adapted from:De Wit et al. (2009).Fungal effectors: past present and future. Molecular Plant Pathology 10: 735-747

genetic reservoir by receptor genes. The fungus, however, uses genetic mutations in the effector genes to escape recognition by the plant.

In the early 1990s, Wageningen phytopathologists led by De Wit achieved a breakthrough when they found the effector gene of the fungus that affects the tomato, and, shortly thereafter, the gene in the plant that recognises this effector gene. It marked the unravelling of the first gene-for-gene relationship. Armed with this knowledge they were able to identify resistance genes and their products in tomato to keep the fungus at bay. This marked the transition from 'trial and error' to the fundamental understanding of the response capacity of the natural plant resistance system. It made the knowledge applicable for a wide range of interactions between plants and pathogens.

Variation increases the chance of identifying specific pathogenic weapons, allowing crops to protect themselves against their main pathogens

Meanwhile, De Wit and his research group have developed the tools to map the entire arsenal of pathogens. One of the most important tools is next generation sequencing, which enables a quick search for the DNA of the genes that code for the weapons of the pathogen and the defence genes of the plant, respectively.

Advanced defence systems

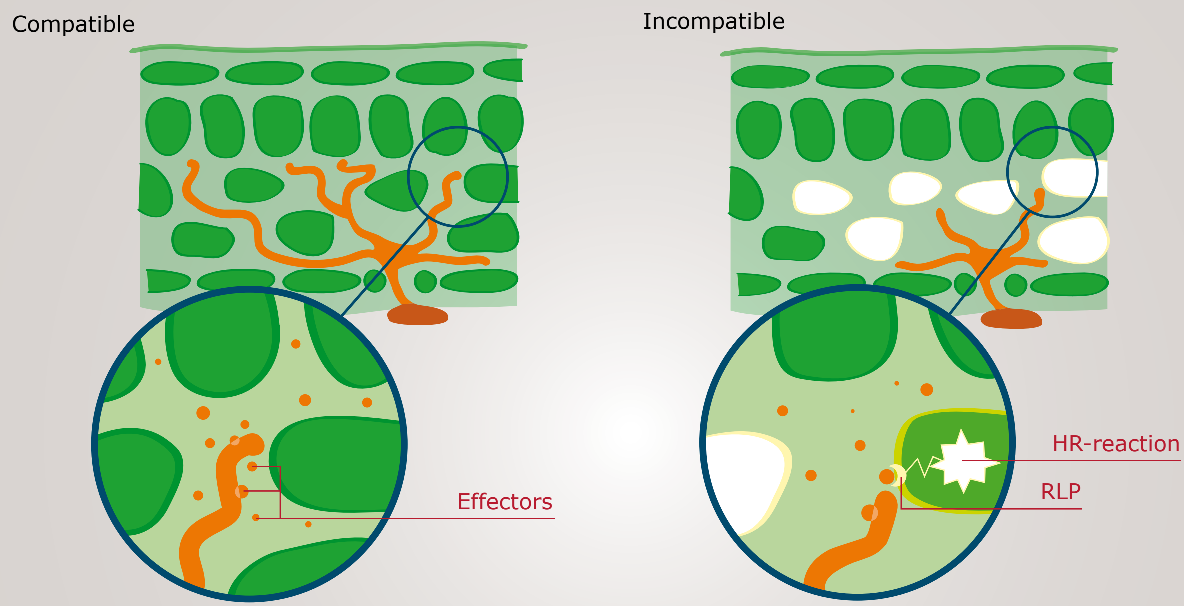
The next step is the development of plants with advanced defence systems. This starts, with unravelling the basal recognition mechanisms; a plant recognises a fungus by components of its cell wall material (chitin) and bacteria via the flagella that contain the protein flagellin. Some of these basic defence mechanisms may have been lost during the yield-improving breeding programs. In addition, it is important to maintain as much genetic variation as possible in plants. The variation increases the chance of identifying specific pathogenic weapons, allowing crops to protect themselves against their main pathogenic attackers.
The markers for resistance genes can be identified with various sequencing technologies (genomics). By combining these markers it is possible to simultaneously build multiple barriers, making it more difficult for pathogens to breach the resistance. In this way chemical pathogen control can be replaced by the development of varieties with natural resistance in their genetic material. These types of biological control always strengthen resistance, although they never provide 100 percent protection against pathogens, according to De Wit.

The scientists are currently working on the possibilities for building in new barriers against pathogens; either through crossbreeding or genetic modification. From a scientific perspective, it is disappointing that the social opposition to Genetically Modified Organisms (GMO) in some parts of the world is thwarting breakthroughs in this field. The feared resistance genes and their products are commonly present in all organisms, including plants and animals (and humans).

More sustainable

The (re-)introduction of natural resistance in crops will come at the cost of the yield. By making plants more resistant to natural enemies, their yield will be reduced as part of their energy is used for defence. It does, however, make the total system less vulnerable and the costs of the investments will be recovered due to the reduced occurrence of diseases and plagues.
If pressure from consumers and the processing industry would increase the focus on the total range of qualities, including nutritional value and health, the overall balance could become even more sustainable.

Infection of tomato leaves by Cladosporium fulvum



A Compatible interaction between C. *fulvum* and tomato. Following germination of a conidium, a runner-hypha penetrates plant tissues through open stomata and colonises the apoplastic space of tomato leaves.

B In an incompatible interaction, a tomato resistance protein recognises the presence of the fungus and a hypersensitive response (HR) is induced, which stops further growth of the fungus.

C During infection, C. *fulvum* secretes several small cysteine-rich proteins that are effectors (Avrs and Ecps) in order to manipulate host defences and support fungal growth.

D In resistant plants effectors are recognised by receptor-like proteins (RLPs), which activates Cf-mediated defence responses including an HR.

Modified from: Ökmen, B and de Wit, PJGM (2013). Cladosporium fulvum-tomato pathosystem: fungal infection strategy and plant responses. In: "Molecular Plant Immunity" edited by G Sessa (John Wiley & Sons, Inc.) pp 211-224.

The industry continues to join forces in the fight against pathogens to protect crops. Sometimes protection will be based on chemicals, but increasingly it is based on enhancing the crops' natural resistance. New dynamics are gradually developing, which is also resulting in shifting partnerships. While in the past phytopathologists were mainly approached on research issues by the chemical sector, now it are the breeding companies who are showing interest. Although this does not mean they will determine the research agenda, it does indicate what type of knowledge is most in demand.

There is a constant battle against (new) diseases and plagues. The evolutionary development of viruses, bacteria and fungi is rapid and they are always looking for new ways to attack plants. For a long time we have given our crops insufficient protection against these enemies, as a result of which we have had to protect them using chemicals. The strongest weapon against pathogens, however, is the natural resistance of the plant. It may seem expensive and time-consuming, but ultimately this is the most sustainable option. Chemical control can be cut back significantly, preventing Rachel Carson's 'Silent Spring' from becoming a reality. ■

4 | Quality food

The quality of food starts with the plants and animals upon which we feed. We can improve the security of our food supply system by developing knowledge of their genetic variety and strength. Such insights allow us to use the powerful instrument of breeding animals and plants to further enhance the quality of food as well as the sustainability of the food supply system. The quantity of food can also benefit from healthy crops and livestock, especially if it is adaptable to change and the more extreme conditions to come.

Genome knowledge improves breeding

Animals of the future

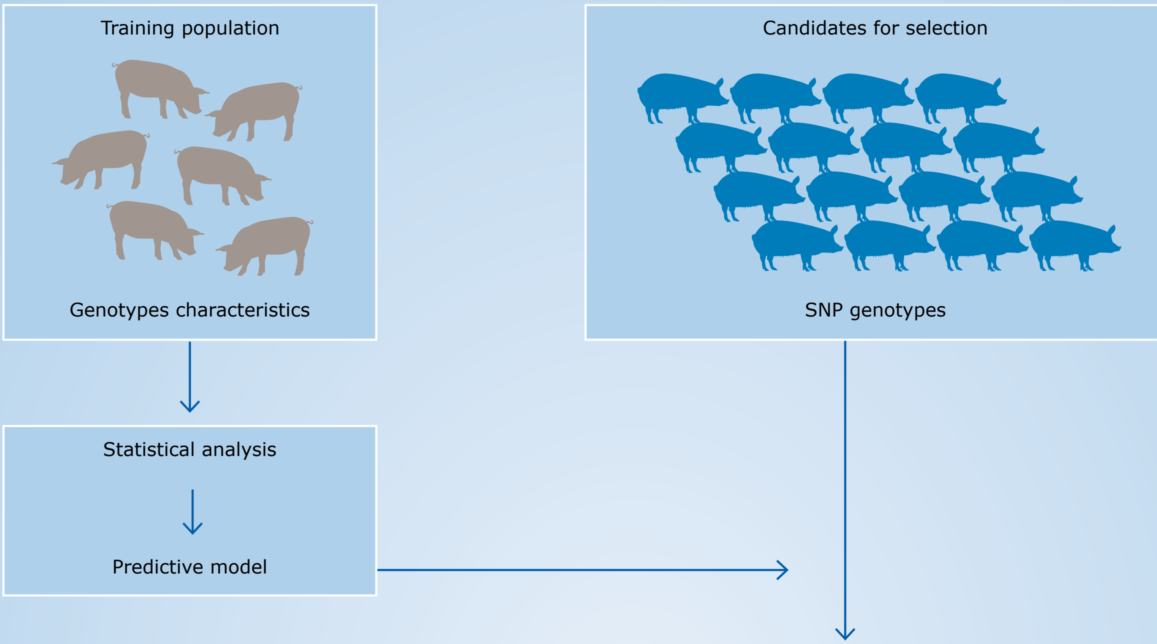
As a result of balanced breeding programmes, cows, chickens and pigs are supplying more and more eggs, meat and dairy products. Attention for welfare, lifespan and feed efficiency is essential to prevent the consequences of a unilateral selection for productivity. Genomic selection gives breeders new opportunities to meet the increasing demand for animal protein in a sustainable and animal-friendly way.

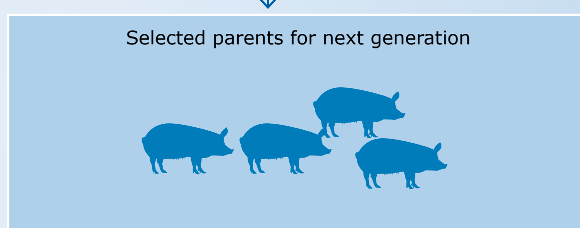
Until recently, the work of breeders revolved primarily around studying and observing traits such as productivity, disease resistance and longevity. Information on phenotypes was combined with pedigree information to infer the size of genetic variation and the opportunities to improve traits by selection. The unravelling of the genome of an increasing number of species is giving breeders a brand-new tool which will drastically change the perspective on traits and the value of animals for breeding in the coming years. This offers unique opportunities to contribute to the challenge of the future: Production systems with healthy animals that supply more with less input. Genetic knowledge can also help us select more social animals, which will influence welfare positively, or cattle with a reduced environmental impact, for example by limiting methane emissions.

Johan van Arendonk, professor of animal breeding and genetics explains: "Innovations are crucial in order to meet the global demand for high-quality animal protein in a sustainable way. Intelligent breeding programmes are necessary to increase the efficiency of the food chain, minimise the ecological footprint, address changing consumer demands and contribute to the wellbeing of people and animals alike.

Research into the pig genome has provided important insights into the effects of domestication; for example, pigs have become taller and domesticated breeds have up to four vertebrae more than wild pigs.

Genomic selection





Parents for the next generation are selected based on single nucleotide polymorphism (SNP) genotypes which are translated into predicted breeding worth based on information from trading population. This system of genomic selection enables selection of animals at a younger age and with a higher accuracy. Genomic selection leads to higher genetic improvement and better opportunities to improve traits that are difficult to record.

Exploring pigs

An important key to more specific and effective animal breeding is contained within our knowledge of genomes. After the genome of the chicken, cow, mouse, dog, tomato and human, the genome of the pig was sequenced at the end of 2012 by an international research team, co-headed by Wageningen UR professor Martien Groenen. His team of scientists investigated genetic similarities and variations between various domesticated and wild pig species in Europe and Asia. A remarkable finding was that genetic variation measured at the DNA level is two to three times larger within most commercial pig breeds than within humans.

Humans and pigs share a history that dates back 10,000 years to a time when people in Europe and Asia independently started domesticating this animal. Since then, the pig has been a major source of animal protein and pork has become the most commonly consumed meat in the world. The annual production and consumption is now some 100 billion kilos. Research into the pig genome has provided important insights into the effects of domestication; for example, pigs have become taller and domesticated breeds have up to four vertebrae more than wild pigs. The effects of domestication on genetic variation have also been mapped as part of the research, providing insights that can be used to improve currently used pig breeds.

Genetic variation measured at the DNA level is two to three times larger within most commercial pig breeds than within humans

Characteristics

With our new knowledge of the genome, breeding can be more effective for characteristics that are difficult to measure in practice. Utilisation of genomic information in breeding is often referred to as genomic selection and used, for example, for pigs to select against boar taint. Pedigree information to relate animals in the slaughterhouse and parents in breeding lines is generally lacking. As a consequence, an observation of boar taint in slaughterhouses cannot be used in the selection of parents in the breeding line. However, the ability to collect genomic information on a large scale allows breeders to use data from slaughterhouses in selecting parents that produce offspring with little or no boar taint. Other opportunities for genomic selection on difficult traits are available in the field of health, methane emissions from cattle, sensitivity to climate and product quality.

Thanks to the rapid technological developments it is possible to determine the complete genome sequence of multiple individuals within a population. By applying bioinformatics, this genome data provides a wealth of information about the origin of genetic variation in traits and the impact of selection on the genome.

The selection of parents for the next generation forms the basis for genetic improvements resulting from breeding programmes. Being able to detect animals with good genetic characteristics at an early stage is essential. By applying DNA knowledge it is no longer necessary to wait for information on their offspring. This form of selection has recently been applied to dairy cattle for a wide range of traits, and the first steps in poultry and pig are also being taken. There are huge opportunities for the improvement of breeding programmes in which information collected at farms or slaughterhouses is used more effectively. The application for boar taint is only one of many examples.

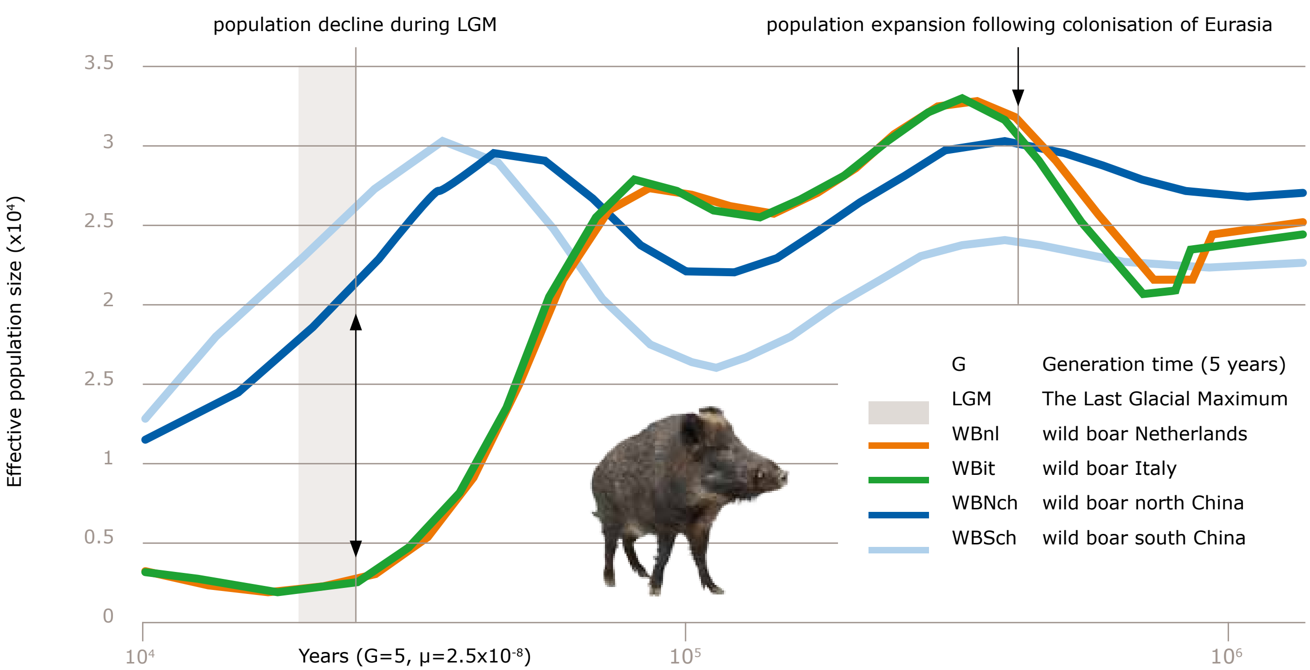
Genomics

The development of sustainable breeding programmes requires better insights into the importance of genetic differences between animals. Within this framework, genomics offers a unique opportunity to trace functional mutations that contribute to genetic variation between animals. The research also provides further insights into mechanisms that form the foundation for the relationship between traits; knowledge that is important to gain an insight into trade-offs between traits and to prevent any unwanted effects of selection.

