Reply to the Royal Society call for evidence: 'Biological approaches to enhance food-crop production'

Note: This document summarises the views of the EPSO Board members. The data collection was jointly undertaken by EPSO and Zurich-Basel Plant Science Centre staff. The EPSO Board fully supports the statements submitted by the Zurich-Basel scientists. The present report presents additional views to complement the Zurich-Basel Plant Science Centre report.

1. Is there a need to increase global food-crop production to support present and future populations and their consumption patterns?

Over the next 50 years, worldwide crop production will be placed under considerable stress by a combination of factors – including an increase in human population, an increase in food consumption, as well as environmental issues.

The United Nation (2007) estimates that over the next 40 years the world population will increase by 50%, from the current 6.7 billion to 9.2 billion by 2050. At least a 50% increase, probably a 100% increase, in food production will be required to meet the needs and expectations of this population. The FAO estimates that annual world agricultural production must rise by some 800 million tons in the 30 years to 2030 and by another 330 million tons in the subsequent two decades (FAO, 2006).

The FAO estimates that food consumption in the developing countries may rise from the current 2,650 kcal/person/day to 3,070 kcal by 2050 (FAO, 2007). In addition, food consumption patterns are also expected to change in developing countries, such as China and India, with an increase in consumption of more animal products. This will have a direct impact on the demand for grain and oil seed crops, increasing at a more rapid pace than population is growing. Moreover, the use of crops for industrial products, particularly ethanol from starch to meet increasing energy demand, is also expected to grow at a rapid pace (Rothstein, 2007).

Based on projected global increases in population and per capita incomes, and on observed dietary shifts with higher income, some experts estimate that the total global food demand will increase by as much as 120% in 50 years (Tilman, 2008).

Considering that there is no longer a large land reserve that could be planted with agricultural crops and that is not already being used for this purpose, any significant increase in crop production must be achieved by increasing crop yield (Rothstein, 2007).

To feed 9 billion people in 2050, crop productivity needs to double (Inze, 2008), and this needs to be accomplished in an environmentally and economically sustainable way.

2. What do you consider to be the major scientific and other challenges to increasing food-crop production in developed and developing countries over the next 30 years?

Doubling of global food production will require seven-times more nitrogen fertilisation, three-times more phosphorus fertilisation, 40% more irrigation and from 35% to 65% more crop land (Tilman, 2008). By far the most important environmental factors impacting crop yield are the availability of sufficient water and nutrients (Rothstein, 2007).

Yield increase and stability

In the past, scientists have mainly paid attention to the quality of yields, now they must turn back to the questions of the quantity of the yield. The aspect of yield stability is very important for future crop production to guarantee a more predictable food crop supply. Part of this could be achieved by breeding or engineering for increased biotic and abiotic stress resistances, but yield stability also includes the development of novel production and delivery systems (Plants for the Future, 2007).

Resistance to stresses

In the last few years plant scientists have been quite successful in understanding the mechanisms by which plants are responding to abiotic stresses. This work has to be continued to finally lead to improvements of food crops. Research on biotic stress resistance must be reinforced since “more than 40% of world food production is lost because crops are destroyed by insects, diseases, weeds, and some vertebrate animals. This tremendous loss is occurring despite the application of about 3 billion kilograms of pesticides and other pest controls now being used in world agriculture.” (Pimentel, 2002). In particular, sustainable management of disease resistances should be devised and implemented.

Field conditions typically represent a combination of biotic and abiotic stresses. Alterations in plant metabolism and regulation to mitigate one specific stress often impact the overall performance of the plant. Therefore it is necessary to develop an integrated approach to abiotic and biotic management.

Other processes and methods

In addition, scientists should also study basic physiological processes and breeding tools that have a direct influence on crop yields, such as photosynthesis, nutrient and water use efficiency, plant reproduction, heterosis etc.

Diversification of crops

Intensification of agriculture in developed and developing countries has led to the cultivation of large areas with the same crops and to the disappearance of crop rotations, contributing to increased selective pressures on plant pests and pathogens, soil degradation and reduction of biodiversity. Diversification of crops and use of better agronomic practices will be needed, and efforts should be made on studying and improving more diverse plant species than is the case at the moment (e.g. legume species).

