EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

Reaping the benefits: towards sustainable intensification of global agriculture

Responses to call for evidence

Part I

Table of contents

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These comments draw on extensive experience with dryland production systems in Africa, particularly in the Sahel of West Africa (e.g. Mortimore (1998), Mortimore and Adams (1997, 2001), Adams 2008). These areas are among the most intractable in the world in terms of hunger, low food crop productivity and poverty. They are central to success in reaching the Millennium Development Goals.

Core conclusions are:
1) The problem of food supply must be understood as part of the wider problem of livelihood security. Crop research must form part of a holistic approach to understanding livelihoods and constraints on wealth creation.
2) Farmers usually mix crop production with other activities, including livestock, trade, handicrafts and other forms of off-farm income; many rural households are linked economically to urban households through labour circulation and migration. A key constraint on food production is therefore labour supply at critical periods. Crop-production research must take account of the opportunity costs of new technologies and practices, or that research will be wasted.
3) A fundamental factor in the success of dryland production systems is their diversity and flexibility. This includes diversity in crop type (landraces adapted to local and contingent conditions) and diversity in ecological management (adapting to local conditions). Food crop production research must work with and enhance this diversity and flexibility and not reduce it.
4) Rural food producers typically show profound knowledge of environmental variation and constraints on production. Crop production improvement there must be organized to build onto this knowledge by working with farmers *in situ*, in villages and fields not metropolitan laboratories and research stations.
5) Where external institutional, economic and governance frameworks allow, small farmers can achieve food and commodity production that outstrips population growth and is associated with investment in land (terraces, trees) (e.g. the Kano Close-Settled Zone in Nigeria, southern Niger, Machakos District in Kenya). Food crop improvement has a role to play in such transformations, but only as part of a wider policy package (Mortimore 1998, Tiffen *et al.* 1994)
6) Future climate change is likely to be a critical problem, particularly in the form of variation in the start, length and adequacy of rainy seasons.
7) Rural food producers in Africa are exposed to huge uncertainties in markets and governance. So the availability of specialized inputs (seeds, fertiliser, pesticide) are subject to disruption. Food-crop research must deliver solutions designed to be robust in unfavourable circumstances.

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

Yes, this is generally true, and follows from growing global population. However, the greatest problems of food shortage are not the result of limited global food production, but of poverty and poor distribution. There are differences in these problems in rural and urban areas. In rural areas, production by most producers is constrained by lack of labour, lack of water supply, lack of appropriate forms of pest and disease control and asset and cash poverty. In urban areas (and statistically the world is now >50% urban, a proportion that will grow), food shortfalls relate primarily to household asset and cash poverty. Increasing food production (for example by improving yields under high-input farming) is unlikely to make a significant impact on food deficiency in either rural or urban areas unless allied to policy and economic change.

Changes outside the crop production sector are likely to make more significant improvements in food availability for the urban and rural poor at far lower cost. Improvements in food crop production (including biological innovation) have an important role to play, but it is vital that this is not seen as a technological 'magic bullet'. The relationship of that food crop research to real problems on the ground will critical to its usefulness.

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?*

Key problems include:

- Climate change: the next 30-70 years will see substantial changes in the timing and amount of rainfall in drylands such as the Sahel, eastern and southern Africa and South Asia. Present food production systems in these areas are based on diversity of crop varieties adapted to unpredictable seasonal rainfall patterns. Future rainfall patterns cannot currently be predicted at regional scale. It is not clear whether existing crop varieties will enable production to be sustained as climate changes.
- Gene poverty: the narrowing of the genetic material in food crops associated with formal crop improvement programmes threatens the loss of genetic variety in landraces that are currently a vital element in the sustainability of rural production systems.
- Reliance on industrial inputs for food crop production: while synthetic fertiliser and pesticide have very significant effects on yields, their use increases vulnerability to price rises (an issue as oil becomes more costly) and market availability. This is particularly a problem in areas that are remote, or with poor governance or highly variable rainfall (e.g. the Sahel).
- Water supply: water will become more scarce, demanding far greater irrigation efficiencies, and raising issues of competition for scarce supplies between urban and rural consumers. Crop production systems need to be adapted to yield reliably without irrigation.
- Non-commercial crops: crop breeding has so far done relatively little for crops that are not important global commodities. Research on sorghum, millet, yams and cassava is urgently needed. It is not clear that such research will be undertaken by private corporate science (because the scattered poor offer an unattractive market).
- Crop storage: the food production in the most food-deficient areas depends on inter-year seed storage (e.g. dryland Africa). The distinction between 'cash' and 'subsistence' crops is meaningless in most areas of rural Africa. Any crop breeding that prevents farmers from storage seed for planting the next year will seriously erode livelihoods and the sustainability of food crop production. Crop storage losses remain a critical problem. Solutions that avoid the use of expensive and potentially toxic pesticides are needed.