Genomic selection also offers good opportunities for breeding programmes in countries with no systematic registration of pedigrees and traits. After all, breeding principles are universal. As long as the implementation is adapted to the conditions, local species can be further improved while maintaining their often unique characteristics. ■

Demographic history of wild boars

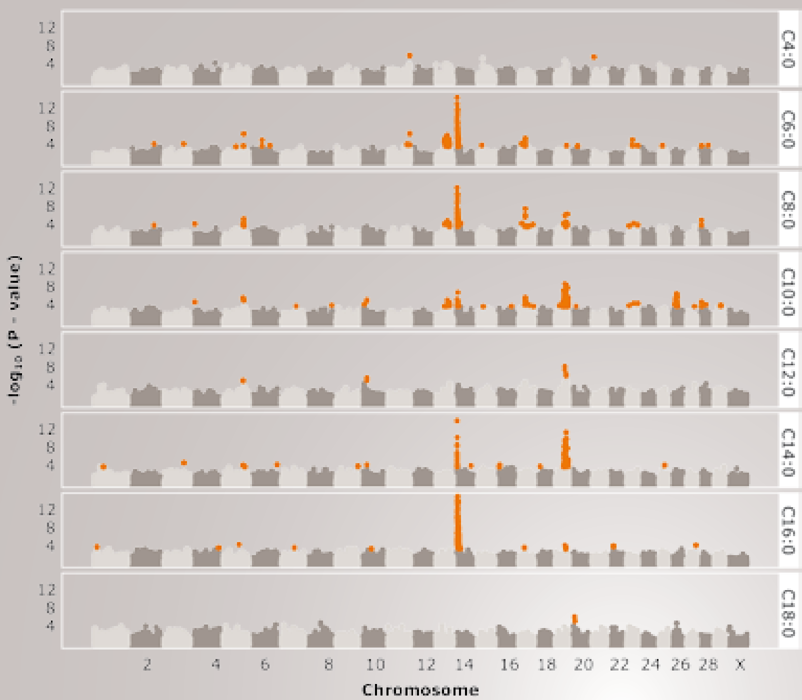
The figure clearly shows that the wild boar populations in Europe and Asia declined as a result of the climate change during the last ice age. This decline was much more severe in the European wild boar.

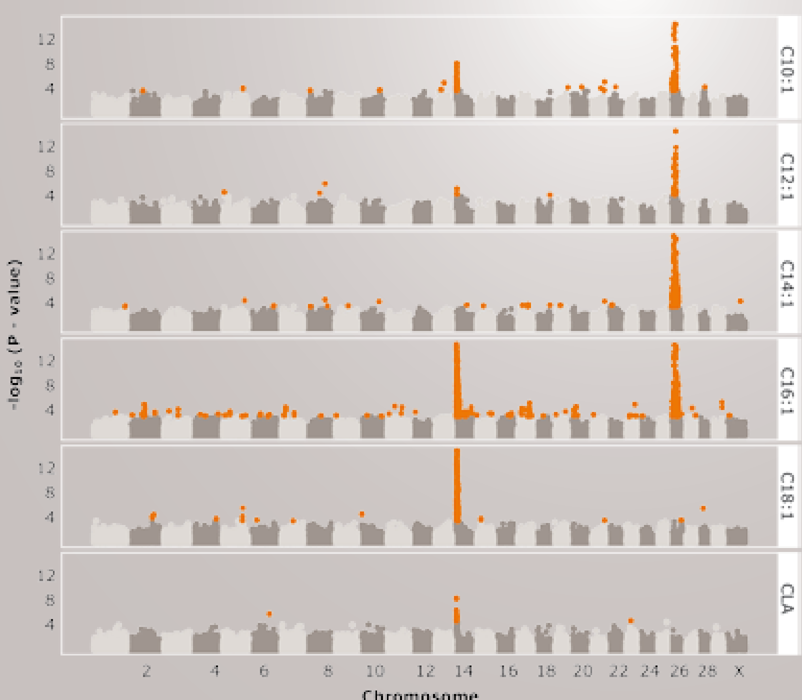


Demographic history of wild boars. Demographic history was inferred using a hidden Markov model (HMM) approach as implemented in pairwise sequentially Markovian coalescence (PSMC)45. In the absence of known mutation rates for pig, we used the default mutation rate for human (m) of 2.531028.

Source: Martien A.M. Groenen et al., Nature 491, 393–398 (2012) doi:10.1038/nature11622

Results of genome-wide association study for different fatty acids in milk





In this study we performed a genome-wide association study (GWAS) to unravel the genetic variaition in bovine milk fatty acids in milk samples collected in the summer. For this GWAS 1656 cows were genotyped for 50,855 SNP markers covering the entire genome of a cow. The GWAS of milk samples resulted in 51 regions associated with one or more milk fatty acids. The most significant region explained 2% up to 50% of the genetic variation in a fatty acid. This analysis provides new insight in fatty acid synthesis. It revealed that milk fat compostion can be altered by selective breeding.

The y-axis gives the amount of evidence that a SNP influences saturated fatty acids (A) and unsaturated fatty acids (B).
The genomic position is represented along the x-axis and chromosome numbers are given on the x-axis. The analysis revealed a number of chromosomes with a clear effect on fat composition (represented by orange squares). (For more details see Bouwman et al. BMC Genetics 2012 13:93)

Natural variation as the key to nutrition security

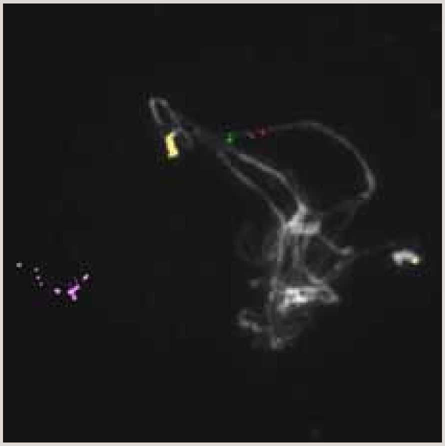
Genes and their environment

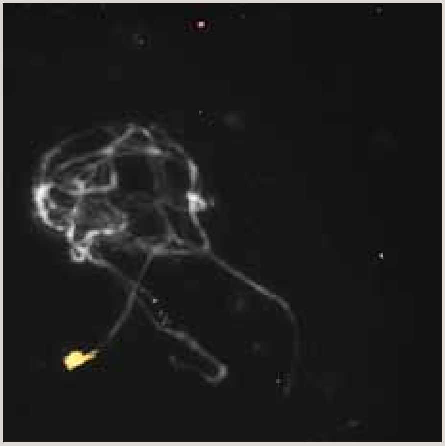
Wouldn't it be great if the earth was one giant greenhouse; not the often discussed greenhouse that results in unpredictable climate change, but a greenhouse in which we can fully control the conditions. In the absence of this (agricultural) nirvana, we have to adapt to changing environmental factors and utilise the natural variation of the planet.

In addition to our green fields and pastures, we will have to use land and natural environments that have thus far remained untouched if we are to feed everyone on earth. There is very little increase in the yield of existing crops on 'ideal' land and certainly not enough to feed the projected nine billion world inhabitants by 2050. Furthermore, many crops are not resistant to plagues in the long term. The commercially attractive banana varieties, for example, are exceptionally vulnerable to Panama disease, which is a very difficult to control disease. Moreover, the conditions in many regions are altering due, for instance, to climate change and the associated extreme weather types. Cultivation of new land and regions that were previously deemed too dry, too saline, too deficient, too cold, or too hot requires plant varieties and animal species that can thrive in more extreme conditions. The question is whether there is a silver bullet, a jack-of-all-trades. Evolutionary biologists, (quantitative) geneticists, and statisticians and mathematicians, united in the Wageningen research groups Genetics and Biometrics, do not think so. They believe that it is mainly natural diversity which will have to facilitate the required global production increase.

In the selection of plants and animals, biologists, agriculturalists and geneticists nowadays look mainly at the interaction between genes and the environment. For a long time, the agricultural system was focused

Chromosome painting in tomato





In support of the DNA analysis of the tomato genome researchers are eager to know the position of small DNA fragments on the chromosomes (here in grey). To this end sequences as small as 700 - 2000 base pairs are isolated, painted with a fluorescence dye and hybridised on the chromomes. The two photo's show small green, purple and red spots of specic painted DNA; the big yellow region represents a big chromosome segment that contains part of the ribosomal genes, one of the most common sequences of the genome.

Arabidopsis thaliana L., selected as model orrganism to investigate the differences in genetic characteristics of the types that thrive in various environments to determine the relationship between genome and surrounding factors.

on strengthening the 'positive' elements of known varieties. Traditional breeding was aimed at achieving the highest possible yields. Practical factors were also important in the history of domestication. Crossbreeding, for instance, led to the development of grain varieties with higher yields because of a relatively short, thick stem. As a positive side effect, and additionally increasing yields, these varieties also much better survive bad weather at the end of the growth season. For a long time, European agricultural policy was also focused on growth in scale and uniformity. Now it seems that things are changing with a greater focus on regional variation, which is in turn creating opportunities for gene-environment research.

Mapping genomes

Fundamental knowledge of genetics became part of breeding a relatively short time ago. Now that scientists have mapped the genomes of certain crops, they can also find out which genes play a part in growth, plague resistance, nutrient intake, resistance to drought and more. With this knowledge they can make better choices and develop agricultural crops for land that has remained unused so far. This has led to a search for the mechanisms behind the successes and failures in agriculture.

The importance of plant and animal environments is shown in a number of practical cases. Dutch dairy cows only produced a fraction of the expected milk when they were introduced in Brazil. A European plant that colonised the United States thrived there in the absence of natural enemies, but turned out to have neglected its resistance against these pathogens and did worse than its immediate ancestors. The relevance of origins is also a factor for 'our' potato; the required pathogen and plague resistance was found in its ancestors from South America. The relative strength of plants can often be explained at the genetic level. This is where the plant holds the possibilities for adapting to new conditions and, therefore, the key to success or failure.

Alpine Pennycress (*Thlaspi cearulescens J. Presl & C. Presl*) is selected to study the characteristics of plants that have fully adapted to extreme conditions.

The evolutionary biological research of the Laboratory of genetics led by professor Bas Zwaan, is performed in three ways. Initially, scientists select a generally occurring plant as model organism (*Arabidopsis thaliana L.*, or thale cress). They look at the differences in genetic characteristics of the types that thrive in various environments to determine the relationship between genome and surrounding factors. In the second approach, they study the characteristics of plants that have fully adapted to extreme conditions. For this they for instance use Alpine pennycress (*Thlaspi cearulescens J. Presl & C. Presl*), which is related to thale cress as a model organism, allowing them to find the genes that make the plant suitable to the environment (and vice versa). With this type of research they can also discover the general mechanisms of, drought, salt or metal tolerance in plants. The third line of research uses selection experiments and experimental evolution with rapidly reproducing micro-organisms and insects to find the – often complex – mechanisms involved in adaptation to strange environments. These studies provide fundamental insights into the causes and limitations of adaptation that are also relevant to plant and animal breeding, biotechnology, and conservation biology.

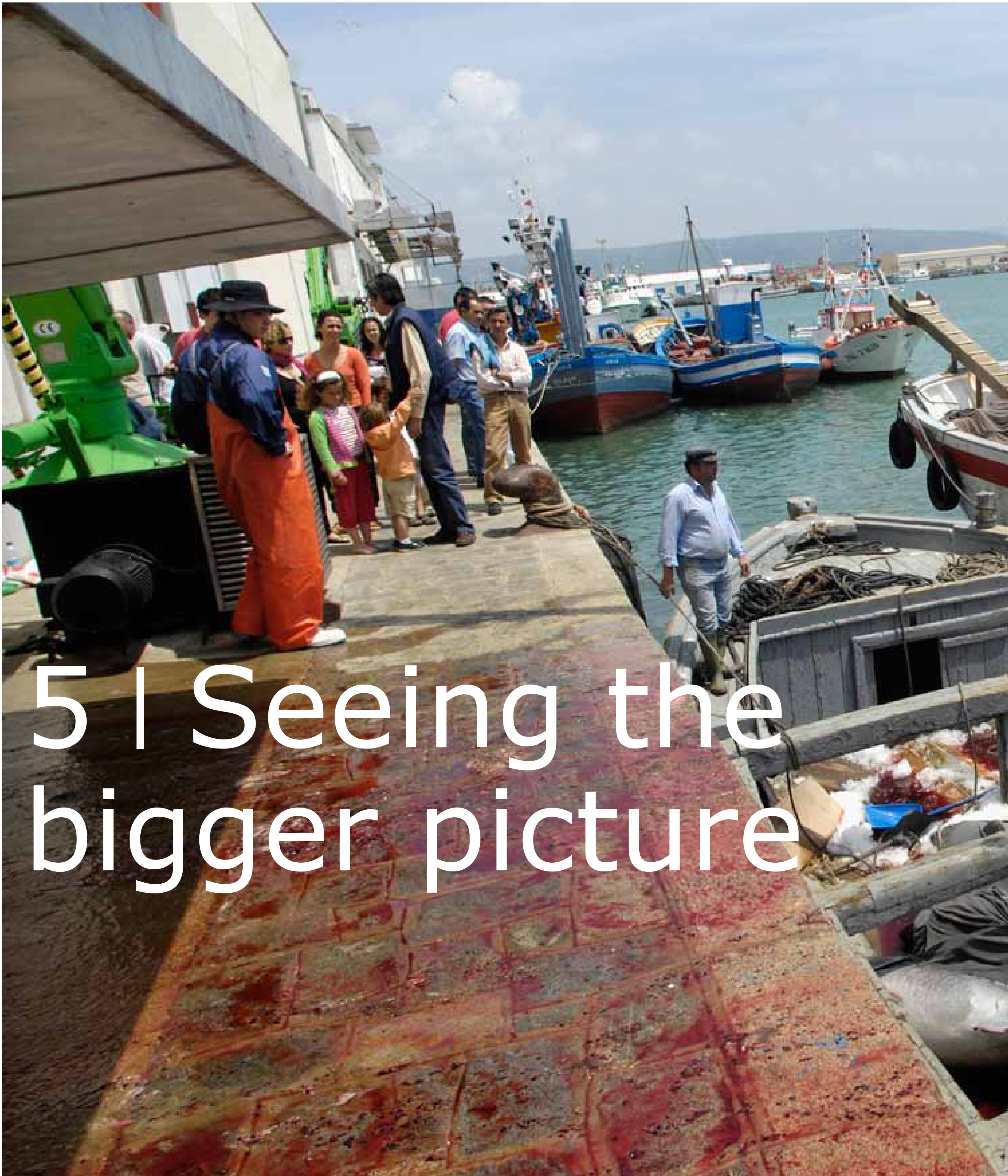
There will always be trade-offs between characteristics such as growth speed, tolerance, weather resistance and resistance against plagues

Smaller ecological footprint

The idea behind the three developments is the same: Achieving a higher yield with a lower input of scarce resources such as energy and nutrients, and limited use of pesticides. Thus, argiculture with a much smaller ecological footprint. 'More with less' can be achieved by looking for the best, most adapted variety or species per environment. This can very possibly be attained by exploiting natural genetic variation, tried and tested over millions of years of evolution. However, adding new genetic variation via genetic modification and/or from different plant varieties can sometimes just give the push breeding needs to develop more efficient varieties. This differs from the traditional GMO development that was largely characterised by the previous desire to strengthen the classic success factor of 'yield'. Since there is no such thing as a free lunch, there will always be trade-offs between characteristics such as growth speed, tolerance, weather resistance and resistance against plagues, as well as individual and group success.

The value of this Wageningen research is its contribution to the growing variation of (food) crops. It is already shedding light on genetic resources that are only visible at the genome level. It shows how crossbreeding can result in varieties that are better adapted to specific environments and which can therefore provide the solution to local problems as a result of issues such as climate change. Breeders have already embraced the philosophy regarding the relationship between genes and environment. They test promising crops and varieties in various countries to see how well they fare in those specific conditions. Preferably, they would like to find a variety that they can sell in as many countries as possible and in emerging economies. Nonetheless, niche markets where specific variations have proven their value are also becoming more relevant. ■

5 | Seeing the bigger picture



Food production is part of a larger system and interventions in the food production system affect other qualities of Planet Earth. We need a systems approach to avoid spiralling into unsustainability and declining food production. The shrinking of the fish population is a striking example. On the animal farm too, neglect of the quality of the ecosystem, animal welfare or the income of farmers' households will have a negative effect in the long run. A systems approach combines local and global views and connects short and long-term perspectives.

Sustainable food supply

A matter of choice

The idea that intensification is required to meet the food demands of nine billion people by 2050 is both obvious and overly simplistic. There is no single solution for achieving a sustainable food supply. The eventual choice for a system or innovation must be individually tailored to each country or region, depending on the agro-ecological and socio-economic circumstances. The urgent need for a sustainable food supply compels us to make choices.

Livestock production stands at a critical crossroad. The impact on the environment is considerable and society is increasingly concerned with issues such as animal welfare. As a result of growth of the global human population, rising incomes and urbanisation, the demand for food from animals is expected to double. Many people have opinions about the future food supply, ranging from 'there is sufficient food for nine billion people, but it isn't being properly distributed' and 'organic is better for animal welfare and the environment' to 'meat consumption should be limited' and 'agriculture should be intensified'. Imke de Boer, professor of Animal Production Systems, is in her element in such discussions: "A transparent discussion requires a clear understanding of the impact of innovations on the diverse issues of sustainability."