Land use

Between the early 1960s and the late 1990s, land in agricultural use in the world has increased by 155 million ha to about 1.5 billion ha. During the same period, the world population nearly doubled from 3.1 billion to over 5.9 billion. By implication, arable land per person declined by 40%, from 0.43 ha in 1961/63 to 0.26 ha in 1997/99. At present some 11% (1.5 billion ha) of the globe’s land surface (13.4 billion ha) is used in crop production. This area represents slightly over a third (36%) of the land estimated to be to some degree suitable for crop production. (FAO, 2003)

The competition between the use of farmland for food production or for other human needs, such as urbanisation and bioenergy production, is rapidly increasing. Moreover, current agricultural practices are identified as one of the factors responsible for land degradation (erosion, reduced fertility, salinisation and desertification of soils) (Bai et al., 2008). Therefore a great opportunity to improve agriculture will be in combining the advantages of all available technologies and agricultural practices.

Environmental impact

Environmental consequences of using fertilisers and herbicides must also be taken into account. Collaboration between plant biologists, breeders, agronomists and engineers is needed to develop crop plants with more efficient nutrient uptake systems in order to reduce the demand of added fertilisers and other chemicals. Precision farming techniques could be further developed to allow a more precise application of herbicides. For example, it is possible to distinguish a weed from the crop plant by chlorophyll fluorescence fingerprinting and apply herbicides only to the weed (Keränen et al., 2003).

Post-harvest losses

Preventing post-harvest losses during storage and transport, which are currently estimated at 20% (Pimentel, 2002), is also an area presently not well enough covered in plant sciences. An integrated approach with (the developing) food supply chains is crucial.

Food supply chain

The predicted increase in global food production will also need to be paralleled by the development of a proper regional and global supply chain with respect to optimisation of stability and amount of food supply. Plants are essential elements of the solution, but interdisciplinary approaches for plant production and development of proper food systems (including supply and storage systems) need to be developed and adapted for the new situation.

The distribution of people to be fed will also change in the coming years. This includes aspects like mega cities that do require different food supply chains and relationships between intensive agriculture and consumers.

Climate change
Current scientific models predict substantial environmental changes caused by increased emission of greenhouse gases. The IPCC (2007) forecasts an increase in global temperature of between 1.4ºC and 5.8ºC by the end of the century. This can affect agriculture both in positive and negative ways, although crop responses to changes in their growing conditions are still poorly understood (Porter and Semenov, 2005). Increasing atmospheric CO_2 levels could have a positive impact in temperate regions for some crops such as wheat, rice and soybeans by increasing growth (fertilisation effect). This can be tempered by alterations in precipitation and temperature patterns, with extreme weather events (droughts, floods) expected to occur more frequently (Smith et al., 2007). On the contrary, in dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger (IPCC, 2007). Lobell et al. (2007) estimate potential losses at 30% in southern Africa (corn) and 10% in South Asia (rice, millet and corn). In current temperate regions changes in climatic conditions will lead to increased invasions of weeds, pests and diseases adapted to warmer climatic conditions and will affect soil stability (Baker et al., 2007).

3. Can you identify recent or imminent scientific developments that will impact substantially on food-crop production over the next 30 years?

Since the 1950s, technological progress has made it possible to achieve remarcable improvements in land productivity and significant increases in food availability per capita, despite a consistent decline in per-capita agricultural land (IPCC, 2007). In 1950, average crop yields were 1,000 kg/ha for wheat, 1,500 kg/ha for maize, 1,600 kg/ha for paddy rice and 1,100 kg/ha for barley – much the same as at the beginning of the century. Since then, yields have doubled or tripled (FAO, 2000). The global average daily availability of calories per capita has increased (Gilland, 2002), with some regional exceptions. This growth, however, has been at the expense of increased pressure on the environment and depletion of natural resources (Tilman et al., 2001; Rees, 2003), while it has not resolved the problems of food security and child malnutrition suffered in poor countries (Conway and Toenniessen, 1999).