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

The most important factor is that scientific advances are made in association with farmers and not in isolated laboratories. Farmer-first approaches work in areas such as dryland Africa, and very little else does (Mortimore 1998; Chambers 2005).

4. *What biological approaches do you think have potential for food-crop improvement over the next 30 years and what benefits would they bring?*

Food crop production research must integrate crop genome research through to rural production system research, and work with real farmers in the field, or it will not achieve anything.

5. *Which traits, across species or in specific food-crops, are appropriate targets for improvement?*

- Resilience in the face of variable rainfall will main critical to food production in drylands for the foreseeable futuree
- Resilience in the face of breakdowns in fertilizer/pesticide supply
- Resistance to pests (including insects and birds), disease, inter-generational fertility

6. *Which current/future husbandry or farm management technologies for the enhancement of food-crop production are appropriate for development and dissemination and why?*

The most significant technology for rural food producers is probably the mobile telephone, allowing knowledge of market prices and making it possible to book transport to market.

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?*

The rising profitability of improved crop production systems for industrial food crops and biomass fuels (e.g. *Jatropha*) will tilt farmer choices away from food crops, and farmer systems away from family farms to larger-scale production. Such industrial production will monopolize scarce resources (this is already happening with water demand for irrigation for flower production in Laikipia, Kenya). There are risks to rural subsistence from the use of labour-replacing machinery, and the use of organophosphorus pesticides by inadequately trained rural workers.

8. *What might be the possible consequences and impacts of biological approaches to enhance food-crop production on:*

c) the environment;

- Nitrate and phosphorus runoff have severe impacts on downstream wetlands and water users. Such agricultural 'externalities' are rarely monitored or controlled, but represent a serious reduction on the value of ecosystem services.
- Pesticide poisoning from used by poorly equipped and trained rural workers is a serious problem.
- Habitat and biodiversity loss will follow food crop system improvements that allow exploitation of currently uncultivated land.

d) the livelihoods of farmers.

Research on the South Asian Green revolution shows that the impacts of new crops and cropping systems on farmer incomes is complex. Smaller and poorer farmers can lose out, especially if rural employment opportunities are not created. Women, members of female-headed households, and the disabled can be made destitute by improved food crop production systems. Research must embrace such issues, and policies must be holistic enough to deal with negative impacts. A narrow focus on food crop improvement is unlikely to yield improvements in the wider human condition, even locally.

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.*

The shift of balance in food crop research from governmental and intergovernmental to commercial institutions is a problem. Poor farmers make an unattractive market, and therefore such research is likely to ignore crops critical to rural subsistence and food trade in areas such as dryland Africa (e.g. bulrush and finger millet, sorghum, and to a lesser extent cassava). Where that research is done, the transfer of genetic material from the hands of farmers into the copyright of corporations is likely to increase the exposure of farmers to market arrangements that reflect corporate profit and not public interest. It is vital that rights to food crop genetic material needed in food-deficit areas of the developing world remain in the public domain.