De Boer's team is studying the consequences of innovations in livestock systems across the world, with special focus on their impact on the environment, their impact on animal welfare and their impact on the livelihoods of farmers. Their research provides insights into the possibility of designing systems that respect individual animals, make efficient use of natural resources, minimise (local) emissions into the environment and are economically viable.
Such a multifaced issue like this cannot be resolved by simple answers; especially with regard to the global food supply. Goals that involve sustainability can be conflicting and the idyllic win-win situation is often unrealistic. A new housing system, for instance, can sometimes be profitable in one issue of sustainability but disadvantageous for others. The eventual choice

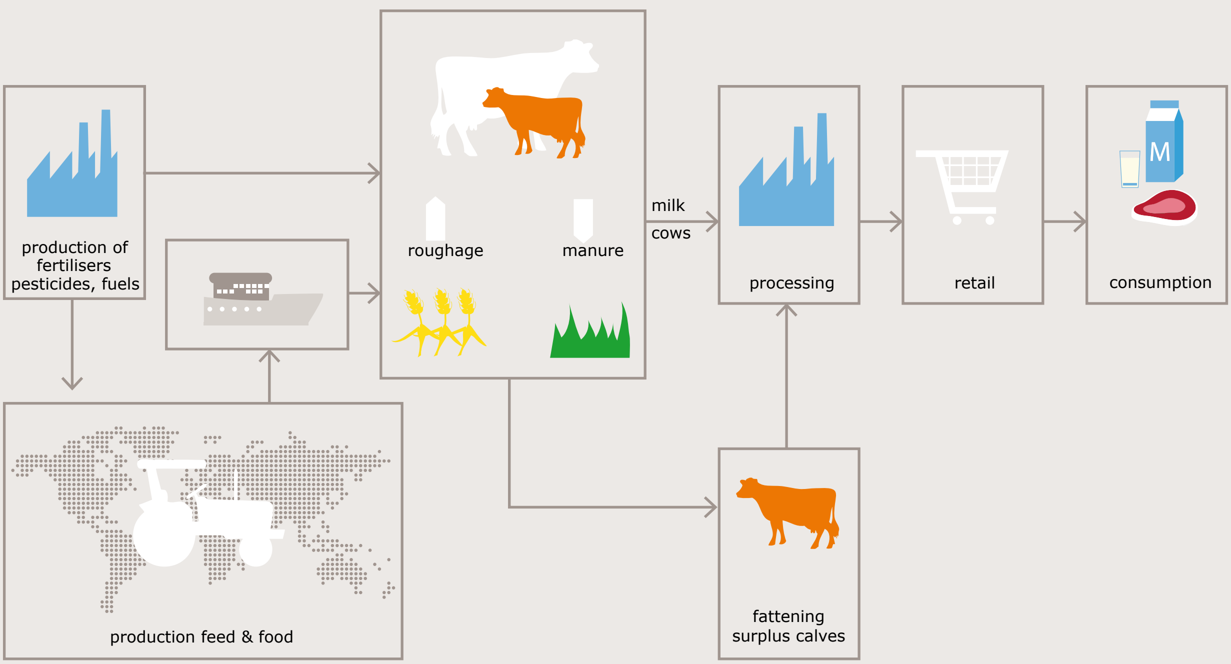

Environment
Innovation
Animal welfare
Livelihood

Water consumption

A recent study focused on measuring freshwater consumption in the production chain of milk – in other words, determining the 'water footprint' of Dutch milk. It made a distinction between the various types of water consumption: Green, blue and grey water. Green water is rain water available for growth of plants; blue water is ground or surface water that is largely used to irrigate food or feed crops; and grey water is a virtual amount of water required to dilute polluted water. The study shows that green water consumption is not automatically negative, as this rain water available for plant growth would evaporate with natural vegetation as well. A change in the availability of green water does have an effect on the environment. The effect of blue water consumption appears to be largely region-specific. For instance, the production of broccoli in Spain has a greater impact on the environment than the production of milk in the Netherlands. Grey water consumption is an indirect measure of water pollution and says little about the impact of water consumption on the environment.

The road from soil to supper

The road from soil to supper offers many opportunities to improve both food quality and sustainability in terms of the environment, animal welfare and farmers' incomes.



for a system or innovation is tailor made and requires careful consideration of all the issues involved.

Organic milk

In the Netherlands, the pasturing of cows helps build a positive image of the dairy sector. It therefore has value, regardless of how important the pasturing is for the wellbeing of a cow or its effect on the environment. For a dairy cooperative it can be an important reason for stimulating farmers to allow their cows out to graze. The choice for organic milk also varies strongly between different countries. This more extensive form of milk production leads to a reduced local environmental impact (i.e. eutrophication per kg of milk and per ha of land), a lower or similar global impact (i.e. fossil energy use or global warming per kg milk), but requires 40 percent more land per kilogram of milk. The percentage of organic milk in the total milk production of a country like Denmark, which has a low population density, is higher than in a densely populated country like the Netherlands. Where in one country land use is less relevant and the local impact of the organic production of milk can be kept relatively low, conventiona milk production is a more logical option in other countries. This does mean, however, that it requires additional measures to limit the local environmental impact.

Goals that involve sustainability can be conflicting and the idyllic win-win situation is often unrealistic

Re-define effiency

Although increasing the productivity per animal is useful in, say, pasture-based beef production systems in Central America, it is less desirable from a welfare perspective in intensive broiler production systems in the Netherlands. A smallholder in Sub-Saharan Africa benefits more from a measure that increases the survival rate of his stock, than from one which improves the productivity of his livestock. Livestock in smallholder systems often fulfil more functions than producing food alone, such as to provide manure or draught power for crop production or serving as a capital asset.

In addition to tailor made solutions, De Boer advocates to re-define efficiency in animal production. “Traditionally, efficiency is defined at the level of the animal, e.g. how efficient does an animal use his or her feed. We should look at efficiency from a chain perspective. It has been shown that innovation at the ‘animal level’ does not always result in an improvement for the entire chain”. For instance, if you feed a cow more maize silage than grass (silage), it will emit less methane (a major greenhouse gas) per kilogram of milk. But if you take into account that grassland will have to be converted into maize land, it turns out that the measure only becomes effective after around 45 years. From a chain perspective, extending the lifespan of a cow is a more effective strategy for reducing greenhouse gas emissions.

It is also important that whenever possible we avoid competition between humans and animals with regard to use of resources, such as land. Research in the UK has shown that pigs and chickens in particular eat more feed (in terms of protein and energy) which humans could eat themselves than the animals actually produce. This is not a sustainable situation. Livestock should preferably be fed products that are not suitable for human consumption, such as grass or waste streams from the industry. Integrating livestock production in cycles and valorising those waste streams, which are unsuitable for human consumption, provides an opportunity for a sustainable livestock sector. ■

Black magic

Nitrogen fixation provides African farmers with room to breathe

Two spoonfuls of 'black magic powder' can double the yield of an average African field used for growing leguminous plants.

Legume crops such as beans, peanuts and soy can fix nitrogen from the air, and flourish on nitrogen-deficient soils. To do so, they need help from *Rhizobium* bacteria. These special bacteria stimulate the growth of nodules on the roots of leguminous plants. The bacteria help the plant by extracting nitrogen from the air, while the plant helps the bacteria grow by supplying carbon. It is a perfect symbiosis. Thanks to the bacteria, the leguminous plants are less reliant on (artificial) fertilisers. As a result they form part of the solution for infertile African fields where the harvests are far lower than in the rest of the world. The cause for these low yields is well-known: A lack of inputs such as artificial fertiliser, limited crop diversity, and poor access to knowledge.

But legumes are minor crops in Africa. Instead, African farmers mainly grow carbohydrate-rich staple crops such as maize, sorghum, millet and cassava. These crops are unable to perform the nitrogen fixation trick and therefore entirely reliant on nitrogen in the soil. Due to low soil fertility, the harvests lag far behind what is technically feasible. This is where we find the so-called yield gap. Moreover, where the bacteria are naturally abundant in the soil elsewhere in the world, they are often absent in the deficient African soils.

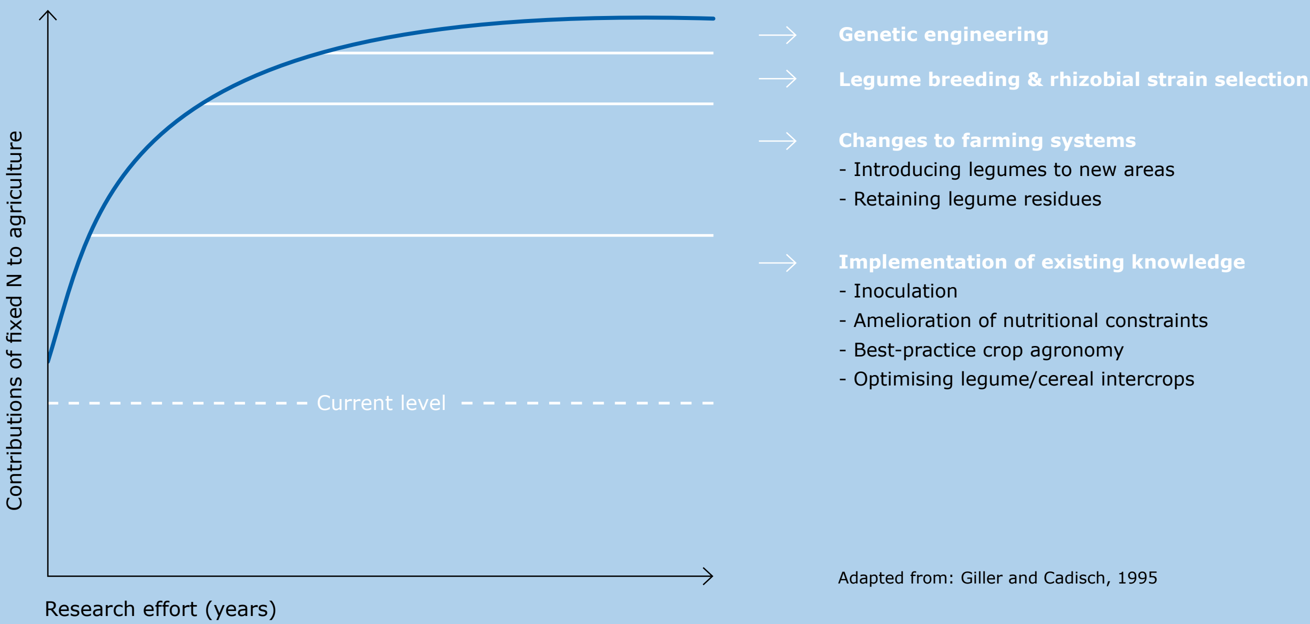
More than 100 years ago, scientists found a relatively simple method for cultivating the bacteria and coating them on seed at planting. Over the past three years, project leader professor Ken Giller introduced new varieties of beans, peanuts, cowpea and soya in eight African countries with the support of the Gates Foundation. Over 200,000 small-scale farmers south of the Sahara saw their land yield increase and sometimes even double thanks to a few spoonfuls of peaty powder in which the bacteria thrives. The local population in Ghana lovingly call it black magic while the scientists speak of inoculants and call the project N2Africa.

System analysis

Although the project had its origins in the desire of the Bill & Melinda Gates Foundation to generate direct results, Giller has shifted from a 'best bet' to a 'best fit'

Potential returns to investment on research and development investment

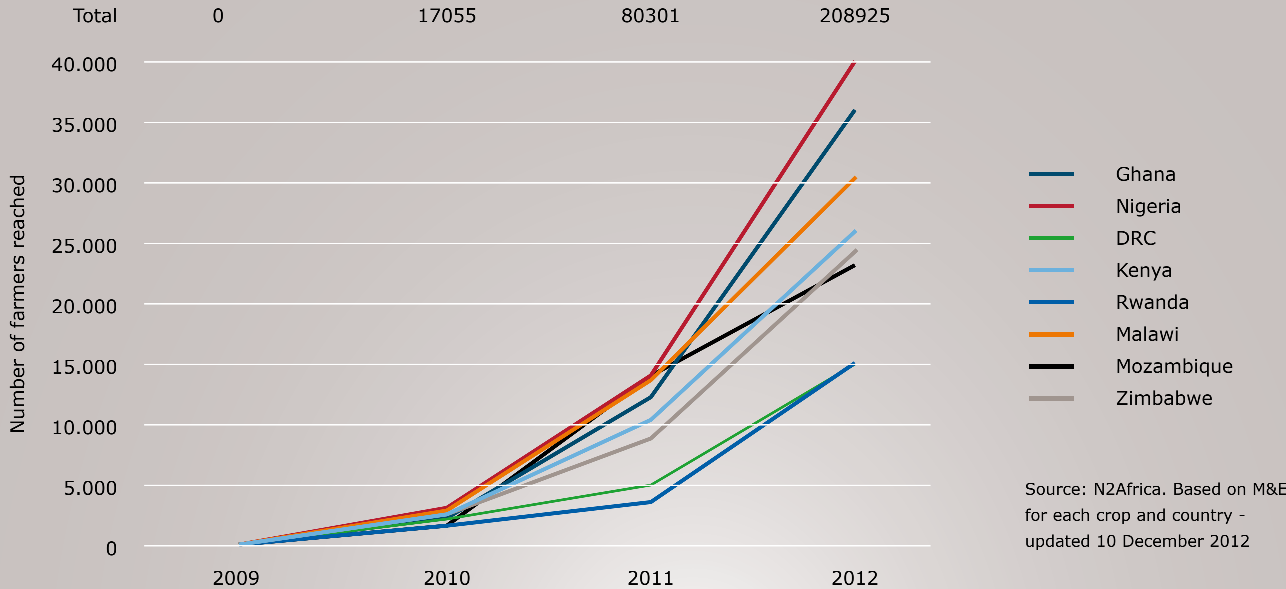
The contribution of different approaches to enhance the inputs from biological nitrogen fixation



Adapted from: Giller and Cadisch, 1995

Women's farmer group in Nigeria, standing a luxuriant crop of soyabean.

Number of farmers reached



Source: N2Africa. Based on M&E for each crop and country - updated 10 December 2012

The use of extra rhizobium bacteria leads to a spectacular increase in both nodule formation and yields.

N2Africa

Scientists of Wageningen UR work in the N2Africa project together with international research and development organisations to improve the nitrogen fixation in African agriculture. The project is focused on exchanging knowledge, implementing modern technologies at a local level and working with local farmers. The joint initiative is active in eight African countries: The Democratic Republic of the Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda and Zimbabwe.

solution in which the scientists first look at the current agricultural methods and enable farmers to try out new technologies. By comparing the experiences in the eight different countries, it will become clear how farmers can best apply the nitrogen fixing bacteria and adapt other production increasing technologies at a local level. The project also looks at how the legume crops can improve operational management, income and food supply for the farmers' families.

The bacterial inoculants are produced in partnership with the local industry, taking into account quality standards that were developed for their production.

'Helping small, poor farmers achieve better yields for their own consumption and to sell at local markets is the most powerful way of combating hunger and poverty around the world'

Bill Gates

By using simple techniques, African farmers can add the bacteria and a small amount of nutrients to the soil when sowing their fields. To ensure the cultivation is successful, they must also apply the best available varieties of the legume crops and an improved crop management. Soil infertility is analysed per region and tackled with organic manures, backed up by artificial fertiliser where necessary. Region- and crop-specific fertilisers are developed in cooperation with manufacturers of artificial fertilisers.

Although fixing nitrogen from the air when there is a lack of nitrogen in the soil is a major success factor, the legume crops cannot overcome the yield gap entirely without the use of other fertilisers. A relatively simple measure such as different mixtures in intercropping, in which grain and legume crops are grown on the same field, also considerably increases production. This can result in twice the yield, enough for many farmers to make the extra money they need for other life necessities and the schooling of their children.

Governance

As the local impact of N2Africa on agricultural yields has been so significant, one could almost forget that the project itself is focused on analysing the regional agricultural, economic and social systems and their resources. Understanding those elements could help develop new systems and networks, and achieve more specific knowledge transfer and development.

Not all factors determined by science can be solved with techniques, however. Giller names weak markets and poor governance in several African countries as a much larger issue than soil infertility. The poverty of many farmers is not only the result of poor natural conditions. The combination of an excessively low yield per hectare and the small farm size forms a serious poverty trap as well.

With these insights Giller hopes to avoid the pitfalls often encountered by scientists who overly focus on technology. ■

Health

The introduction of leguminous plants represents more than just an increase in the diversity of food crops. The high-quality proteins and higher concentrations of B-vitamins, iron, calcium and zinc from legumes are, in particular, a valuable addition tothe often one-sided and carbohydrate-rich African diet. Soya milk, for example, can also provide essential nutrients for growing children.

The balance between short-sightedness and utopian thinking

Perhaps the main reason why food provision is so high on the agenda today is that the world allowed itself to be lulled into complacency by the successes of the 1990s. Food prices were falling and, apart from some environmental problems, no clouds seemed to be on the horizon. Confident that we could feed a growing world population, agricultural innovation was neglected – a mistake that has been haunting us ever since.

The fairly dramatic price increases, especially of grain, between 2007 and 2008 were a wake-up call. The cost of food as a proportion of daily expenses had been decreasing for half a century but this might be coming to an end. This is not an acute problem for the Western world, which barely felt the increase in its disposable income. For people with limited purchasing power and an unbalanced diet, however, the price rises came as a hard blow.

According to Martin van Ittersum, professor of plant production systems, the global agricultural system is undergoing a paradigm shift. Stagnating production growth, a rising world population, increasingly protein-rich diets, the development of biofuels, weather extremes as a possible harbinger of climate change, and market liberalisation are all current issues which require a response from politicians, industry and scientists. To call only for intensification of cultivation and a new green revolution is short-sighted and inadequate for tackling such a nexus of problems.

Based on a scientific perspective, Van Ittersum focuses on the difference between potential and actual farm yield, the so-called yield gap. How can we benefit from the growth potential of a plant? How high a yield is

theoretically feasible in a given situation? What are the causes of the yield gap? How do we deal with the finiteness of certain inputs, such as phosphate? And how do we stay within ecological limits in the long term?

The crucial biophysical factors are nutrients, crop protection and the availability of water. In the Netherlands, a proper alignment of these factors since the 1960s has allowed a doubling of yield per hectare. In Asia, too, rice yields have increased substantially. In the Netherlands, new varieties combined with nutrients and crop protection were behind this success, while, in Asia, it was mostly water and nutrients in combination with the new varieties. Nutrients will be the initial focus in closing the yield gaps in Africa.

Yield gap atlas

Van Ittersum is currently charting production possibilities and local shortcomings in a global yield gap atlas as part of an international programme funded by the Bill and Melinda Gates Foundation, among others. The first studies are already showing major differences: Relatively small yield gaps in the EU and Southeast Asia and large ones in sub-Saharan Africa and Eastern Europe. The studies conducted so far bring practical insights to light. For example, the yield gap in two rice exporting countries – Thailand and Vietnam – was found to be lower than in two other countries – Indonesia and the Philippines – which produce mainly for the domestic market. It was also found that the 'better' farmers had a lower yield gap, while using less fertiliser and labour per kilogram of rice. In two of these countries, such farmers had spent longer in school. Knowledge seems to be an important factor here.