High-quality and well performing plant varieties are necessary prerequisites for the sustainable production of food raw materials. Improving food safety and traceability are becoming issues of major consumer concern. Plant scientists in close cooperation with breeders must develop varieties that are more resistant to pests and diseases. (Plants for the Future, 2007)

According to Rothstein (2007) “a considerable amount is known about the genes controlling plant growth and development, and the question is whether this knowledge can be used in a predictive sense to help develop improved crop cultivars”. Further research is needed to:

- discover the genetic factors controlling partitioning into the grain to optimise for this trait;
- understand the linkage between regulation of carbon and nitrogen metabolism;
- discover the fundamental processes underlying inter and intra-species competition on yield;
- understand gene function in major crops;
- understand how to modify genetic variation to alter phenotype;
- develop a comprehensive understanding of the genetic variation present in each crop plant of interest (genotype-phenotype correlations);
- improve crop quality and yield through introgression and genetic engineering of traits from wild relatives;
- sequence major plant pathogens and assess plant-pathogen interactions.

Development of modelling approaches will be necessary to integrate knowledge from different disciplines and predict the behaviour of modified plants in various environments.

Some recent scientific developments that will have an impact on food-crop production are:

- breakthroughs in understanding how plant cells are recognising different hormones and which signalling pathways are activated by hormones;
- the role of small RNAs in plant development;
- sequencing of major crop plant genomes (in progress or already achieved) and assessment of intra-specific genetic variability by high-throughput sequencing technologies;
- understanding how interactions between the genome and the environment make a plant body (“phenome”).

There is an urgent need to bridge the gap between lab and field conditions. It will be necessary to make the wealth of information available from molecular biology useful to tackle agricultural challenges. It is of outmost importance to train a new generation of scientists who can move comfortably between molecular biology and agronomy to better implement these tools.

4. What biological approaches do you think have potential for food-crop improvement over the next 30 years and what benefits would they bring? These may include biotechnological, agroecological and other agronomic technologies. In your answer, please outline the current state of knowledge and the time you think it will take for the benefits from these approaches to be seen.

Food-crop improvement over the next 30 years could be achieved in a sustainable way by combining currently somewhat disparate approaches, including agricultural biotechnology, cropland management and certain organic farming practices.

Precision agriculture and the upstream development of suitable technologies in crop plants are key to sustainable food security. This includes an integration of breeding and agricultural management. Similar to the upcoming approach in medicine ("personalised medicine") we need the appropriate plant for specific conditions of production ("performance prediction and monitoring"). We need appropriate new crop varieties that respond efficiently to modern practices of agricultural technology in the sense of an integrated plant-technology application.

In the coming decade, all different 'omics' techniques will remain as cutting edge technologies. In parallel, phenotyping (i.e., imaging both on cellular as well as whole plant level, in controlled and in field conditions) is becoming more and more important. The latter makes plant cell biology and developmental biology much more important than it is at the moment.

Ecology and biodiversity

The elite crops used in modern agriculture contain germplasms developed over hundreds, sometimes thousands, of years by farmers and plant breeders. In many cases, genes for characteristics such as yield, nutritional quality, and disease resistance have been introgressed into crop varieties from sexually-compatible wild species or local isolates by careful selection. The genetic diversity represents a largely untapped resource that can now be harnessed more rapidly using modern molecular breeding methodologies. A first step will be to create a phenotypic and genotypic inventory, including precise information on origins, of wild species or local isolates that can be exploited for selected target crops such as cereals, Solanaceae, Brassicaceae and grain legumes. In a second step this improved access to the biodiversity resources available for the improvement of today's crops will contribute towards an increased stability of food by increasing and stabilising yields and food quality. These objectives are especially important given the unpredictability of future climate change.

A multidisciplinary approach combining expertise from ecology, evolutionary biology, developmental biology and molecular biology will highly facilitate further breakthroughs. One approach will be the development of new crops within a framework of protecting and enhancing biodiversity in the farmed landscape. Strategies will include breeding new crops with improved yield and reduced inputs (Plants for the Future, 2006).