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Agricultural Biotechnology Council (abc)

Introduction

The Agricultural Biotechnology Council (abc) welcomes the opportunity to provide evidence on the challenges to world food-crop production.

abc is the umbrella group for the agricultural biotechnology industry in the UK. The companies involved include BASF, Bayer CropScience, Dow Agrosciences, Pioneer (Du Pont), Monsanto and Syngenta. Our aim is to provide information about genetically modified (GM) crops in the UK and around the world and the important role of GM technology in delivering high quality affordable food in a way that minimises the environmental footprint of agriculture.

- A combination of population growth, the effects of climate change in terms of variable weather patterns, an ever-diminishing supply of fresh water, and changing diets require a significant increase in food production around the world.
- The use of science and technology in agriculture spawned the highly effective Green Revolution. A second such revolution is required if we are to sustain predicted increases in population.
- Agricultural biotechnology and GM crop**s** are increasing yields and improving the nutritional quality of our food, whilst reducing the environmental footprint of agriculture.
- Extensive field trials are demonstrating that further increases in yield are achievable under conditions such as drought and other stress, together with nitrogen efficiency gains that will significantly reduce the requirements for additional fertilisers.
- Farmers should be in a position to utilise and benefit from opportunities deriving from the growing of GM crops in the UK.
- For that to happen, field trials of GM crops, licenced under UK rules and enshrined under European law, should be permitted to be carried out without fear of their being destroyed by individuals or groups opposed to this technology.

Responses to Specific questions posed by the Royal Society

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

Abc would assert that there is a clear need to respond positively to the combination of an ever increasing population, and changing diets in southeast Asia which are resulting in the need for an increased supply of animal feed. The food inflation of the last eighteen months is a clear indication that, at least in part, the food supply and demand dynamics have shifted decisively to demand equalling or exceeding supply for the first time for thirty years or more.

The problem of matching global production of food and feed to the demand required by the global population is a fundamental challenge. It is undeniable that technology (crop breeding, fertilizers, crop protection and agronomy) has played a major part in keeping supply abreast of demand as the population grew almost 5 fold last century. The contribution of new lands was a relatively small component. But further major production gains cannot come from new agricultural lands: Assuming that irrigation of the Sahara is out of the question, and that the Brazilian rainforests must remain uncultivated, the necessary increase in food production would have to be achieved *without* a significant area of land going under the plough. The answer to this is clearly increased *productivity*, and in the situation where demand exceeds supply, crop productivity must also be recognized as a significant consumer benefit.

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?

Methods of increasing crop productivity are multifaceted and involve:

- ✓ maximising the amount of energy that a plant devotes to producing the harvestable element of the crop plant;
- ✓ reducing the loss of yield due to stresses such as drought and salinity
- ✓ reducing the loss of yield due to insufficient nitrogen and other important nutrients
- ✓ reducing the impact of yield robbing vectors such as competing weeds, fungal and viral diseases and insect pests;
- ✓ reducing post-harvest spoilage

Advanced genetic science as currently widely implemented by the plant breeding sector, both public and private, is focused on all these areas.

Key to achieving these various targets will be the use of both fundamental and applied research into plant genetics (including genomics, genetic marker assistance and GM techniques) as well as crop protection and agronomy. For this combination of disciplines to deliver successfully, there has to be Government and consumer support, and an acceptance that (a) the challenges are real, and (b) the ability of universities, institutes and companies to transfer that research to the field must be supported.

Industry and public sector institutes alike are highly confident that the tools available can meet the productivity challenges. But the current politicisation of the regulatory authorisation process for GM crops in the European Union and some other countries threatens to derail the very real crop improvements that have already been achieved as well as those in near-market development. For Europe to benefit from future progress, that political delay has to be removed.