Van Ittersum's research group also looked at the phosphate question, a concern because the mineral is both indispensable and finite. The picture seems less dramatic than many forecasted, however, in part thanks to the 'waste' of the past. The excess phosphate applied in a number of places actually formed a stock in the soil that can be made available in the future. In some places, particularly in Western Europe and parts of Asia, substantial replenishment will occur from the soil over the coming decades. The additional phosphate required may be less than the projected growth of food demand by 60%.

Tailored Solutions

There is a general conclusion that Van Ittersum feels he can already draw from the current studies: To tackle the global food problem, solutions will need to be carefully tailored to local conditions. Intensification of agriculture, in the sense of more inputs achieving higher yields, will not be an end in itself. For a sustainably higher and more efficient production in some situations, including in the Netherlands, a more economical and precise use of inputs may be an answer. In Africa, intensification will still be the solution to the yield gaps, but always in a way that is adapted to the local conditions.

To close yield gaps, and technological solutions must go hand in hand with lifting social and economic constraints. This includes rights to land and to land use, critical infrastructure, and links to the world market for food and raw materials. Science can contribute to integrated studies in this field which map the whole range of problems and opportunities: Conversion from plant to animal, collective dietary patterns, or food waste – from post-harvest losses

The excess phosphate applied in a number of places actually formed a stock in the soil that can be made available in the future

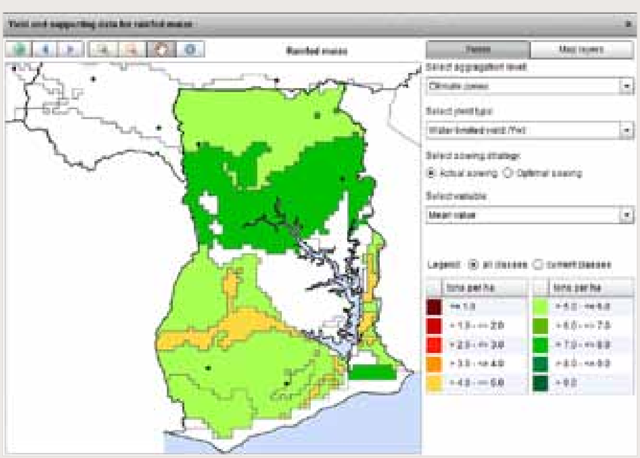
due to poor harvest-ing techniques and rot during storage, to preventing disposal and damage in the retail sector and by consumers.

In order to expand the opportunities for integrated research into farming systems and yield gaps, more than 150 scientists from around the world have been involved in the interdisciplinary research project SEAMLESS over the past years. This project developed research tools in several fields of science – agronomy, economics, environment, social science and IT – which can be used on different scales – on the level of the field, farm, region, country and world. SEAMLESS has ensured that the scientists can better understand each other in conceptual terms, allowing them to work together on solutions for the short and long term.

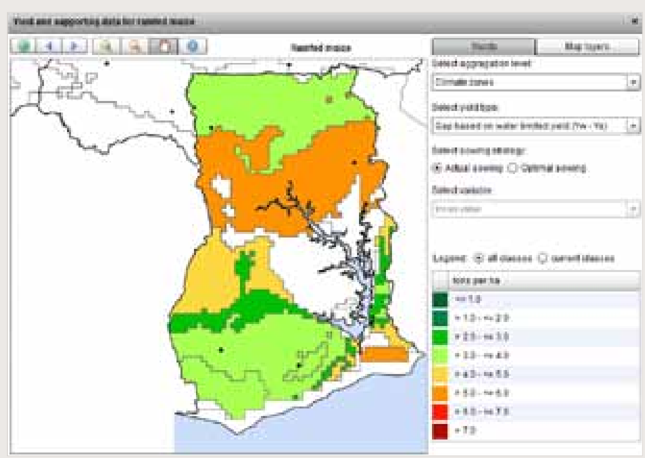
Food prices

In his research, Van Ittersum examined the delicate balance between short-sightedness (myopia) and idealised solutions (utopia). The myopic view focuses too much on food prices today: At the end of the last century they were low and lulled us into complacency; now they are high and a lot of new land is being reclaimed as part of a short-term solution to a long-term problem. Ideals such as organic agriculture can also lead to suboptimal solutions. The research programme is looking for forms of agriculture that score well on as many important factors as possible. Local sensitivity to the solutions is integrated in the research. How much of each input in terms of phosphate, crop protection and the like is actually needed? How does organic farming compare to the traditional approach? Can we invent biofuels that provide both a good energy output and profits to small-scale farmers without expanding acreage? These are all tricky questions, where the answer always must be sought at different scales and not lost in generalisations. Van Ittersum always strives to quantify the difference in yield and input use at the system level and illustrates this with both figures and maps. ■

The simulated water-limited yields



The yield gap (difference between water-limited and actual yields)



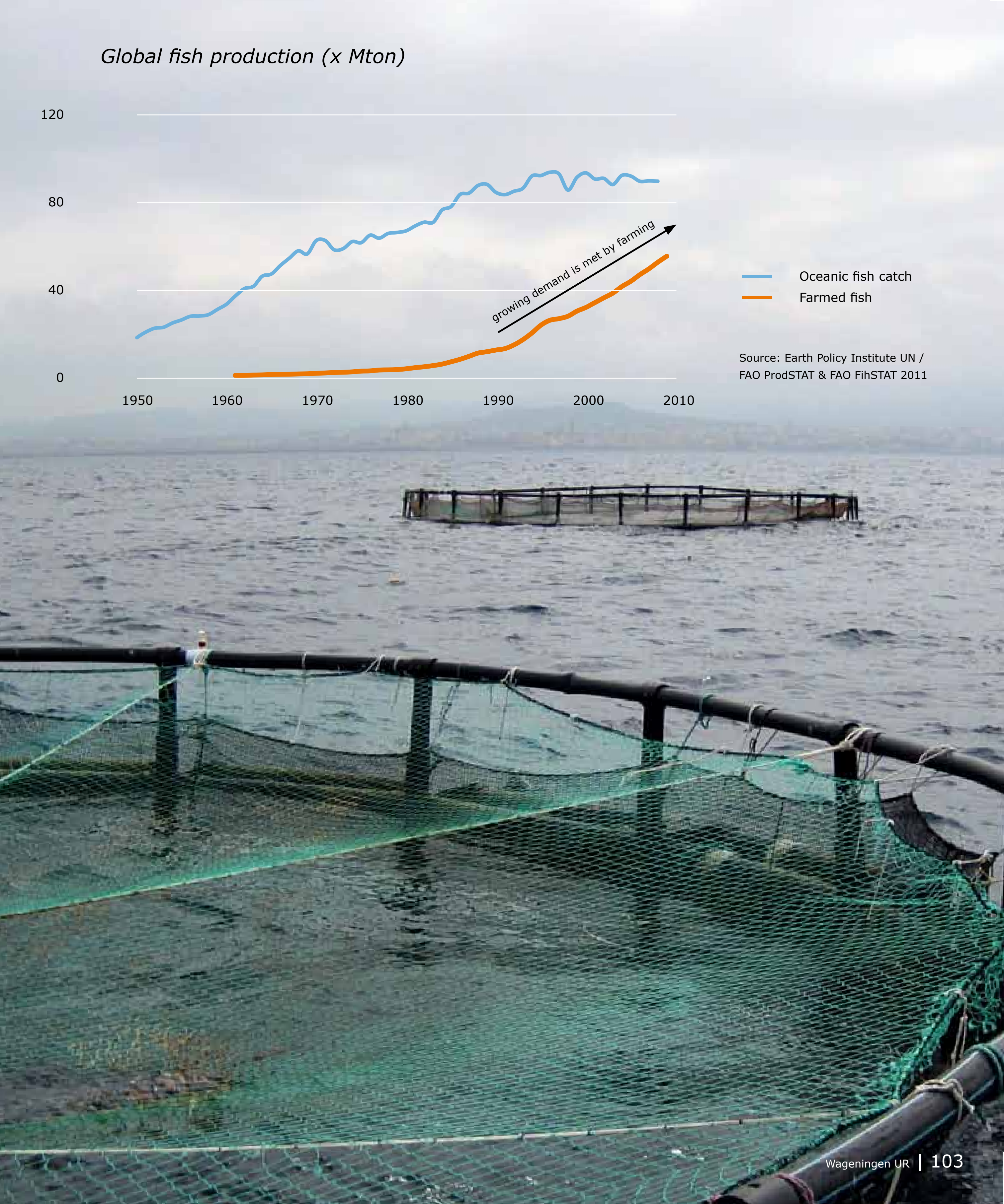
Securing sustainable seafood

Food production is not only land-based. Seafood production also deserves an important place on the agenda for sustainable nutrition security. Around 70 percent of the world's surface is water and a third of the animal proteins we consume have their origin in fisheries and aquaculture.

In addition, seafood offers significant advantages over many of its land-based alternatives, being rich in oil, omega-3 fatty acids and essential proteins, vitamins and minerals. Moreover, the efficiency of solar energy use is almost twice as high in aquatic food chains compared to land-based food chains.

The production potential of the sea was long thought to be limitless, and the harvesting of seafood has been a major source of human nutrition since the beginning of mankind. However, with many fish stocks in peril, we have come to realise that the sea and its resources need be managed much better if we are to feed a world population that is both increasing in numbers and shifting its diet preference towards animal proteins. Since 1970, the yearly per person consumption of seafood has increased dramatically from about 11kg/person/year to more than 17kg/person/year. This equals an increase of some 35 percent.

The annual production of seafood from capture fisheries has increased from 20 million tons in 1950 to 90-95 million tons today. The demand for seafood, however, is much larger, and cannot be met by fisheries alone. Controlled seafood production via aquaculture has been developed to provide the required additional seafood. Aquaculture is now a booming agribusiness, increasing its production volume by 8 percent a year over the last decade. Global aquaculture production capacity (mainly concentrated in Asia) has grown to almost 70 million tons a year. If the seafood supplies are to keep pace with the expected growth of the world's population, aquaculture should increase its output by another 60 percent in the coming decade. It is expected that the share of sea-food (fisheries and aquaculture combined) in the global food production will further increase to more than 200 million tons per year.


Global fish production (x Mton)
120
80
40
0
1950
1960
1970
1980
1990
2000
2010
growing demand is met by farming
Oceanic fish catch
Farmed fish
Source: Earth Policy Institute UN /
FAO ProdSTAT & FAO FihSTAT 2011

Maximum sustainable yield

Fish production and consumption is now regionally divided, with Asia and Africa as net exporters and Europe and North America as net importers. This geopolitical market situation will change dramatically as fish consumption in Asia and Africa increases. The challenge is to realise this expanding production and market transition in a more sustainable manner. For fisheries this means an ecosystem approach reducing losses and with less impact on the ecosystem. Such an approach must be based on the principles of 'maximum sustainable yield', with a greater focus on fish for food instead of fish for feed (currently one third of fisheries production) and less consumption of fossil fuels when harvested with passive equipment such as traps and hook-and-lines. For aquaculture this entails a reduction in the dependency on fish proteins and an enhancing of production efficiency. An example is improving fish-to-fish conversion to <1, reducing water use and shifting cultivation from (predatory) finfish to herbivorous fish, (algae feeding) shellfish and seaweeds. Poly-cultures (fish, shellfish, algae) may not only produce food for specific nutritional values, but also bio-refines and energy content.

The latest technical innovations in fisheries are related to selectivity (prevention of bycatches), quality (from a food and environmental perspective), traceability and cost (oil) reductions. Aquaculture is becoming a mature specialisation of agriculture, under controlled conditions, with applications of knowledge from the livestock farming domain such as smart breeding, customised nutrition and preventive health care.

Blue revolution

Dr Martin Scholten, in collaboration with the Wageningen UR marine scientists, is working on securing marine protein production for the coming generations by exploring the potential of the oceans. We combine our biological knowledge to devise new

Prawner

technical innovations as a contribution to the Blue Revolution. While fisheries and aquaculture are often treated separately, we sometimes explore innovations by combining the benefits of both. The essence of this *Farm the Sea* approach is to foster fish production near platforms and use passive and selective harvesting methods. These platforms can be either traditional smallholder rafts, as used in fishing practices in the Caribbean and Oceania, or modern high-tech installations for offshore energy production (oil, gas, wind, tides).

Aquaculture is becoming a mature specialisation of agriculture, with applications of knowledge from the livestock farming domain

A better understanding and smarter use of the oceans' production capacity will contribute to the challenge to feed the world within the carrying capacity of planet earth, now and in the future. While land-based agriculture phosphate is becoming running out, the oceans contain plenty of phosphates. The type of yield gap analyses used in land-based agriculture is needed to map the oceans' potential for a maximum sustainable yield from controlled fisheries and aqua-culture, or the entire spectrum of ocean farming. ■

Sole nursery

Mussel seed capture installation

Breaking the spirals of unsustainability

Green revolutions have significantly improved the global food supply over the last half-century. They have led to sharp rises in per-hectare production in the three most important food crops: Maize, wheat and rice. These discontinuities were possible due to agro-technological innovations and the expertise of the farmers who were able to make use of these new possibilities in practice. The innovations had their genesis in various disciplines and farmers received support from a number of dedicated institutes.

Rudy Rabbinge, emeritus professor of sustainable development and food security at Wageningen UR, has studied these developments and their impacts druing his entire career. Rabbinge found that the enormous growth in prmary production was – in many cases – accompanied by pollution and the inappropriate use of production systems. The question as to how sustainable the production systems are has therefore become very current. History teaches us that a careless approach to production systems can have disastrous consequences.

Erosion is in most cases caused by overexploitation, deforestation, overgrazing and poor management

The bare, eroded mountains of Greece, the silted irrigation systems along the Euphrates and the collapse of the Inca Empire are just three examples of the major impact people can have on the production capacity of agricultural areas. And widespread damage to the future production potential is still taking place on a large scale today.

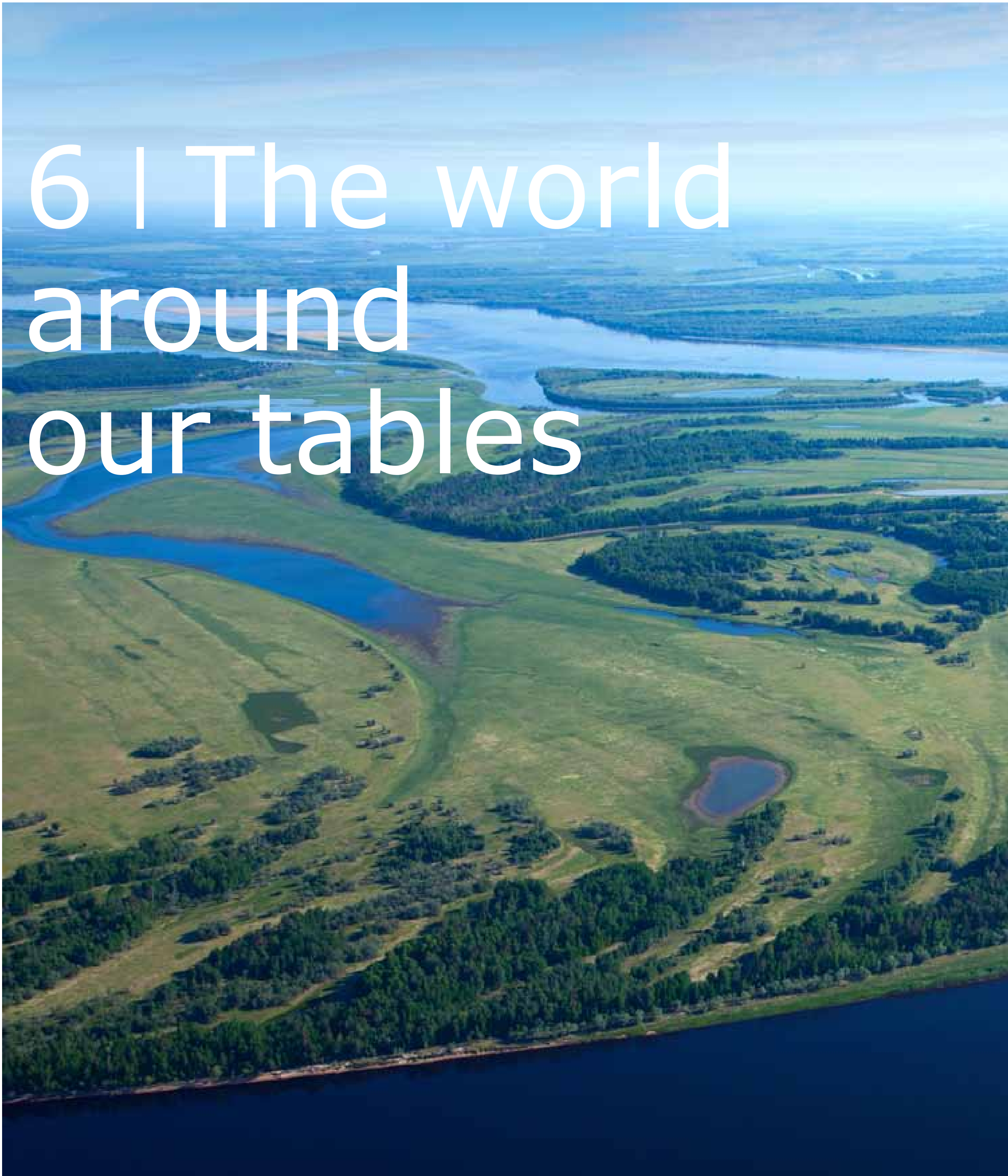
One of the most important unsustainable trends is the incorrect use of land in ways that lead to huge increases in erosion. Erosion is in most cases caused by overexploitation, deforestation, overgrazing and poor management. Another unsustainable trend is the excessive use of products like fertilisers and pesticides. Some 50 years after Rachel Carson's book *Silent Spring*, we can state that much has changed for the better. However, in many areas the overuse of the aforementioned products poses a genuine threat to future production capacity.