Biotechnology

In 2007, 23 countries – 12 developing and 11 industrial – cultivated biotech crops on 114.3 million hectares (ISAAA, 2007). In the EU in 2008, only seven of previously eight countries cultivated biotech crops on 107 719 hectares, a 2% decrease compared to 2007 due to the ban on GM crop cultivation in France, but a 21% increase if France's GM cultivation in 2007 is not considered (EuropaBio, 2008).

Since 1996, biotech traits have added 53.3 million tons and 47.1 million tons, respectively, to global production of soybeans and corn. The technology has also contributed an extra 4.9 million tons of cotton lint and 3.2 million tons of canola (Brookes and Barfoot, 2008).

In terms of additional production (arising from yield gains), in 2006, global production of soybeans, corn, cotton and canola were respectively +5%, +1.4%, +5.2% and +0.5% higher than levels would have otherwise been if GM technology had not been used by farmers (Brookes and Barfoot, 2008). The levels of herbicides and pesticides used on biotech crops is estimated to be on average 7.8% lower than levels that would have been used if all of the biotech crop area had been planted with conventional cultivars (Brookes and Barfoot, 2008).

Cropland management

As discussed in question 2, precision farming techniques could be further developed for more precise applications of herbicides and pesticides for crop protection and of fertilisers for optimising nutrient management. For example, the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) developed a microdosing technique to deliver small amount of fertilisers to crops. Field test in West Africa showed yield increases between 44 and 120% for pearl millet and sorghum (ICRISAT, 2006).

Current practices of crop production, such as no- and low-tillage, are a considerable improvement to restore degraded cropland, but losses still occur, albeit at a lower rate (Rothstein, 2007). By reducing the intensity of tillage, soil conservation can be improved, and water and wind erosion can be considerably reduced (Holland 2004). A Switzerland long-term trial that is currently under way analyses the effect of reduced tillage on crop yields and weed infestation under organic conditions. First years results suggest that even in heavy soil, reduced tillage systems may be applicable without negative consequence on yield (Berner et al., 2005).

It is estimated that approximately 50% of the nitrogen applied as fertiliser is lost from agricultural landscapes through denitrification, leaching and erosion (Smil, 1999; Galloway and Cowling, 2002). This results in application of large amounts of fertilisers to produce desired yields in intensive agricultural systems. Diversified rotations, including leguminous and non-leguminous cover crops to replace bare fallow periods, could be used to increase nitrogen retention while maintaining acceptable yields (Tonitto et al., 2006). For example, nitrate leaching can be reduced by 40% in legume-based systems compared to conventional fertiliser-based systems (Tonitto et al., 2006).

Water scarcity, defined in terms of access to water, is a critical constraint to agriculture in many areas of the world. The International Water Management Institute estimates that without further improvements in water productivity or major shifts in production patterns, the amount of water consumed by evapotranspiration in agriculture will increase by 70%–90% by 2050 (Earthscan and Colombo, 2007). Improved water management practices include a spectrum of options, from irrigation, to soil conservation and ‘crop per drop’ (gaining more yield and value from water) techniques.

Organic farming

“Among the benefits of organic technologies are higher soil organic matter and nitrogen, lower fossil energy inputs, yields similar to those of conventional systems, and conservation of soil moisture and water resources (especially advantageous under drought conditions). Conventional agriculture can be made more sustainable and ecologically sound by adopting some traditional organic farming technologies.” (Piementel et al., 2005)

Crop productivity in intensive agriculture has increased substantially by high inputs of soluble fertilisers and pesticides – mainly nitrogen. Productivity in sustainable agriculture, especially in organic agriculture, is enhanced by many indirect measures based on improving soil fertility and stimulating the role of plants and microbes in natural soil processes (FAO, 2008). These can be based on symbiotic and asymbiotic nitrogen fixation and exploiting soil phosphorus and water resources by symbiotic mycorrhiza (Mäder et al., 2002; 2006).

However, some shortcomings of organic farming practices (such as yield limits, copper use and storage in the soil) can be addressed by combining advantages of all available technologies.

Vertical farming

A new development is vertical farming (Vogel, 2008), in which we will produce crops in a completely conditioned manner. Important in this respect are the complete control of photosynthesis and the development of new type of climatic controlled 'green houses'. The idea is to produce basic plant components such as starch, proteins, metabolites in fully controlled dedicated systems. This overcomes high use of inputs such as water and energy.