Besides the well documented yield and productivity gains cited above, nutritional enhancements to crops are already in progress. Both soybean and oilseed rape crops have been developed with an oil profile with a near zero trans-fat potential. Likewise, and at the opposite oil spectrum, other oil profiles are near market with a high polyunsaturate content, including profiles with a significant concentration of long chain omega-3 and omego-6 fatty acids. Improvements in cassava as a crop are also currently in progress (http://www.scidev.net/en/features/scientists-target-super-cassava-.html)

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

From the range of advances in development, two examples illustrate the huge potential gains from advanced crop genetics: The current work carried out on both drought (stress) tolerance and nitrogen efficiency is important not only in regard to direct productivity but equally to their contribution to alleviating some of the impacts of climate change and fuel costs. In the case of drought tolerance, work is being carried out in both the private and public sector to improve stress tolerance with significant successes under field conditions in crops such as rice and oilseed rape[1] and maize. Likewise, companies such as Arcadia[2] are working on improving the nitrogen efficiency of important crop plants such that maximum yields are likely to be achieved with half the current use of nitrogen fertiliser; this is as relevant to UK farmers trying to reduce costs and improve the environmental footprint of crop production, as it is to African farmers where the availability and cost of such farmers seriously undermines productivity.

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.**

Marker-assisted breeding, where useful genes within a crop are identified and then bred into used varieties without the resultant crop being defined as "genetically modified", is becoming a standard tool in crop research and development. Whilst the opportunities that can arise from such advanced breeding techniques are clearly enormous, marker-assistance is limited by the constraints of the any crop's genome. In many cases, however, valuable crop improvements will require the use of genes not currently part of a particular plant's genome. The production of insect tolerant varieties and of long-chain omega 3 essential fatty acids are just two examples. In these situations, biotechnological techniques leading to GM crops will be the obvious way forward.

Already, herbicide-tolerant crops have been developed and cultivated for over 12 years, which reduce the cost of controlling yield-robbing weeds; in countries in South America, controlling these weeds has resulted in substantial increases in yield. Several second generation herbicide tolerant varieties are about to be commercialised which show even greater yield benefits in trials. As a result of the introduction of herbicide tolerant crops, concomitant reductions in soil erosion, fuel use and spraying have resulted in a decrease in the carbon and environmental footprints of soybean and maize farming in those countries. (http://www.pgeconomics.co.uk/pdf/agbioforumpaper2008final.pdf).

Likewise, the introduction of insect-resistant crops has significantly increased yields of crops such as maize (http://www.pgeconomics.co.uk/pdf/Benefitsmaize.pdf) and cotton, the oil from which is used in both food and animal feed.

Both types of traits will undoubtedly form the base crop over which other useful traits will be added. We have already described stress resistance and nitrogen efficiency as being key traits which have reached full scale field trials.

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).**

See responses to previous questions

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[1] http://www.research.bayer.com/edition-19/19_Photosynthesis.pdfx

[2] http://www.arcadiabio.com/nitrogen.php

6. Which current/future husbandry or farm management technologies for the enhancement of food-crop production are appropriate for development and dissemination and why? Comments could include information on the benefits they may bring, difficulties in scaling up their use in different parts of the world and time needed to get improved methods incorporated in farm practises.

Abc has no specific comments to make on this subject

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?

Abc has no specific comments to make on this subject

8. What might be the possible consequences and impacts of biological approaches to enhance food-crop production on:

a) crop yields and quality;

The impacts of adopting GM crops on yields have been demonstrated on many occasions; this is a combination of the realisation of potential yields by reducing losses to weeds, pests and diseases (for example, virus-resistant papaya in Hawaii, and insect resistant maize in Spain) and an increase in the intrinsic ability of a plant to produce more food (for example, canola in Canada).

The increase in the quality of food production with the use of GM technology has also been demonstrated; for example studies looking into insect-resistant maize indicate that levels of mycotoxins are reduced in comparison to their non-GM counterparts (*Wu, F.A., J.D. Miller, and E.A. Cassman. 2004. The economic impact of Bt corn resulting from mycotoxin reduction. Journal of Toxicology, Toxin Review 23:397-424)*

b) world food prices;

Abc has no specific comments to make on this subject

c) the environment;

The positive impacts of GM crops on the environment has been widely demonstrated (see Q4 and http://www.pgeconomics.co.uk/pdf/agbioforumpaper2008final.pdf for details)

d) the livelihoods of farmers; and

A recent Belgium study suggests that "…on average, two thirds of the global benefits are shared 'downstream', i.e., among domestic and foreign farmers and consumers, while only one third is extracted 'upstream', i.e., by gene developers and seed suppliers."[3]