These trends related to the unsustainable use of the agricultural production capacity are known as unsustainability spirals. Human interventions have a negative impact on the productivity of agro-ecosystems, reducing their resilience and threatening their continuity. In order to maintain nutrition security on this planet it is vital that the unsustainable spirals caused by poverty – mainly via erosion – and due to wealth – primarily the overuse of fertilisers/pesticides – are broken. A start has been made with tackling the latter via agro-ecological renewal in various parts of north-west Europe, but much more is still possible.

Many people in Africa and Asia are being confronted with the unsustainability spirals caused by poverty and these are much more difficult to break. The majority of farmers have limited or no access to the requisite resources or knowledge. This is where breakthroughs should primarily be found, in order to prevent the despair and disempowerment that drives farmers in developing countries and regions further into poverty, and therefore leads to even more unsustainable practices. Access to services, properly functioning markets for inputs and products, and increasing the levels of know-how are therefore necessary. Obviously, attention must also be paid to the optimal use of external inputs so as to ensure that an unsustainability spiral caused by poverty is not replaced by another spiral driven by wealth. This would once again threaten the continuity of production systems that are already vulnerable.

Erosion, a wide spread damage
to the future production potential

6 | The world around our tables



For all its achievements, the green revolution has also had less welcome repercussions. We now know that many technological and social innovations in the food production-consumption chain have caused environmental damage and health hazards. With this knowledge we now can develop interventions that enhance nutrition security, sustain essential resources and protect the natural environment. In doing so, we can enable food and nutrition for generations to come via the development of smart agro-systems. Climate smart agriculture, for instance, offers a triple win: nutrition security, resilience to changes in the climate and the mitigation of climate change effects. Increasing the resource efficiency and recycling of nutrients will also help sustain the planet's ecosystem.

Algae as a multifunctional raw material

Some believe it is the solution for the raw material problem while others see a threat for nutrition security. The biobased economy gives food for thought with regard to agriculture, and has already resulted in at least one 'new' crop: Algae.

The biobased economy is developing rapidly. Within this economic system, plants play a leading role as a supplier of nutrients, energy and materials. It is the potential solution for the time when – for whatever reason – we no longer use fossil fuels. Biomass can be converted via biorefining into a number of functional chemical compounds, and from there we can theoretically make all currently used commodities. It is not a new concept, but advances in knowledge, raw material shortages, the climate issue and the constantly high price of oil have accelerated the development.

There are concerns regarding food production being reduced due to the production of crops for processing into biofuels. There is at least one crop that is excluded from the debate about food or fuel, namely algae. Algae are not traditionally a major food crop and do not take up existing agricultural acreage. They do, however, have potential as a source of protein and fat in human and animal nutrition.

Alternative raw material

After two brief periods of increased interest – as a source of protein in the 1950s and as an energy source during the energy crisis of the 1980s – the breakthrough of algae seems definitive since Al Gore's 'An Inconvenient Truth' in 2006. Gore advocated a careful relationship with the planet and a reduction of CO_2 emissions. With this increased awareness, biomass caught the attention of scientists, companies and politicians as an alternative raw material. It also resulted in renewed interest in the possibility of extracting fats, fish oil and protein from algae. This combination made algae interesting to the food industry and energy companies. Today algae serve as a source for protein, glucose, fats, pigments, omega-3 fatty acids and biofuels. They are not food or fuel, they are food and fuel.

René Wijffels, professor in Bioprocess Engineering started his research into algae in 1997, based on the idea that it would enable increased biomass production

Food commodities from microalgae

Overview of key features, which need to be considered to enable successful sustainable, cost effective and safe product applications

Production technology
Photobioreactor
Location
Microalgal species
Water source
Medium use
Process strategy
Down stream processing
Biorefinery

Sustainable assessment
Water use
Land use
Land use change
Medium use
Eutrophication
Global warming
Energy demand

Safety assessment
Toxicological data
History of safe use

Oil
Triacylglycerides
Fatty acid profile
Function
Health benefits

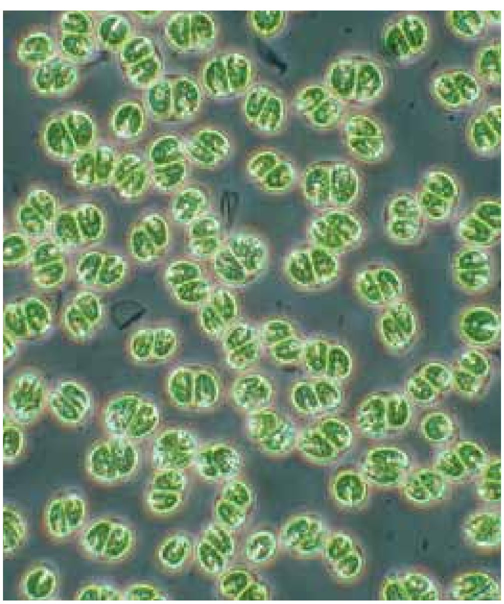
Protein
Amino acid profile
Solubility
Function
Health benefits

Product application
Taste
Appearance
Colour
Nutrition
Structure
Processability
Stability
Consumer acceptance

Source: Food commodities from microalgae, René B. Draaisma, René H. Wijffels, Ellen Slegers, Laura B. Brentner, Adip Roy and Maria J. Barbosa.

Wageningen and the Biobased Economy

The algae research by René Wijffels and Maria Barbosa is part of the much wider research field of biobased economy, in which Wageningen is involved with various groups throughout the university. Together with partners from the industry, government and other knowledge institutions, scientists are developing applications and solutions by combining as much technical innovation and socio-economic value as possible. The research is focused on the production and processing of biomass and upgrading it into biobased raw materials and (semi)manufactured products. Wageningen UR is working on creating a fundamental basis by initiating technological developments, organising new partnerships, establishing chains and creating new biobased products and production processes. The principle behind the Wageningen research into the biobased economy is that it contributes to an economy in which food for people and animals, chemicals, materials, transportation fuels, electricity and heat are generated from green, renewable raw materials in an economical and sustainable way. Determining the sustainability of biobased developments relies largely on life cycle analyses. Another tool that is also used to qualify developments in the biobased economy is the value pyramid, partly developed in Wageningen. It classifies products and product groups based on their social and economic value. This shows that pharmaceutical products have the highest added value, followed by food and animal feed. The basis is formed by the energy applications – these have a much more limited value per product unit, but have a large social value due to the wide range of applications. For some it is a matter of choosing between the base and the top of the pyramid, but achieving a biobased economy requires successful combinations of all product types.



Tetraselmis suecica

At the test facilities in Spain algae absorbed an impressive 6.5 percent of sunlight to create biomass.

with the same amount of light. The majority of plants only use one percent of the sunlight that reaches them; most algae absorb twice as much. But this did not satisfy Wijffels who sought to move towards the theoretical maximum of ten percent. In 2008 he achieved 6.5 percent in optimal summer conditions. For this breakthrough, Wijffels' research group used test facilities in Spain. Nowadays Wijffels and his colleague Maria Barbosa have an AlgaePARC at their disposal at the Wageningen campus where they can develop the best possible conditions.

Cowboys

Wijffels is reluctant to make predictions about the future: "There used to be cowboys who promised that they could resolve the energy issue using algae within two years. We have been telling a more realistic story since the outset. As an independent party, we are also more able to list the disadvantages." These currently include the high consumption of energy, water and phosphorus. Progress is further held back by the slow upscaling and industrialisation of the processes. Moreover, it is still difficult to extract CO_2 as a growth substance from the atmosphere.

The combination of fuel and food gives algae unprecedented potential whereas the production of biofuels from algae also supplies a useful 'waste product': Protein. A complete switch to biofuels in the EU, if based on algae, could provide as much protein as a by-product as Europe currently imports as soya protein. Despite this obvious win-win situation, the world needs breakthroughs in algal research. The industry is however, interested as is illustrated by its involvement in the AlgaePARC. Companies from the oil sector and the food industry (human and animal food) support this pilot research facility within Wageningen UR and keep in close contact regarding the developments.

2x more with 2x less

Sustainability is a precondition for scientists and companies alike. Palm oil in food and cosmetics, fishmeal for fish farming, maize as a basis for biofuels; these are all scarce raw materials that should be handled with care. Algae could be a welcome addition or replacement. They also contribute to Wageningen UR's goal to double food production while reducing the environmental impact under the motto: '2x more with 2x less'.

When it comes to locations, Wijffels is looking both south and towards the sea. There are already possibilities in the Sahara, where algae cultivation would be possible with salt groundwater. Sea water could be used at other locations, like the coastal desert at the border of Chile and Peru and around the Red Sea. Growing algae and seaweed at sea is another attractive option as well, although it still faces many technological and financial hurdles.

The contribution of algae to global food security is definitely an option in certain tropical countries where the standard diet is monotonous, based on carbohydrates from maize and other grain. With the protein from an algae installation, the local population can avoid hidden hunger. The direct use of algae as food in fish farming, and especially tilapia, also contributes to controlling food shortages. ■

Palm oil in food and cosmetics, fishmeal for fish farming, maize as a basis for biofuels; these are all scarce raw materials that should be handled with care

Environmental benefits and high nutritional value

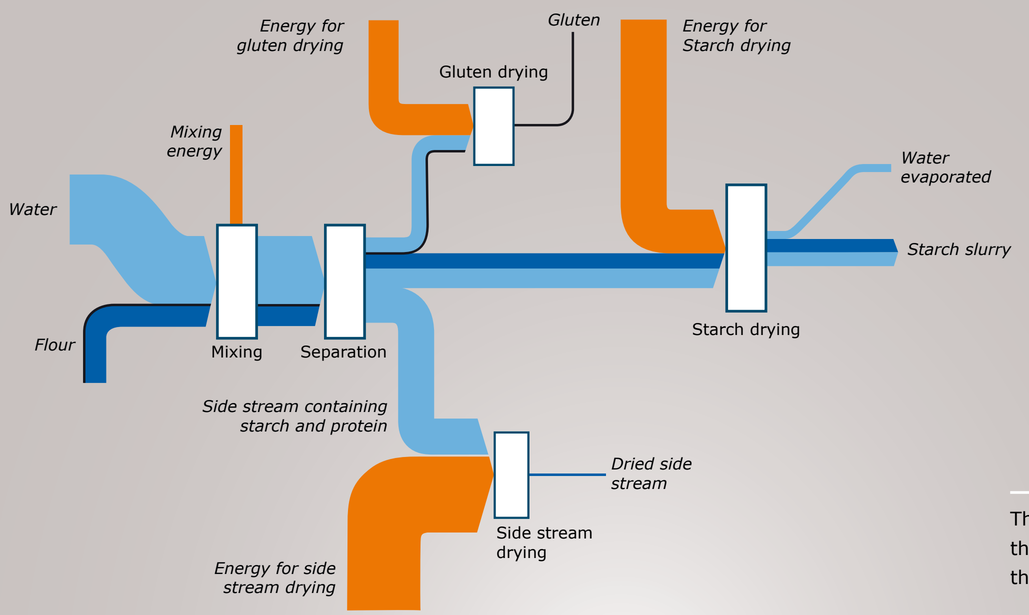
People stopped living on fresh food alone a long time ago. Preservation methods make it possible to stockpile supplies; adding or mixing various ingredients allow for better taste or nutritional quality; processing boosts shelf life, and the production of ready-to-eat meals increases convenience. Food technology thus ensures a better use of nutrients within the chain from field to mouth, reducing the primary food production required.

The chain from food production to consumption generally consists of many steps. Historically, the primary consideration was to make food easier to store. After all, harvests depend on natural factors and have corresponded completely with the seasons, for most of human history. To provide sufficient food of good quality during other times of the year as well, a variety of techniques were developed to extend shelf life: Drying, salting, smoking and, later, cooling and freezing. While most of these preservation techniques are centuries old and low-tech, advanced technological progress has considerably expanded them over the last half century.

Concentration replaces dilution

Remko Boom, professor of food process engineering contributes with his group to contributes to the continuing innovation in food technology, ranging from improvements in the efficiency of processes to the introduction of new basic ingredients. In many processes, separation is part of the treatment. For a long time, industrial processes consumed copious amounts of water and energy to produce those ingredients. The discovery that the separation of particles is possible in concentrated dispersions may lead to breakthroughs in a number of future separation processes. While many separation techniques have previously required dilution, concentrated dispersions can be separated by using the intrinsic properties of the high concentration. A major advantage of this new approach is that the subsequent drying process requires considerably less energy and thus has less impact on the environment and climate.

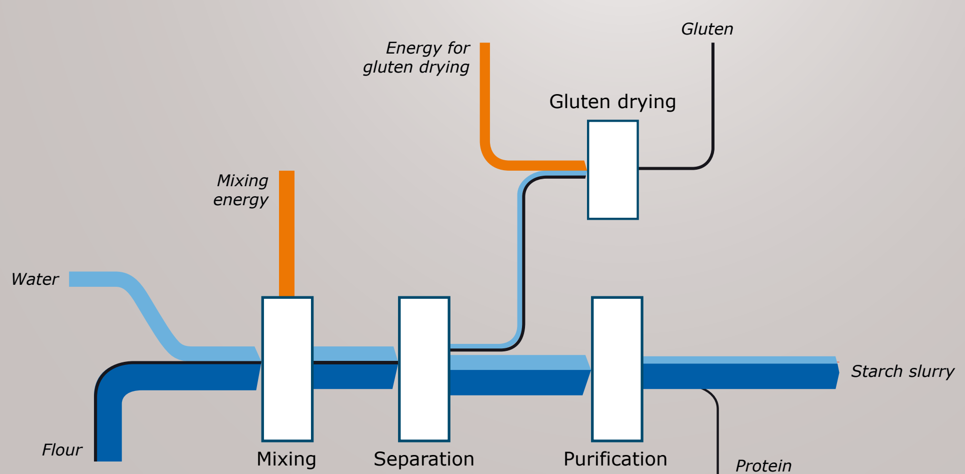
The current wheat separation process



The thickness of the arrow represent the size of the stream

- Starch
- Gluten
- Water
- Energy

The new separation process using a higher flour concentration



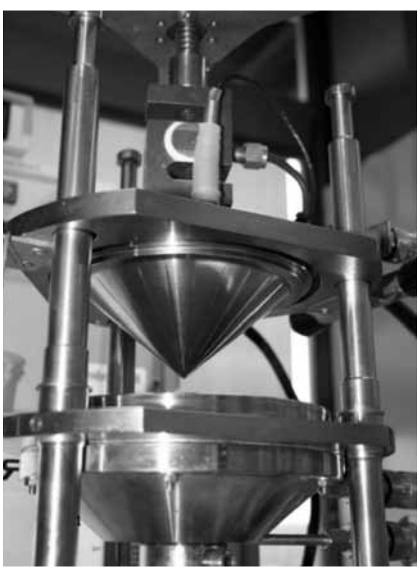
Adapted from: E. Van der Zalm, PhD thesis, Wageningen University, 2011

Ending waste

Much of the food in the fields is discarded unnecessarily and never reaches the consumer. To a large extent, this is the fault of the consumers themselves, points out Toine Timmermans, Programme Manager Sustainable Food Chains at Wageningen UR. "The main motivations are tastefulness, convenience, health and price. There are also many people who would like their consumption to be more sustainable but do not always know how to make this happen."
A study at Marks & Spencer showed that 75 percent of customers want their purchasing to be socially responsible. Actual buying behaviour, however, is decided after deliberations based on motivation, availability and capacities (including finances and familiarity). An intention to do the right thing may or may not ultimately be translated into actual behaviour.

The same model may be detected in the way people dispose of food. Between 1.5 and 2.5 million tons of food, which corresponds to 4.6 billion euros, is thrown away in the Netherlands annually. Consumers are responsible for more than half of this value loss. The rest is caused by private quality standards, oversupply in certain seasons, inefficient processing, errors in planning and the passing of product shelf-life in warehouses and shops. While consumers prefer to throw away less, they often lack sufficient knowledge of the actual quality of the food. People have largely lost the capacity to use their own senses to assess this and rely therefore on the information provided on the package – i.e., the best before date – which does not indicate when something has become inedible.

A useful development designed by Timmermans and a team of scientists from the semiconductor sector is a smart chip/(tag) which can measure and predict when a fresh produce is best to eat. Just one square millimetre in size, the chip can measure temperature, humidity, pH and concentrations of CO_2. In the future it will also measure the plant hormone ethylene to predict the shelf life of meat, ripening of fruit or vase life of flowers. This chip can be read out wireless by, for example, a mobile phone or (in the future) a smart fridge, and warns people to consume the product in time.



An in-house developed device for making fibrous protein structures

Lupin beans are a potential new protein source

Soybeans

Understanding the behaviour of concentrated systems offers new possibilities for separation. Gluten and starch, for instance, appear to have very different viscosities in a solution containing a minimal amount of water. These grain components can be separated based upon this difference. Additionally, research enables a better understanding of how dough behaves in the baking process.

Vegetable replaces animal

Another area in which the knowledge of concentrated systems has proven its value is the development of fibrous textures. These textures might form the basis for products such as meat substitutes, which contain plant instead of animal protein. Depending on the animal species, a production animal requires approximately two to eight kilograms of feed protein to gain one kilogram of body protein and major sustainability gains can be realised if this conversion can be improved or skipped. The new plant protein source is often relatively rich in carbohydrates and therefore does not have the same nutritional value. The question, however, is whether this is a problem, or that a change in composition can lead to additional benefits. As an example, the carbohydrates in certain plant materials are present as dietary fibres, of which we now often consume too little. The inclusion of those carbohydrates in meat substitutes can therefore lead to health benefits, neatly combining health and sustainability. What applies to people can apply equally to animals. Wageningen UR is carrying out research into the replacement of animal protein in fish feed – often fishmeal – by vegetable components. Here, too, enrichment with, for instance, gluten or soya appears to give an extra boost to efficiency. Algae are promising in this context, provided they can be used completely and without further purification.