5. Which traits, across species or in specific food-crops, are appropriate targets for improvement? Comments could include information on why such traits are appropriate targets, the benefits they may bring, difficulties involved in targeting such traits and time required to see benefits from such improvement (for example, time needed to get improved varieties in farmers' fields).

Previous experience suggests that it takes 10 to 15 years between basic knowledge acquisition and translation into improved crop genetics and production (Rothstein, 2007).

The following traits are targets for improvements:

- mechanisms controlling plant growth under normal conditions;
- abiotic stress tolerance (drought, water logging, cold, salinity, subsoil stress like boron, macro/micro-nutrient use efficiency);
- pathogen resistance, especially in harsh environmental conditions which can devastate crop yields across the developing world;
- C3, C4 and CAM cross-engineering; by using synthetic biology approaches, one of the future goals is to introduce the essential parts of the C4 pathway to rice;
- photosynthetic efficiency and targeted allocation of assimilates, transport of minerals, production of secondary metabolites;
- belowground traits, which are presently totally empirical. Here is a great potential for improvement in breeding especially as techniques are coming up that allow for the first time quantitative approaches on roots and root systems and how roots respond in their natural soil environment.

7. Do you anticipate/foresee any advances in engineering, materials science, chemistry or other non-biological science that will strongly influence future developments in food-crop production?

As discussed already, food-crop production competes with bioenergy/biofuel production and scientists should find means to prevent the use of fertile land for bioenergy production (this does not apply to the use of plant waste from food and feed crops for bioenergy production). Here, strong emphasis should be placed on photosynthetic microorganisms (e.g. algae) that are more efficient than crop plants for biofuel production (Dismukes, 2008; Chisti, 2008). More importantly, they can be grown in areas not suitable for food-crop production. Plant scientists should stress this point since they have the expertise in photosynthesis and in modification of biosynthetic pathways, which is pertinently needed in engineering efficient microorganisms for biofuel production. Engineering technology is needed, together with plant biology expertise, to build efficient bioreactors. For example, the light harvesting properties of the photosynthetic apparatus are extremely important in this respect. Synthetic biology is a key process to finally build an efficient "cell" primarily targeted for biofuel production.

Information technology (IT) will be a major source of future improvements at various levels of the food production chain. Basic research already benefits a lot, and this will spread to breeding with increasing availability of new sensors (e.g. non-invasive technology) into breeding practices in the field that provide quantitative data on key plant processes in the field and that monitor environmental parameters at a very different intensity compared to what we know today. Such systems are presently under preparation. IT will also be increasingly used in agricultural management.

8. What might be the possible consequences and impacts of biological approaches to enhance food-crop production on:
a) crop yields and quality;
b) world food prices;
c) the environment;
d) the livelihoods of farmers; and
e) any other areas you think relevant.

Nutritional requirements

In 2006, biotech crops are likely to have contributed enough energy, protein and fat to meet the requirements of about 67 million (similar to the population of Thailand), 207 million and 124 million people respectively (Brookes and Barfoot, 2008).

Income
Farmers using biotech traits have increased their incomes by a total of $33.8 billion (1996-2006). About half of this has been to farmers in developing countries (mostly insect resistant cotton). This has added to farm household incomes which, when spent on goods and services, have had a positive multiplying effect on local, regional and national economies. (Brookes and Barfoot, 2008)

Environmental benefits
From 1996 to 2006, pesticide use in four crops studied (soybean, corn, canola and cotton) in countries where biotech crops have been planted has fallen by 286 million kg (a decrease of 7.8%), resulting in a 15.4% reduction in the associated environmental impact. Greenhouse gas emission reductions have also been facilitated, equal to 14.76 billion kg of carbon dioxide in 2006, equivalent to removing 6.56 million cars from the roads for a year. (Brookes and Barfoot, 2008)

The socio-economy of crop production such as rural development will be a crucial element beyond the plant science aspects.