[3] GM Crops in Europe: How much Value and for Whom? U Leuven

As Terri Raney, from FAO recently pointed out, "The economic evidence available to date does not support the widely held perception that transgenic crops benefit only large farms; on the contrary, the technology may be pro-poor. Nor does the available evidence support the fear that multinational biotechnology firms are capturing all of the economic value created by transgenic crops. On the contrary, the benefits are shared by consumers, technology suppliers and adopting farmers, although non-adopting farmers are penalised as their competitors achieve efficiency gains they are denied".

e) any other areas you think relevant.

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.

The huge improvements in crop production associated with the adoption of GM technology around the world have tended to focus on commodity crops such as maize, soybean, cotton and oilseed rape. The reason for this is clear; the huge costs of gaining regulatory approval for new traits and new crops has reduced the options for companies to invest in smaller crops and acts as a significant disincentive for universities and research institutes to enter the market.

Public/private partnerships such as the African cassava project (http://www.scidev.net/en/features/scientists-target-super-cassava-.html) and the CIMBAA project in India (www.cimbaa.org) will be important in progressing "lower-value" projects that can make a significant impact in those countries.

Clearly, the current European Union *de facto* moratorium on new cultivation files has now been in place for ten years; this political impasse has had a significant and negative impact on the development of novel GM crops; it is important that regulatory authorisation of new traits coming to the market is science-based; whether such traits are acceptable from a consumer perspective should be left to market forces without politicians *assuming* they know best.

ENDS

abc is the umbrella group for the agricultural biotechnology industry, comprising representation from Bayer CropScience, BASF, Dow AgroSciences, DuPont, Monsanto and Syngenta. Our goal is to provide factual information and education about the agricultural use of GM technology in the UK, based on respect for public interest, opinions and concerns.

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Dr Pedro Arreas

Embrapa

1. Yes It is not only the population growth but is the enhancement of the living standard in the developing countries that will increase also the demand for more food production.
2. One of the main strategies will be the truly integration of plant breeding and genomic tools. Discover more efficient ways to produce and utilize fertilizers. Developing cropping systems that maintain the soil quality.
3. Developing of new generation of transgenic plants; The use of principles of nano particles to enhance the use of fertilizers and pesticides.
4. Remote sensing technologies associated with the ability to generate and accumulate data will provide tools for decision making process based on simulation studies;
5. The mains trait will be drought resistance and nitrogen fixation. Obviously the understanding of host phatogens interaction also will play a major whole.
6. Development of innovative ways to produce and distribute seeds for small farmers.

Professor Howard Atkinson

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For brevity, I have limited my responses to six of nine posed questions in relation to transgenic crops. The issues are a) their uptake for food security in the developing world and b) European and UK policies that hinder scientific progress on such crops.

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

1.1. Yes. Eight leading economists including three Nobel laureates ranked the need to increase spending in research into new agricultural technologies appropriate for poor countries fifth among the seventeen global challenges they considered (Lomberg *et al.*, 2004). Recent events have raised rather than diminished this priority.

1.2. In 2004, Kofi Annan called for a uniquely African Green Revolution to help the nearly one third of the Sub-Saharan African (SSA) population which is severely undernourished (http://www.un.org/News/Press/docs/2004/sgsm9405.doc.htm). That continent did not reap benefits from the previous Green Revolution based on conventional plant breeding for crops other than those on which most SSA Africans depend.

1.3. Calls for agricultural improvement set down major challenges for SSA that relate to its dependence on rain fed crops, a weak infrastructure for agricultural development (Annan, see above) and a reliance on orphan crops (http://www.croptrust.org/documents/newsletter/newsletter_croptrust_v2_final.htm).

1.4. The claim that there is enough food in the world but it needs better redistribution carries some weight but it requires a global Utopia that will not be realised before many go hungry.