Biorefinery replaces standard refinery

Obesity is a major health problem in the developed world today and a driver in the development of food technology. Refined foods contain more calories, without a corresponding increase in nutritional value. Wageningen UR is aiming to replace parts of the refined foods with food that contains most of the structure and composition of the original natural product. This approach does not necessarily imply a total reintroduction of a diet based on pure vegetable or animal products. The solution is partly to be found in so-called food-driven biorefinery. In this method, plants such as soya, lupins, peas and wheat are deconstructed in a way that allows existing structures – dietary fibres, original fatty acids and proteins – to be preserved and subsequently added to foods. This composition shift – less refined – leads to less energy-rich and, probably, healthier food. Moreover, it means that less primary food production is required to achieve the same nutritional value.

Wageningen UR is aiming to replace parts of the refined foods with food that contains most of the structure and composition of the original natural product

While the application of this high-tech food processing is currently limited to developed countries, it may trickle down to rapidly developing countries. As a rule of thumb, improvements in income and wealth go hand in hand with an increase in the consumption of animal protein and refined foods according to the Western diet. A change in the Western diet might also lead to a chance to healthier and more sustainable eating habits elsewhere in the world. ■

Pot luck

Materials, water and energy from waste water

In both rich and poor countries, farmers use animal manure to maintain the fertility of the soil. This is a classic example of a closed cycle. But what do we do with the valuable nutrients in human faeces?

The Environmental Technology department of Wageningen UR develops methods for recovering raw materials such as phosphorus, nitrogen and potassium from water treatment. These are valuable nutrients which often end up in domestic wastewater via our food and toilets.

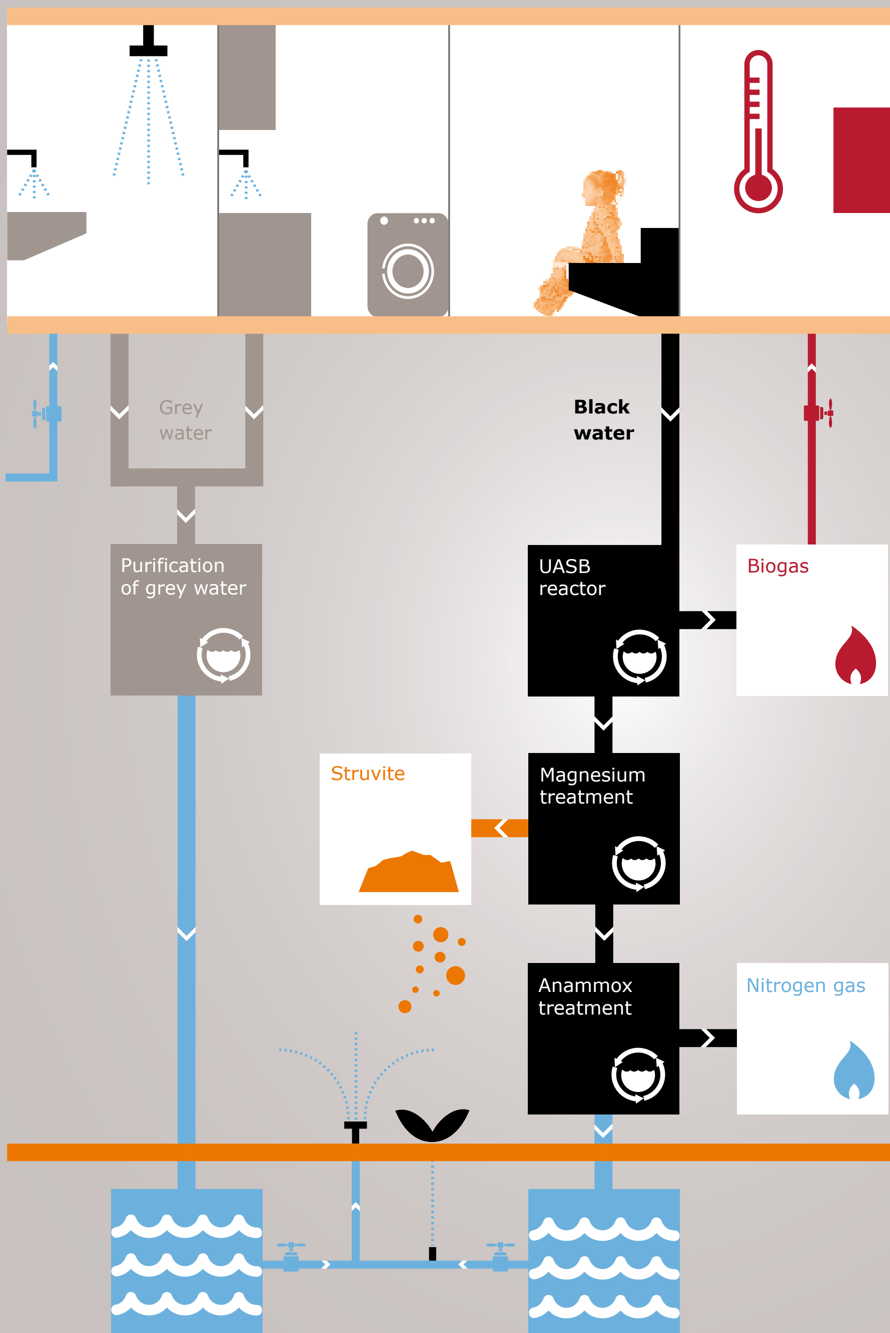
Grietje Zeeman, professor of New Sanitation, calculated that recovering phosphates from black water and kitchen waste could satisfy a quarter of the present worldwide artificial phosphorus fertiliser use. The supplies of mined phosphorus, an important component in artificial fertiliser, will be exhausted by the end of this century at the current pace of extraction. Moreover, we are highly dependent on extraction in China, Morocco and the USA.

This concept is being translated into practice In the Noorderhoek neighbourhood of Sneek (NL). Faeces and urine (black water) are collected by vacuum toilets and transported, together with kitchen waste, to an anaerobic treatment plant for the production of biogas, which is then used to heat houses in Sneek.

The purified water that comes out of the anaerobic treatment plant still contains a great deal of phosphate and nitrogen in the form of ammonia. Adding magnesium transforms the phosphate and a part of the ammonia into struvite, which can be used to fertilise fields. This recreates a cycle that was broken in the last century for reasons of hygiene.

Gains in water & energy

Current sanitation and sewerage systems use a lot of water to bring a relatively small amount of waste to the treatment plant. In the Netherlands, ca. 130 litres (20 flushes) is used per person per day, while the corresponding figure in the US and Canada is three to four times higher. The vacuum toilets in Sneek only use one litre per flush, instead of the usual six to eight litres, which allows a considerable decrease in the use of water and in the volume of wastewater. Especially in



'New public sanitation' stands for the collection, transportation and treatment of household waste water so that minerals can be extracted from it. The first step in the method is to separate black water (from the toilet) from grey water (from the bath, shower and kitchen).

After a relatively simple purification process, the grey water can be reused in the household and for irrigation.

The black water – which contains the most minerals – is purified by anaerobic bacteria in a UASB reactor which produces biogas, mainly methane.

Treatment with magnesium leads to precipitation of phosphate and some of the nitrogen compounds in the form of struvite.

The remaining nitrogen compounds are converted into nitrogen gas with the Anammox technology.

Algae

Wageningen UR and Netherlands Institute of Ecology (NIOO-KNAW)work together to study the possibilities of using algae after the anaerobic treatment of black water. Algae can process all phosphorus from faeces and capture some three quarters of the nitrogen, with the help of sunlight and absorption of the greenhouse gas CO_2. Once harvested, the algae can serve as a source of oil, which can in turn be used as biofuel, as a raw material for biobased chemicals, or directly as a fertiliser in agricultural use.

Flat panel on laboratory scale

Removing pharmaceutical residues and pathogens from the water

Treated wastewater still contains components of pharmaceuticals and organic compounds from shampoos, scrubs, conditioners and, cleaning agents. After being discharged, these can be harmful to fish, frogs and water fleas and can also reach human drinking water. Another problem are pathogenic viruses and bacteria (such as the infamous MRSA or Ehec). New chemical and biological treatment techniques are therefore being developed to remove these substances and pathogens at a later stage of treatment. There are also studies to examine whether these can be made harmless in ground and surface water through a natural purification process. The aim is to reuse water while keeping the environment, drinking water and agricultural products clean.

Recovery of nitrogen and phosphate from urine

A pilot for the recovery of nitrogen from urine will be started in 2013 using microbial fuel cell technology (MFC), developed in collaboration with Wetsus, Centre of exellence for sustainable water technology. MFC allows ammonia to be recovered from human urine, in combination with struvite precipitation for phosphate recovery. Unlike existing techniques, this process generates energy rather than consuming it. The technology is also interesting for the recovery of ammonia from anaerobically treated black water.

A toilet which collects urine seprately, to make recovery of nitrogen and phosphate from urine possible.

areas where water is scarce, such savings are essential. Grey water (bath, shower, laundry and kitchen water) can be used for irrigation after treatment.

The second problem of traditional water treatment is energy use, particularly the energy used to blow air into reactors which supply purifying bacteria with oxygen. The installation in Sneek is a net producer of energy, however, as it uses anaerobic (oxygen-free) treatment in an upflow anaerobic sludge bed (UASB) reactor, a technique developed by Wageningen UR. UASB reactors are used around the world to treat concentrated industrial wastewater. The challenge is to separate black and grey water at the source with water-saving toilets and thus treat household wastewater on a large scale while saving water and energy.

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Nitrogen

Zeeman would also like to harvest nitrogen from black water. Nitrogen is an important nutrient for cultivated and other crops and therefore one of the main components in fertiliser. Despite the significant water savings achieved with vacuum toilets, the nitrogen concentration in the black water is still too low for efficient recovery. As the nitrogen from black water is converted to N_2 using a low-energy Anammox technique in Sneek, the N_2 disappears into the air, therefore not directly contributing to any fertiliser.

Disinfection

Another of Zeeman's goals is to develop a (hyper) thermophilic anaerobic treatment technique which would also provide disinfected fertiliser in addition to biogas. A condition for this is further flush water reduction, as this would allow the temperature in the reactor to be increased from the current 25-30 degrees to a safe 60-70 degrees (rendering most pathogens harmless) with the same amount of energy. The fertiliser and water can then be reused in agriculture. Of course, legislation must be adapted to allow this. Conventional sewage sludge in the Netherlands is taken to incinerators, where the nutrients are lost, not allowing the cycle to be closed. To apply it in agriculture, the sludge must comply with established limits on heavy metals. The sludge from anaerobic black water treatment contains far fewer heavy metals than conventional sewage sludge as it contains no rain or grey water. According to the standards enforced in the Netherlands, the latter contains too much copper and zinc in particular. Ongoing studies will show whether these heavy metals only come from food. If this is the case, Zeeman feels that regulations should be adapted to allow the cycle of manure to manure via crops and food to be closed in a neat way. ■

7 | Who's got the power

The food chain has become increasingly innovative and globally organised. This has changed the playing field in terms of the people and institutions that are involved in food production, processing, trade and consumption. Governance tends to shift from the public domain towards the private domain, where companies step in and take responsibility for feeding the world and establish markets for food and agricultural inputs. Governments and large companies in turn are confronted with countervailing powers of farmers, consumers and concerned citizens. Organised consumers and citizens license the companies to produce food that meet consumer demands. Given the shifting balance of power in the global food systems, all forces collectively determine how the systems develop. Ultimately, this may be one of the most decisive aspects of nutrition security.

The rise of the social animal

In the Dutch political arena animal welfare is a major issue when it comes to food provision. The industry – agribusiness, breeders, processors, supermarkets – is currently making a major and highly risky manoeuvre by trying to reconcile animal welfare with efficient production. But might it be possible to actually achieve higher returns by enhancing animal welfare?

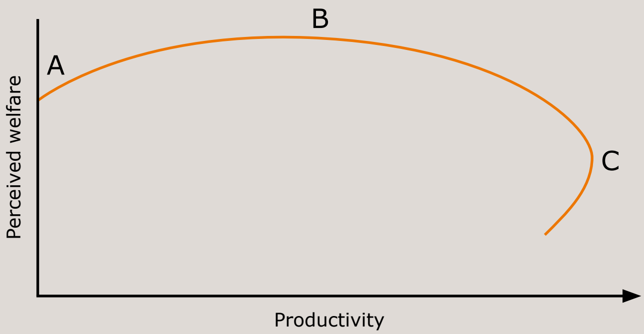
The issue seems to be the most important in the global debate about meat consumption and the world food supply has tended to be whether we can afford an increasing number of farm animals within the world's current agricultural capacity. Animal welfare has traditionally played a relatively small role. The question of whether we need to recalibrate our diet towards less animal protein overall has so far been answered in the negative by the growing number of people in the world who can afford to eat meat in many societies. The welfare of animals is simply not a focal point.

In the Netherlands and many other Western countries, however, the animal welfare issue is literally and metaphorically on the menu, and is taken seriously by industry and science alike. Legal measures and consumer preferences and perceptions are ensuring the gradual elimination of rapid-growing broilers, price stunts with meat and eggs from cage-housed hens – i.e., situations in which high-production animals are kept in suboptimal conditions – by more pleasant variants. The Wageningen scientists Piter Bijma, Liesbeth Bolhuis and Bas Rodenburg, involved in breeding, behaviour and adaptation physiology are also studying opportunities to improve the living conditions of animals. This is relevant for the design of housing systems, as well as for issues such as genetic selection. The future belongs to social animals housed in suitable environments.

Excessive aggression

Traditional breeding programmes are focused on individual winners, with the fastest-growing animals

Relationship between animal welfare and productivity



A model of the relationship between animal welfare and productivity (after Bennett, 1997; McInerney, 1998). Imagine that humans are starting to exploit animals, at Point A on the graph. This model assumes that up to Point B, animals and humans derive mutual benefit from their association. Point B marks maximum welfare for animals, with some benefits for humans; however, maximum output of animal products for human benefit would be achieved at Point C, at a cost to animal welfare, and exploitation beyond this point would decrease production.

Adapted from: Bennett, 1997 and McInerney, 1998)

used as parents for the next generation. This ignored the effects of the other characteristics of these individual winners in their environment, notably on their peers. Selection for high productivity sometimes leads to excessive aggression and other hostile behaviour against conspecifics, ranging from tail biting and feather pecking to outright cannibalism. While beak-trimming and tail docking in chickens and pigs can limit the damage, there is growing public opposition to such interventions. Moreover, individual winners are not always the collective winners. Studies into quail bred for improved individual performance, for instance, found that, even after 25 generations of selection for growth, they had a lower weight and a much higher mortality from cannibalism, on average, than the base population.

The two study directions – focus on animal welfare and necessity of increased collective efficiency – come together in the Wageningen research into social animals. Is it possible to design animal pens so that damaging behaviour decreases and positive social behaviour is enhanced and rewarded? And can breeding be carried out in a way that results in more social and less aggressive animals? For now, the answers seem positive. For instance, selection for pigs which have a positive effect on the growth of their pen mates has led to better productivity of the group as well as a more harmonious atmosphere. By focusing on the group, rather than on the individual, performance regarding both animal welfare and efficiency, can be improved: From competition to cooperation, an approach consistent with the principles of Darwinian Agriculture.

True natural behaviour

Stimulating true natural behaviour can also be profitable. For instance, there are ongoing experiments in more natural forms of maternal care both in chickens and pigs. Newborn piglets that must suckle in very close quarters with their mother appear to develop a greater tendency to damaging behaviour after weaning compared to piglets that spent time with a mother allowed to exhibit natural foraging behaviour. And chicks that stay with their mother longer become less anxious and are less likely to exhibit feather pecking behaviour. It is possible to create artificial alternatives for natural shelter, for instance by setting up a dark space where chicks can take refuge, as if under their mother's wings. Overall stress in the group thereby drops significantly and standard measures such as beak trimming and tail docking are no longer needed. This, in turn, can help bring down the use

Selection of sociable pigs in a suitable environment

Focusing on group performance may also benefit the behaviour and welfare of pigs. Recent studies show that pigs with a heritable positive effect on the growth of their pen mates show less harmful behaviours, such as tail biting. Providing a suitable environment troughout life further supports both welfare and efficiency.

Good start in life important

Both pigs and chickens show less harmful behaviours if they have had ample opportunities to interact with their mother during early life. Design of systems that allow for more natural forms of mother-offspring interaction or that mimic the properties of maternal care, such as shelter for chickens, holds great promise for simultaneously improving welfare and efficiency.

of antibiotics. A number of undesired conditions, notably in the legs of animals, already occur less often. Problems and solutions alike are a combined effect of genetic predisposition and a good start in life.

Combining welfare, safety and efficiency

There is now a focus on combining welfare, safety and efficiency throughout the industry. Wageningen UR can only carry out this type of experiments on a limited scale and is therefore actively seeking collaboration with practical application centres and the breeding industry. Such centres can trigger more large-scale involvement by the sector, initially by bringing in more progressive farmers and parts of the processing industry. The latter can then disseminate scientific knowledge and experiences among other farmers. Science also needs to start a dialogue with society.

Within the research project focused on the breeding and farming of social pigs, there are explicit discussions with groups of citizens about how pig farming should look in the future. Potential solutions based on the project are also proposed here: Social breeding versus improved housing environments. Within the triangle formed by citizens, farmers and researchers, there is a search for the pig farming practices of the future and exchanges of ideas and opinions. These kinds of approaches are likely to become increasingly important.

Ultimately, the trick will be to create a farming system that is both socially accepted and combines the best of both worlds, efficiency and animal welfare. The Wageningen researchers believe that this combination will result in a greater focus on more natural behaviour in animal-friendly group pens for more social and efficiently growing animals. ■

Selection for high productivity sometimes leads to excessive aggression and other hostile behaviour against conspecifics

Social genetic effects for survival in domestic chickens

	Line W1	Line WB	Cross W1xWB
Total heritable variance	19%	16%	26%
Proportion due to social effects	65%	44%	87%

We studied social genetic effects for survival in domestic chickens (Gallus gallus), using data on two purebred lines (W1 and WB) and their cross (W1xWB). Heritable variation detected with a model including social genetic effects explained between 16% (line WB) and 26% (cross W1xWB) of the phenotypic variation. This proportion was substantially larger than the proportion estimated with traditional model (i.e. model without social genetic effects). Social genetic effects contributed the majority of heritable variation in crossbreds (87) and around half of heritable variation in purebreds (65 and 44%) (Peeters et al. 2012 Genetics 192: 705).