9. What are the potential barriers to the application of biological approaches to enhance food-crop production? These barriers might include matters relating to regulation, national and international policies, adequacy of the skills base, research infrastructure and resource availability including germplasm conservation, and knowledge transfer and intellectual property issues.
Please also comment on the appropriate relative contribution of private and public sectors, and on whether there is sufficient public sector breeding and training in plant breeding.

"Feeding the world's population in 50 years without increasing land for farming and in an environmentally responsible way will take considerable drive, commitment, and a substantial increase in research funding to use gene knowledge in a predictive fashion to alter important crop traits. For this to be successful, it also will require a significant change in how fundamental knowledge is translated into applications." (Rothstein, 2007)

Genetic resources of crops and related species are strategic for understanding plant adaptation to its environment and for breeding. Genetic resources conserved in Biological Resource Centres should be characterised in depth both genotypically and phenotypically, and the germplasm and information made publicly available by international stock centres. Recurrent funding of such stock-centres is necessary.

The most important constraint to biotech crops in most developing countries is the lack of appropriate cost-effective and responsible regulation systems that incorporate all the lessons of a dozen years of regulation (ISAAA, 2007).

The introduction of a new genetically modified plant according to existing regulations is a high-cost activity. Currently, the demands for the approval of a new plant event result in costs of tens of millions euros. This has two effects: first it prevents and discourages most SMEs and often even larger companies from applying the technologies and reduces the applications of these technologies to a small number of crops and traits; second, biotechnology can only be further developed in the companies that can afford the investments. There are even voices calling to extend the existing regulatory system for GMOs to any new genetic modification or novel crop, such as those produced by marker-assisted breeding or cell-culture based approaches. This would produce an enormous economic barrier to development and application of any new technology, whether GMO or other. Public institutions and small producers feel the need to reach an international agreement in the requirements for the cultivation of any new plant variety and to identify the data that really contribute to ascertain the effects of new varieties on human and animal health and the environment.

A system to protect intellectual property for plant varieties has been developed during the last century leading to the UPOV system. The recent introduction of a patent system for genes and characters in plants may have been distorting the extent of the applications of genetics in crop plants and may have been used essentially as a defensive action against new uses of the genes. An evaluation of the most appropriate system of plant variety protection that balances the right of the inventor and the uses of genetic variability by plant breeders is urgently needed.

Moreover, subsidies hinder the development of competitive agriculture and prevent the transfer from invention to innovation.

Education is key in sciences, but also in the transfer of science to agricultural management on the farms. Here a stronger integration is necessary providing an easier flow from plant sciences to practical parts of the crop production network. Breeding expertise has to be maintained or developed in the public sector in order to address issues not considered as economically relevant for private companies, to develop new concepts or methods, and to train students. A boost in education of highly skilled junior scientists and students in classical disciplines such as plant breeding, physiology and cell biology is crucial.

Submission date
20 October 2008

Authors

EPSO Board members

Wilhelm Gruissem, Institute of Plant Sciences, ETH Zürich, Switzerland
Ulrich Schurr, Institute Phytosphere, Research Centre Jülich, Germany
Eva-Mari Aro, Laboratory of Plant Physiology and Molecular Biology, Turku University, Finland
Raoul Bino, Plant Science Group WURC, Netherlands
Jacek Hennig, Institute of Biochemistry and Biophysics, Polish Academy of Sciences Warsaw, Poland
Hélène Lucas, Genetics and Plant Breeding Division, INRA Versailles, France
Kirsi-Marja Oksman-Caldentey, VTT Biotechnology, Espoo, Finland
Christophe Plomion, UMR Biodiversity Genes & Communities, INRA Bordeaux, France
Pere Puigdomenech, Barcelona Institute for Molecular Biology, IBMB-CSIC, Spain
Chiara Tonelli, Department of Biomolecular Sciences and Biotechnology, University of Milan, Italy
Erkki Truve, Department of Gene Technology, Tallinn University of Technology, Estonia
(Jonathan Jones, Sainsbury Laboratory, United Kingdom is an EPSO Board member, however he did not contribute to this report since he is a member of the Royal Society's working group that will read and synthesise the reports)