Aiming for food security

The proportion of people suffering from hunger should be halved by 2015 according to the Millennium Goals of the United Nations, set in 2000, while local communities in developing countries aim to democratise the decision-making process regarding food. Professor in Public Administration and Policy Katrien Termeer analyses the administrative processes involved at both ends of the spectrum."Food security cannot be realised by means of idealistic plans or new technologies only. It requires advanced steering strategies that involve governments as well as companies, NGOs and citizen."

Termeer and her group are searching for innovative governance strategies to tackle food security issues. Unlike the traditional policymaking process, governance is a matter of creating alliances within a complex society. Termeer explains the difference: "Traditional policy is developed by governments only. Today however, national states and their governments can rarely succeed in isolation. Many issues are cross-border matters, and even within their own borders governments do not have a monopoly on effective policy. Governance is when policies are developed in collaboration with civilians, companies, social organisations and other stakeholders."

Food security is one of the so-called wicked governance problems. It involves conflicting problem definitions, contradictory facts, changing political agendas, inflexible policy systems, long-term deadlocks and tension between the different scales. Moreover, todays problems are often the result of yesterday's solutions. No politician in the world will ever be able to say that they solved the global food issue, but well thought-out governance arrangements can contribute to improving food security. It is all about taking small steps.

Termeer is studying which strategies are applied by governments and other parties in trying to achieve

Capabilities

There are five governance capabilities that are important for the governance of sustainable food security. They are focused on:

a understanding complex issues (observation);
b the policy strategies to tackle them (action);
c the circumstances or institutional changes needed to enable these strategies (enabling).

Governance capability	Definition	Aspect of problem to be addressed	Effects of deficit
Reflexivity	The capability to appreciate and deal with unstructured problems and multiple realities	Unstructured problems Multiple frames and perspectives	Risk of tunnel vision or intractable controversies
Resilience	The capability to flexibly adapt one's course in response to frequent and uncertain changes without losing identity	Interconnected problems Unpredictable consequences of action Uncertainties	Risk of failure to keep fulfilling basic functions
Responsiveness	The capability to respond legitimately to unlimited demands and concerns	No stopping rule. Unlimited number of issues and demands Moral responsibilities	Risk of overreacting and losing citizens' trust and legitimacy
Revitalising	The capability to unblock stagnations and reanimate policy processes	Stagnating and unproductive interaction patterns	Risk of more of the same and of regression
Scale sensitivity	The capability to address cross-scale and cross-level issues	Problems stretch across jurisdictional, spatial and time scales	Mismatch between the scale of a problem and the scale at which it is governed

Governance Capabilities for Dealing Wisely With Wicked Problems. Catrien J. A. M. Termeer et.al. Administration & Society Published online 6 January 2013

a sustainable food supply. “We find all kinds of innovative solutions: Public-private partnerships, regional partnerships, social dialogues, self-governing communities, round-tables or private certification systems. These innovative strategies, ultimately aiming at changing the behaviour of people and organisations, often conflict with existing policy systems and power relations, however. To develop new strategies it may sometimes be necessary to change the existing governance system.”

Innovative strategies, aiming to change the behaviour of people and organisations, often conflict with existing policy systems and power relations

CAP

Organising food security in Europe after WWII was realised surprisingly quickly as a result of the newly developed and highly effective Common Agricultural Policy (CAP). Although the policy instruments used (market protection through import levies, export subsidies and guaranteed prices) led to plenty of food at affordable costs, it also resulted in a range of undesirable side effects. Since the 1980s, the CAP has been through various consecutive rounds of reform. Every new turn in the CAP’s history saw its own definition of sustainable food production problems. Termeer and her colleagues are analyzing how the presence or absence of five capabilities has produced or prevented progress in dealing with the issue of sustainable food production under the CAP.

Reflexivity

The main goal of the CAP – sufficient affordable food – quickly led to overproduction. However, it took until the early 1980s until this was framed as a problem. The framing of overproduction with metaphors like “butter mountains” and “milk lakes” helped to accelerate reflexive observations. In 1983, the European Commission saw two types of solutions with two different frames attached to them. The first was to limit the amount of production by introducing a milk quota system; an intervention on which the member states and lobby groups could not agree. The second was to reduce the milk price. This would irrevocably lead to increases of scale and the bankruptcy of small agricultural family businesses; companies that were previously explicitly supported by the policy frameworks. Termeer: “This is a typical example of *reflexivity*, the capacity to look at the problem from various perspectives, reconsidering existing standpoints and reviewing perspectives where necessary. Finally the milk quota system was implemented in1984. The production ceilings debate meant the weakening of the dominant frame of supporting production increases within the CAP.

Resilience

The actual *resilience* of the CAP was tested in the second half of the 1980s when the CAP became seriously criticised by its main international trading partners within the Uruguay Round of the GATT (General Agreement of Tariffs and Trade) negotiations for its distorting effects on international markets, and for dumping subsidised food surpluses. This ‘untenable’ European agricultural system even brought to a halt the GATT negotiations, with possible repercussions for other European export products as a result.
At the same time, Spain and Portugal’s entry to the EU, and the rising costs of the CAP led to tensions within Europe. As the CAP had resulted from lengthy negotiations and compromises between member states, it was difficult to address new developments in a flexible and resilient way. This lack of resilience was strengthened by the powerful agricultural lobby, which blocked fundamental reforms. To enable reform, European Commissioner MacSharry proposed a comprehensive CAP reform arguing that this was

necessary for budgetary reasons, but the foremost aim was to adapt better to international markets. The reforms he suggested would resolve the European budget problem by replacing the system of guaranteed prices with a direct income payment scheme to farmers to compensate them for declining incomes."

Responsiveness

Initially the CAP had been developed within a closed agricultural policy community, consisting of a small number of public officials, politicians, experts and stakeholders; a closed stronghold that showed little interest in the growing social unrest over the side effects of the CAP, such as the impact on the landscape, pollution and the lack of animal welfare. Outbreaks of animal diseases such as BSE, swine fever and foot-and-mouth, combined with the resulting media attention to the drawbacks of our food production systems, led to a social debate about animal welfare and other sustainability aspects. It was no longer possible to neglect these concerns. In order to respond to these *post-materialistic* preferences the Agenda 2000 and the Fischler reforms were realised. It led to the introduction of the principle of *cross-compliance*, a requirement for farmers to comply with a set of criteria (public, animal and plant health, environment and animal welfare) in order to qualify for the CAP payments. Rural development now became a definite second pillar of the CAP.

Revitalisation

With the passing of time, more new challenges have come up that are related to the production of food, such as the effects of agriculture on climate change, biodiversity, renewable energy and water management. In return for the subsidies, farmers should produce more public goods, such as landscape elements or agri-environmental products. Attempts to reform the CAP in these aspects have been difficult or unsuccessful. In order to revitalise the process and to prevent new societal conflicts and policy deadlocks, the European Commissioner Ciolos decided to change old policymaking routines by means of public debates about the future of the CAP. Today, 2013, the Dutch government is also organising various debates in local halls and via social media. This is resulting in innovative ideas, new alliances and raised expectations. Unfortunately, the financial crisis and reduced budgets are causing many traditional parties to fall back on the defensive routines, which in turn is threatening the revitalisation process. ■

Millennium goals

The proportion of people who suffer from hunger should be halved by 2015 according to the Millennium Goals of the United Nations. In 1990 the figure was 20%, with nearly a third of all children under five being malnourished.

The right to food, as agreed within the UN Millennium Goals, is not the same as a duty to accept certain (international) food programmes. A classic example is Malawi refusing to accept food aid from the US due to the presence of GMO crops from the company Monsanto. This is in line with communities in developing countries claiming food sovereignty. By doing so, they hope to make clear that they will not be told what to do by multinationals or the World Trade Organisation. To them, food security at a local and national level is a matter of democratising and decentralising the decision-making process with regard tp production and the global trade in food.

Round tables push back frontiers

With higher production helping feed more mouths at lower costs, we have long relied on technology to increase agricultural yields. During the 1980s it became clear that technological intensification was approaching certain practical and moral boundaries. Although the green revolution provided the world with an increasing amount of food, it failed to solve the threat of hunger in parts of the world.

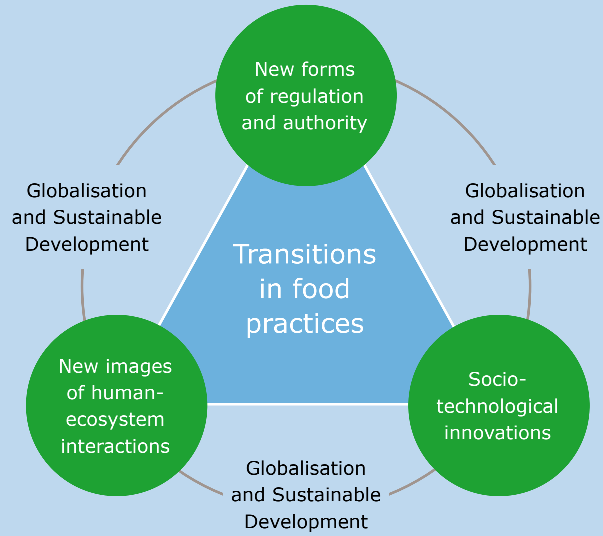
Food security involves a number of political and social dimensions. It includes allocation and distribution issues that require solutions beyond technology. Insights into global and local power relations, institutional and social innovation, and the trust and support of producers and consumers are equally essential.

So how should such insights be translated and implemented within the institutions and practices that are intended to safeguard nutrition security? Arthur Mol, professor of environmental policy: "National governments are losing power and control in an economy that is globalising at an ever faster pace. Markets and the environment do not stop at national borders. Powerful food multinationals increasingly work directly with global and local NGOs in governing food sustainability and security". Is this a bad thing? "Not necessarily. It has been shown that such new coalitions can offer powerful new impulses to solving food security and sustainability issues. An example is the establishment of the Marine Stewardship Council (MSC) which aims to increase sustainability in the fishing industry and prevent the world's seas from being emptied. These types of consultative and cooperative roundtable models are also implemented to make the global production and consumption of palm oil, wood, biofuels, soy and sugar cane more sustainable, without the need for complex agreements with hundreds of national governments. Such round tables, form partnerships that can establish cross-border agreements reasonably efficiently with a limited number of stakeholder".

Although it is only a small group of consumers that make conscious choices, their impact can be substantial.

Food consumption and production

Food consumption and production are changing as the result of the processes of globalisation and of sustainable development. These developments lead to socio-technical innovations, to new understandings of the interactions between humans and ecosystems and to new forms of regulation and authority, in different combinations.



Democracy

The reliability of MSC and comparable certification schemes and resulting labels is not so easy to determine, especially when product chains start in less developed countries. Here, information can be hard to collect and verify, transparency is limited and local producers sometimes have a hard time to fulfil sustainability requirements. One can also have doubts about the level of democracy involved in these types of roundtable agreements: Who defines the requirements and makes the actual decisions, and to whom are they accountable? Nevertheless, multi-stakeholder roundtables are a new reality to which governments, producers, retailers and consumers must adapt.

Consumers are certainly not sidelined within this new governance system, but they do have to face an information overload, and find their way in competitive labelling systems and greenwashing. Systems for verification, transparency and accountability of labels and certification are therefore essential to cultivate trust. It is up to companies to put consumers' wishes into materiality, although it is usually organised groups (NGOs) or retailers who are best empowered to articulate these demands. Taking the MSC label as an example once again, it was the supermarkets that accelerated the proliferation beyond a niche label by announcing they wanted to exclusively sell sustainable fish by 2015 as they expect there to be a sufficient market for it.

Multi-stakeholder roundtables are new reality to which governments, producers, retailers and consumers must adapt

Political consumerism has also become an important factor. Political (or ethical) consumerism points at the development that consumers demand not just cheap quality products, but also products that are sustainable, animal friendly, and fair. Fair Trade labels and the rankings provided by the Dutch RSPCA are expressions and answers to political consumerism. On behalf of consumers, NGOs have banished chickens fattened in industry-like conditions from several Dutch supermarkets.

Authority and legitimacy

Although it is only a small group of consumers that make conscious choices, their impact can be substantial. Now the ball is with the suppliers who have to meet demands for timely, well-balanced and reliable information on issues such as origin, environmental impact and social aspects. Science must also take into account the new distribution of power and the role of the conscious consumer. Like national governments, science is also at risk of losing its authority and legitimacy in this multimedia era, and is increasingly seen as becoming one of the many information providers on claims of food sustainability. While multinationals and NGOs are the new transnational superpowers, this does not mean that they are invulnerable. Unconditional consumer and member loyalty to brands and labels no longer exists, so even these superpowers are constantly held accountable. This further complicates sustainable food governance in times of globalisation and uncertainty.

An example is the discussion about genetically modified crops, which could strongly contribute to solve the world's hunger issues. Scientists provided solid arguments in favour of the application of this new technology and the agrofood industry saw plenty of opportunities. European consumers wouldn't accept this, however, and even in Africa people have refused food aid from GMO fields. This proves that, when providing solutions for sustainable and fair food, it is essential to include the demand side and ensure that proper communication is provided. Legitimacy and public support are at least as important as power and scientific authority in getting solutions for sustainable food implemented. ■

The consumption junction

The consumption junction: consuming food ultimately requires trust in its quality, safety and sustainability and this trust has to be built on the shopping floor where retailers and consumers meet, each with their own background.

Adapted by the author from Spaargaren and Van Vliet (2000)

What's eating us?

Exploring food preferences

The main reason why people eat what they eat is simple: Because it's there. The reverse is also true: You cannot eat what isn't there. But behind the supply of food available to any given individual, hides a mix of biological, psychological, social, cultural and historical influences. While a Christmas dinner or the complex seasonings in an Indian dish are unnecessary (perhaps even harmful) from a nutritional standpoint, the socio-cultural aspects of sharing, togetherness and refinement contribute to determine our choices, belonging and status in society.

Food plays a very important role in people's lives. At least 50 percent of income is spent on food in underdeveloped countries, while rich countries spend less than a quarter. After sleeping and working, however, food-related activities take up most of the majority of people's time throughout the world.

What we eat is determined by our personal preferences as well as availability and geographical and economic conditions – the choice is naturally more limited in less developed countries than in the industrialised world. Some of our preferences are rational: Sometimes we consciously choose a healthy salad instead of a tempting ice cream.

While choosing certain foods for reasons of health or cost is understandable, taste preferences tend to be a much more decisive factor. This process is studied by psychologists as we still do not know exactly why people like certain things or not. It is a complex choice process which is closely related to context. Something we enjoy for breakfast may have little or no attraction for us later in the day. Steak and cream are both in the category of highly valued foods without being enjoyed simultaneously by most people.

Biology

Some of our taste preferences are innate and help us choose from a selection of thousands of potential


De Ruijter

nutrients and toxins. Sweet is positively associated with fruit, for instance, while bitter flavours are (initially) avoided as they may indicate the presence of toxins. The aversion to very strong flavours – including bitter and sour – also seems innate. Our olfactory sense appears to be programmed differently: The nose learns and develops mainly after birth. According to the evolutionary school, human behaviour focuses on selecting the best possible food by finding out what is and is not edible, and which combinations are good and which are not. Anthropologists in particular also believe that traditional food preparation methods can have an influence on useful nutritional value. For instance, using spices may inhibit bacterial growth (i.e., decay) and traditional caustic processes remove toxic cyanide from cassava.

Psychology

If our food choices are largely determined by supply and cultural traditions, why do tastes vary so widely across cultures? When looking for logical influences in the psyche of a child, the parents, who provide the first life experience, are a natural candidate. But the correlation between parental influence and ultimate food preferences is surprisingly low. The same applies to other obvious influences (relatives). Food preferences are set early in life, sometimes before birth. Many of them are fixed by the age of two to three years, and remain the same in adulthood. This does not mean, however, that preferences cannot change.

How our preferences are formed has not been studied at length. It has, however, been established that exposure to use is influential. The greater the exposure, the more we tend to appreciate something. There are indications that this is also true for food. Another factor that plays a role is conditioning. A flavour and a biological meaningful outcome can be linked through a positive or negative Pavlovian reaction. For instance, if someone feels nauseous the first time they taste a new flavour, this can permanently reduce appreciation of that flavour. In the group of Kees de Graaf, professor of sensory science and eating, a great deal of attention is paid to such learned preferences for the taste of vegetables.

Social influences are an unclear but important factor in the development of taste preferences. The experience of enjoying a certain type of food together increases the chance that we will develop positive preferences for its flavour, or flavours similar to it. The idea that reward or punishment strongly changes our food preferences

The correlation between parental influence and ultimate food preferences is surprisingly low.

is questionable, however. While social punishment can ensure that we eat less of the relevant food, it may not necessarily result in a decline of sensory liking.

Sociology

Sociological differences in food choices have a strongly demographic character. There are visible differences based on age and gender within cultures, for instance. Meat avoiders in the Western world are usually women, and women often prefer light products as they are more concerned with their weight. A preference for low-calorie raw food or (part-time) vegetarianism may also be a fad, which is a quintessential form of social organisation.

Anthropology (culture)

You are what you eat, the cliché says. Anthropologists who wish to know what kind of food people will choose will ask about their culture. Culture largely determines how people look at food and eating patterns.