EPSO staff

Isabelle Caugant, Science Writer
Karin Metzlaff, Executive Director

About EPSO

EPSO, the European Plant Science Organisation, is an independent academic organisation that represents more than 185 leading research institutes, universities and departments from 25 European countries, Australia and New Zealand. EPSO's mission is to improve the impact and visibility of plant science in Europe. www.epsoweb.org

---

References

- Badgley, Moghtader, Quintero, Zakem, Jahi Chappell, Avilés-Vázquez, Samulon, and Perfecto (2007)
  Organic agriculture and the global food supply.
  Renewable Agriculture and Food Systems, 22(2), 86-108.
- Bai, Dent, Olsson and Schaepman (2008).
  Global assessment of land degradation and improvement 1: identification by remote sensing. Report 2008/01 (GLADA Report 5), ISRIC
  www.isric.org/isric/webdocs/docs/Report%202008_01_GLADA%20international_REV_Aug%202008.pdf
- Barker, Bashmakov, Bernstein, Bogner,. Bosch, Dave, Davidson, Fisher, Gupta, Halsnæs,. Heij, Kahn Ribeiro, Kobayashi, Levine, Martino, Masera, Metz, Meyer, Nabuurs, Najam, Nakicenovic, Rogner, Roy, Sathaye, Schock, Shukla, Sims, Smith, Tirpak, Urge-Vorsatz, Zhou (2007)
  Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P.R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
  www.mnp.nl/ipcc/pages_media/FAR4docs/final_pdfs_ar4/TS.pdf
- Berner, Frei, Dierauer, Vogelgsang, Forrer and Mäder, P. (2005)
  Effects of reduced tillage, fertilisation and biodynamic preparations on crop yield, weed infestation and the occurrence of

toxigenic fusaria. In: Köpke, U., U. Niggli, D. Neuhoff, P. Cornish, W. Lockeretz, H. Willer (2005): Researching Sustainable Systems. First Scientific Conference of ISOFAR. 21st-23rd September 2005, Adelaide.