While it is easy to define the characteristics of Chinese or Mexican cuisine, there is more to culinary culture than a series of typical dishes – the same way a meal is more than a plate of food with a given degree of variety and nutrients. A food culture is a social organisation of meals, composed of table manners and rituals. Food has meaning in the interaction between people. If you compare French and American food culture, it is clear that the French assign a far more important role in their lives to food and eating together. They are also less busy with the health aspects of food than Americans, who, strangely enough, often consume much larger portions. ■

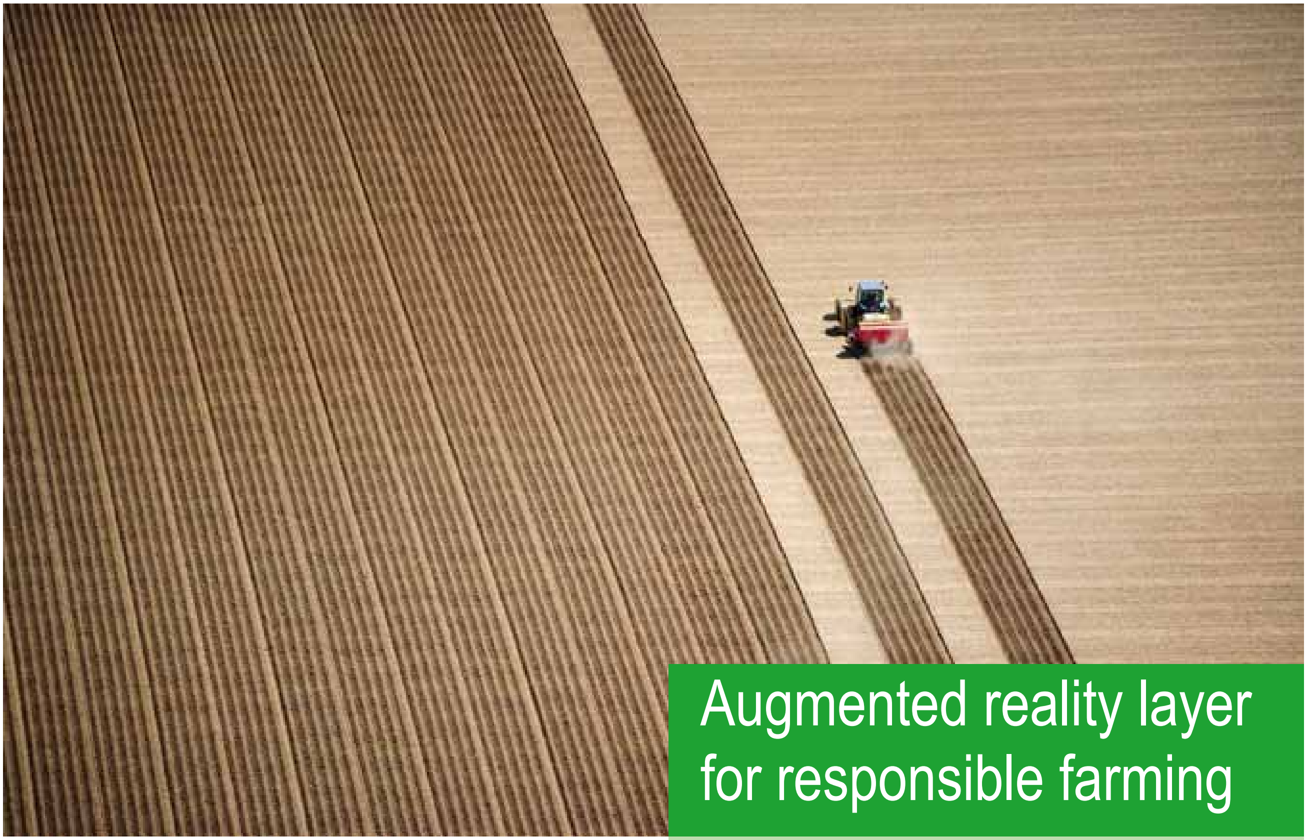
The idea that reward or punishment strongly changes our food preferences is questionable

Back from the Future

The date is March 2018, and the Rector Magnificus of Wageningen University that celebrates its 100th dies natalis is looking back on the events of recent years. "Wageningen UR has contributed to the debate on 'nutrition security' with new scientific insights, designs for new agricultural systems and new theories about the effective management of food chains".

"For a long time, increasing and improving primary production was the dominant force in the food sector and within our organisation. Today, the sustainable development of the food system as a whole is seen as crucial. Over the last few years we have developed new technologies that contribute to sustainable food production as one of the functions of our 'ecosystem earth'. We have also been able to predict the effect of changing resource prices on the food supply. In all these breakthroughs, our system approach played a crucial role. Not only do we know considerably more about the functioning of organisms, we have also learned a great deal about the mutual functioning of these organisms within ecosystems and of ecosystems as a whole. As a result we are now able to make balanced choices in, for example, the use of biomass for food or alternative goals such as materials and energy."

The Rector Magnificus describes the scientific breakthroughs in recent years. "The true strength of Wageningen UR lies not within each discipline, but in the interaction between them."



Augmented reality layer for responsible farming

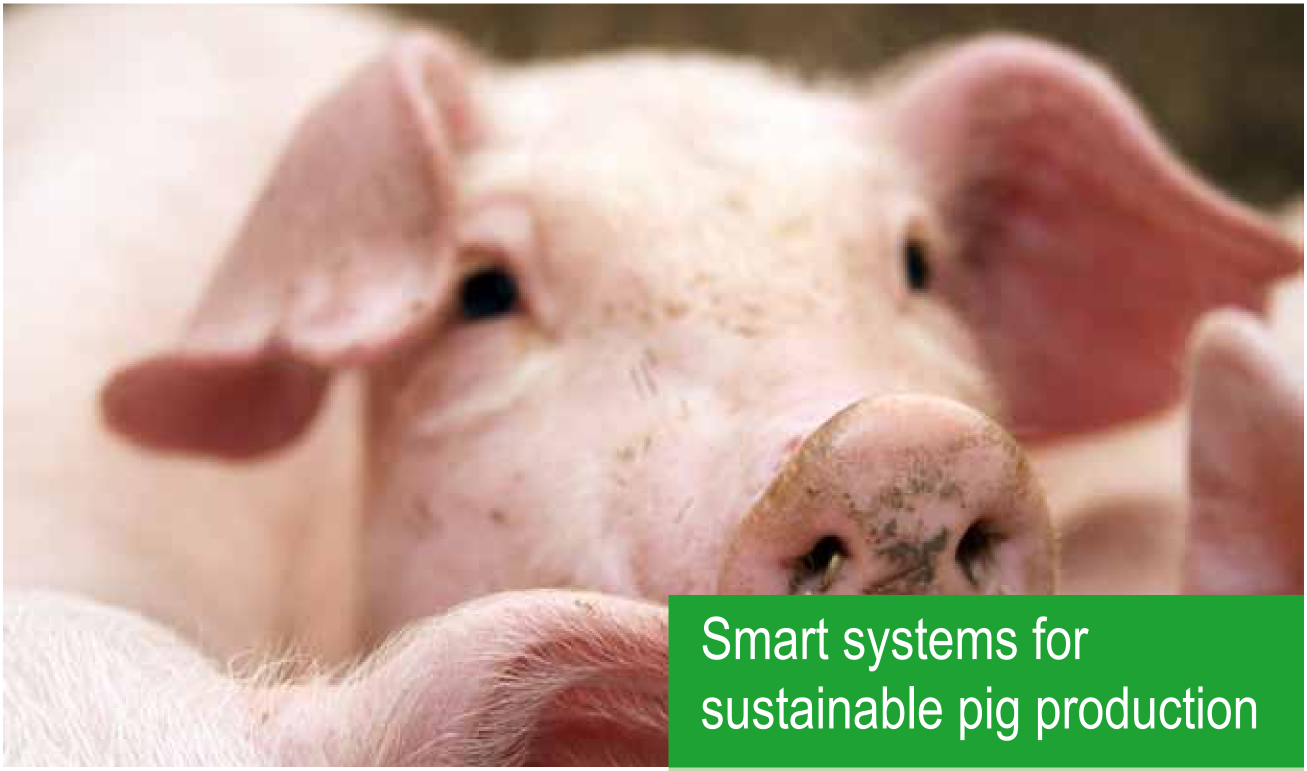
Ecosystems not only contribute to the food production, but also serve as a habitat for many animals and plants and may help to keep our climate stable. We also enjoy spending our leisure time in a variety of rural areas. Farmers worldwide manage the landscape and constantly face the dilemma of making choices that affect the various functions. Wageningen UR has developed an augmented reality layer that helps farmers make well-considered choices. It allows them to literally see the effect of their management measures and determine their choices. In this way Wageningen UR contributes to a better quality of life.

WAGENINGEN UR
For quality of life

In Wageningen, food production is considered a part of ecosystem earth. How does this affect research?

"Sustainable food production is only possible when it is in balance with other important ecosystem services. Examples include clean water, the continued availability of essential resources, preventing climate change and preserving biodiversity. We have taken major steps towards achieving an optimal balance between food production and the other functions of ecosystems. For several regions, for instance, we have analysed the various functions of the different ecosystems and the opportunities within these systems to improve food production. The concept of 'marginal land' now has a different meaning: Areas that make a marginal contribution to food production have been shown to be essential for other functions". "We now have a better understanding of complex adaptive systems, which enables us to better predict and steer the effects of change. This allows us to weigh the alternatives.

A great result of this research is the *augmented reality layer* we developed with several other parties. It allows farmers to make well thought-out choices regarding agricultural management. Another result is that we are now able to increase the resilience of production systems. This makes food production less sensitive to extreme (weather) conditions."



Smart systems for sustainable pig production

High-quality feed can allow pigs to grow efficiently. The faster a pig grows with the same quantity of feed, the smaller the impact on the environment. Research performed by Wageningen UR shows, however, this can also be achieved with low-quality feed – which mainly consists of waste flows. Pigs grow less efficient at these lower quality feeds. However, providing low-quality feed reduces the environmental impact of pork. Low-quality feed also improves the welfare of the animal as it is more in line with its natural needs. Using waste flows in pig farming therefore benefits both the environment and animal welfare. In this way Wageningen UR contributes to a better quality of life.

WAGENINGEN UR
For quality of life

In recent years, issues such as closed cycles, waste reduction and the biobased economy have all contributed to a broad discussion on agriculture. How does food production fit into these dynamic developments?

"The biobased economy was developed based upon an understanding that fossil fuels are finite and that we have to be careful with how we use them. Moreover, the combustion of fossil fuels contributed to climate change, which has a huge impact on food production in certain areas. A major issue at the start of the millennium was *'food or fuel?'* It seemed that food production was being sacrificed in order to meet the demand for bio-energy. Research into the biobased economy by Wageningen UR and others has confirmed that the use of biomass has major benefits over the use of fossil fuels. We have focused on an integrated approach for the production and processing of our natural resources. Within this approach, *'food or fuel'* has been replaced by *'food and fuel'* or, even better, *'food, chemicals, feed, and fuel'*! This has become possible by applying the latest ecological insights, using waste flows, applying new refinery techniques, improving plants and animals and, last but not least, ensuring a greater involvement by societal organisations in our research. This combination of factors has contributed to high-quality solutions with a wide social acceptance."

A good start for children with moringa leaves

The leaves of moringa trees are nutritious for children, but it is difficult to extract the nutrients from the leaves. Nevertheless, scientists of Wageningen UR have managed to do so. Now children can enjoy moringa paste, a cheap sauce for rice, other grains or bread. Moringa contains high levels of zinc, iron and other essential nutrients and can easily be processed in products. In this way, Wageningen UR contributes to affordable health for children.

WAGENINGEN UR
For quality of life

How did Wageningen UR contribute to these developments?

"In recent years we have taken major steps in new refinery techniques, and, more importantly, in the system approach and the skills to evaluate various systems. These steps could be taken as a result of intensive and innovative cooperation between social and natural scientists who wanted to look beyond the horizons of their disciplines. For example, we have become much better at indicating the role algae can play in systems focused on the production of food and energy. We approached issues regarding the optimal balance between animal and vegetable protein in the same way".

"Another major factor is our increased knowledge of transition processes. We now have a far better insight into the effects of seemingly small innovations, how they can be upscaled to system changes, and the opportunities and bottlenecks in translating innovations from Europe to, for instance, Africa. We can indicate how effective changes in production and retail can be realised. Although changes in consumer behaviour are more difficult to manage, we are also making headway in this field. Examples include reducing the amount of food that is wasted, and the provision of healthier choices in terms of food variety."

Cheese from the sea farming

Plankton in the sea is an excellent raw material for healthy products. Wageningen UR has developed systems for harvesting this plankton in a sustainable way. In this process, the scientists developed a way to extract the oil and protein-rich fractions from the plankton and convert it into a new product: Sea cheese. Sea cheese is rich in nutrients and has excellent saturating properties. Moreover, is tasty too. Sea cheese helps the cognitive development of children, and stimulates the memory and thought processes of the elderly. The use of plankton does not lay claim on precious agricultural acreage, and sea production is highly sustainable. This is another way in which Wageningen UR contributes to the quality of life.

WAGENINGEN UR
For quality of life

Returning to the most pressing social issue: In 30 years, how will we feed nine billion people in a sustainable way?

"In Wageningen we look at the entire food system. The issue is much wider than just the production of or access to sufficient food. Also an important aspect is how people consume food, and the effect food has on their wellbeing and health. Technological improvements have enabled us to unravel processes on a cellular level, giving us an increasing insight into the effect of nutrients on the human body. Technology has also led to improvements in our production systems. These new systems are designed based on the latest ecological insights, and together with community-based organisations we have managed to create a wide societal acceptance for these innovations. Partly based on these developments, various alternative types of production systems have been developed. This, in turn, led to the design of new arrangements for producing, distributing and consuming food. Also here we close the cycle.

The recently implemented new labeling system for food products, which was developed in collaboration with Wageningen scientists, allows consumers to 'track-and-trace' their food via the internet, providing them with more insight into the quality of both the food itself, and the production methods. We have seen that consumers adapt their purchasing patterns as a result, and that this in turn is addressed by retailers, illustrating increased consumer power. We also developed varieties of plants and animals that use the increasingly scarce resources more efficiently, are less vulnerable to pathogens, and contain increased levels of essential nutrients. We have subsequently been able to stimulate the use of alternative protein sources.

The prediction that marine ecosystems would become more important has also come true, partly due to contributions from our maritime groups and the establishment of a new chair in this field. We also studied better and fairer food distribution, and how to make the 'right to food' a more widely accepted and implemented fundamental human right. In short, research at Wageningen UR contributed to redesigning the food supply with a focus on sustainability and organisation."

Health and wellbeing are another field Wageningen UR focusses on. Significant progress has been made in tackling both obesity and undernourishment. How did Wageningen UR contribute?

“This is a prime example of a field that has benefitted from the cooperation between social, biological and technological sciences. We worked hard to acquire knowledge on the conversion of food and its effects on the processes in the human body. Understanding the needs of the consumer allows us to customise and adjust the food offer so that healthy nutrition is in line with consumer demands. As well as leading to adapted processing techniques to get the proper nutrients to the table, it also resulted in strategies to influence consumer behaviour and stimulate people to adopt a healthier diet. Thankfully, the number of obese children in the Netherlands has stopped increasing. This is partly due to the new attractive and healthy products that have entered the market. We are proud that our research contributed to this development. It shows that combined knowledge can find its way into society, and it encourages us to continue our policy of combining fundamental research with applied research.”

What's next?

“There is a constant stream of new challenges, such as those related to the huge increase in marine food production. We have to realise that it is important not to focus on a single solution. There is no ‘silver bullet’. Nutrition security requires bespoke solutions, combining knowledge and strengths, integrating various biological and ecological specialisations (from soil to mouth), and integrating the technological and social aspects of an innovation. It requires constantly adapting the research agenda to new insights and changing social conditions. There are many options, which is why it is important to have a clear overview of the impact of research. Which innovations have been effective, and, more importantly, which are expected to have impact on sustainable food supply? We have for some time been successfully using systems such as the ‘h-factor’, which measures the impact of publications on science. This is important but not yet sufficient. We are contributing to the development of the ‘i-factor’, which gauges the impact of science on society and, in our case more specifically, the quality of life. The 'i-factor' is an important source of inspiration for our entire organisation. It allows us to be more result-oriented in the sustainable preservation and use of ecosystem earth. It allows us to provide people with better support in their choices and use of food. And it puts us in an even better position to fulfil our mission: *To explore the potential of nature, to improve the quality of life*”.

3 | Protecting our crops

Eat and be eaten

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Sustainable food supply

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6 | The world around our tables

Algae as a multifunctional raw material

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Pot luck

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Round tables push back frontiers

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The Wageningen UR website has a special page with direct links to the above-mentioned publications and websites: *www.wageningenUR.nl/dies2013*

Colophon

Food for all Sustainable nutrition security

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In addition, many scientists contributed to the roundtables that led to chapter Back from the future

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About the cover

Nutrition security deals with the amount and the quality of food that people need. The pictures on the cover represent families with their weekly food purchase as photographed by Hungry Planet photographer Peter Menzel, illustrating the diversity in food that people consume. The background map illustrates the urbanisation of our planet.

Wageningen University 95 years 1918 2013

While the world produces enough food on average to feed everyone, an imbalance in food security regionally is caused by a lack of accessibility and utilisation. Both globally and regionally we face serious challenges as a growing population and an expected shift in diet requires more productive farming systems in the decades ahead. An additional 70 percent of production is predicted to be required to feed the global population by 2050. And this must be realised in the context of a shift to an increased bio-economy, a growing awareness of the importance of other ecosystem services than food production such as biodiversity, water supply and recreation and changing climate conditions.

At Wageningen UR (University & Research centre) we summarise these challenges with the maxim 2 x more with 2 x less but much more is possible. Almost all of the 90+ chair groups at Wageningen University contribute in one way or another to this central theme, as do the research institutions that also form an integral part of Wageningen UR. The theme is central to our domain of healthy food and living environment, and to our mission. With approximately 30 locations, 6,000 members of staff, 8,000 BSc and MSc students and 1,700 PhD students spanning 120 nationalities, Wageningen UR is one of the leading international organisations in its domain worldwide. By participating in many international networks, Wageningen UR faculty, staff and students make a genuine difference.