- Brookes and Barfoot (2008), PG Economics Ltd
  GM crops: global socio-economic and environmental impacts 1996-2006
  www.pgeconomics.co.uk/pdf/globalimpactstudyjune2008PGEconomics.pdf
- Chisti (2008)
  Biodiesel from microalgae beats bioethanol
  Trends Biotechnol, 26, 126-131
- Conway and Toenniessen (1999)
  Feeding the world in the twenty-first century
  Nature, 402, C55-58
- Dismukes, Carrieri, Bennette, Ananyev and Posevitz (2008)
  Aquatic phototrophs: efficient alternatives to land-based crops for biofuels
  Curr Opin Biotechnol, 19, 235-240
- Earthscan and Colombo (2007) – International Water Management Institute.
  A Comprehensive Assessment of Water Management in Agriculture – Water for Food, Water for Life
  www.fao.org/nr/water/docs/Summary_SynthesisBook.pdf
- EuropaBio (2008) Press release
  Latest figures show that more EU farmers choose to grow biotech crops to boost their competitiveness, but are the EU's Ag Ministers listening?
  www.europabio.org/articles/GBE/EuropaBio%20Press%20Release%20cultivation%20figures%202008_290908.pdf
- FAO (2000)
  World Food and Agriculture – Lessons from the past 50 years
  www.fao.org/docrep/x4400e/x4400e08.htm#TopOfPage
- FAO (2003)
  World agriculture: towards 2015/2030
  www.fao.org/docrep/005/y4252e/y4252e00.htm
- FAO (2006)
  World agriculture: towards 2030/2050 – Interim report: Prospects for food, nutrition, agriculture and major commodity groups
  www.fao.org/es/esd/AT2050web.pdf
- FAO (2007)
  The state fo food and agricultuer – Paying farmers for environmental services
  ftp://ftp.fao.org/docrep/fao/010/a1200e/a1200e00.pdf
- FAO (2008)
  Low Greenhouse Gas Agriculture: Mitigation and adaptation potential of sustainable farming systems
  ftp://ftp.fao.org/docrep/fao/010/ai781e/ai781e00.pdf
- Galloway and Cowling (2002)
  Reactive Nitrogen and The World: 200 Years of Change
  Ambio, 31, 64-71
- Gillan (2002)
  World population and food supply. Can food production keep pace with population growth in the next half-century?
  Food Policy, 27, 47-63.
- Holland (2004)
  The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence.
  Agriculture, Ecosystems and Environment 103, 1-25.
- ICRISAT (2006)
  Small fertilizer doses yield big impact in sub-Saharan Africa
  www.icrisat.org/New&Events/Smallfertilizer.htm
- Inze (2008) – Boosting sustainable crop productivity
  Venice conference 'The future of science' http://www.thefutureofscience.org/
- IPPC (2007)
  Climate Change 2007: Synthesis Report
  www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf
- ISAAA, International Service for the Acquisition of Agri-biotech Applications (2007)
  Global Status of Commercialized Biotech/GM Crops: 2007
  www.isaaa.org/resources/publications/briefs/37/executivesummary/default.html
- Keränen, Aro, Tyystjärvi and Nevalainen (2003)
  Automatic Plant Identification with Chlorophyll Fluorescence Fingerprinting
  Precision Agriculture, 4, 53-67
- Lobell, Burke, Tebaldi, Mastrandrea, Falcon, and Naylor (2007)
  Prioritizing Climate Change Adaptation Needs for Food Security in 2030
  Science, 319, 607-610
- Mäder, Fliessbach, Dubois, Gunst, Jossi, Widmer, Oberson, Frossard, Oehl, Wiemken, Gattinger, and Niggli (2006)
  The DOK experiment (Switzerland). In: Long-term field experiments in organic farming. Raupp, J., Pekrun, C., Oltmanns, M., Köpke, U. (eds.). pp 198. Koester, Bonn.
- Mäder, Fließbach, Dubois, Gunst., Fried., and Niggli (2002)
  Soil Fertility and Biodiversity in Organic Farming.
  Science, 296, 1694-1697.
- Pimentel (2002)
  Encyclopedia of Pest Management
  Taylor & Francis, NY
- Pimentel, Hepperly, Hanson, Douds, and Seidel (2005)
  Environmental, energetic, and economic comparisons of organic and conventional farming systems.
  Bioscience, 55, 573-582.
- Plants for the Future (2006)
  Survey on future plant research activities in Europe
  bioinformatics.psb.ugent.be/FPRA/pdf/Report_Survey.pdf

- Plants for the Future (2007)
  Strategic Research Agenda
  www.epsoweb.org/Catalog/TP/Launch_25June07/TP_SRA_PART_II+III.pdf
- Porter and Semenova (2005)
  Crop responses to climatic variation
  Philos Trans R Soc Lond B Biol Sci, 360, 2021-2035
- Rees (2003)
  A blot on the land.
  Nature, 421, 898
- Rothstein (2007)
  Returning to our roots: making plant biology research relevant to future challenges in agriculture.
  The Plant Cell, 19, 2695-2699
  www.plantcell.org/cgi/reprint/19/9/2695
- Smil (1999)
  Nitrogen in Crop Production: An Account of Global Flows
  Global Biogeochem. Cycles, 13, 647–662.
- Smith, Martino, Cai, Gwary, Janzen, Kumar, McCarl, Ogle, O'Mara, Rice, Scholes, Sirotenko (2007)
  Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
  www.mnp.nl/ipcc/pages_media/FAR4docs/final_pdfs_ar4/Chapter08.pdf
- Tilman (2008)
  Food, energy and the environment: the next 50 years
  Venice conference 'The future of science' http://www.thefutureofscience.org/
- Tilman, Fargione, Wolff, D'Antonio, Dobson, Howarth, Schindler, Schlesinger, Simberloff, and Swackhamer, (2001)
  Forecasting agriculturally driven global environmental change.
  Science, 292, 281-284.
- Tonitto, David, and Drinkwater (2006)
  Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics
  Agriculture, Ecosystems and Environment, 112, 58-72
- Vogel (2008)
  Upending the traditional farm
  Science, 319, 752-753
- UN (2007)
  World Population Prospects – The 2006 Revision
  www.un.org/esa/population/publications/wpp2006/WPP2006_Highlights_rev.pdf