1.5. The current study should build on the very broadly based report of the International Assessment of Agricultural Knowledge Science and Technology for Development (IAASTD; http://www.agassessment.org/docs/SR_Exec_Sum_280508_English.pdf). The IAASTD report acknowledges that "biotechnology has always been on the cutting edge of change" but recognises that "assessment of modern biotechnology lags behind development". The current study should show foresight of what biological approaches can achieve. It also needs to encourage other disciplines to address the issues such progress raises more rapidly and effectively than has prevailed to-date.

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

2.1. There has been an inadequate level of investment in an infrastructure to ensure crop improvements developed by the advanced science base reaches the poor. This is evident if one looks at CGIAR institutes. For instance, IITA and its partners have delivered 70% of the impact of international research for development in sub-Saharan Africa (http://www.iita.org/cms/articlefiles/75-r4d_model_english_4_fold.pdf). However, it has less than 120 international staff (http://www.iita.org/cms/details/who_details.aspx?articleid%20=609&zoneid=362). This is less than the number of biological scientists in the Faculties of several UK universities and research institutes. Its small size is a powerful indicator of the lack of commitment of the international community to-date to the challenge of future food security in Africa. This low number needs to be increased considerably or further effective pathways for uptake need to be developed.

2.2. Many people in Africa and S. Asia depend on orphan crops for calories and protein. It is probably unrealistic for cultural reasons to change crop preference in many of these poorer regions within the timescale available but exploring where this is possible to improve nutrition and food security would be valuable.

2.3. Investment in public science for international public good is required. Major companies do and should make traits, supporting technologies and know-how available for orphan crops but they are unlikely to develop applications vigorously because an income stream is not evident to them.

2.4. Safeguards are needed to avoid the types of impact on the rural poor that accompanied the benefits of The Green Revolution. Interdisciplinary public research offers the best basis for mitigating these concerns.

2.5. Transgenic crops that are appropriate for smallholder farming in Africa must meet a set of criteria that have been defined (D. Glover, 2003. http://www.ids.ac.uk/UserFiles/File/knots_team/Briefing10.pdf). It is clear that public research can achieve these requirements.

2.6. The UK lacks a robust system to ensure its science outputs are linked to the next steps in the pipeline to CGIAR institutes or NARs etc. We lack transformation capacity in the key crops of Africa (e.g. cassava) in contrast to the large USA base. UK and EU scientists lack the equivalent of the essentially USA-based activities ISAAA (http://www.isaaa.org/inbrief/default.html) or PIPRA (http://www.pipra.org/) to support their efforts.

2.7. The Gates Family are clearly outstanding humanitarians but their generosity is not without risk to international research priorities. The Bill and Melinda Gates foundation can distort research priorities as reported by the New York Times for malaria (http://www.nytimes.com/2008/02/16/science/16malaria.html?_r=2&hp&oref=slogin&oref=s

login). The approaches the Foundation favour for food security are necessarily based on expert advice that is narrower than available globally. As with malarial research, the financial dominance of the Foundation risks that other donors including governments decide to invest in other millennium goals than food security. This is a response to assure their distinctive contribution to international development.

4. What biological approaches do you think have potential for food-crop improvement over the next 30 years and what benefits would they bring?

4.1. Transgenic crops are not a panacea for improved crop yields but they can make a substantial contribution to food security if their uptake was not continually hindered by a variety of influences including INGOs and both international (9.4-9.6) and EU policies (see 9.5-9.9).

5. Which traits, across species or in specific food-crops, are appropriate targets for improvement?

5.1. Transgenic crops have a particular potential when a) conventional plant breeding lacks the trait required at its disposal or b) the crop of interest has little past record of rapid progress by that approach. Cooking bananas and plantains provide an example. They provide more than 25% of the carbohydrates of approximately 60 million people in West Africa. Annual consumption of Uganda's domestically produced banana was 243 kg/person in 1996 representing 27% of the daily calorie intake of its population (see above, http://www.fao.org). *Musa* is an example orphan crop and the third most important crop in Africa. They are produced by small farmers for basic food security, they are easy to grow, and central to rural small farmer economies. The crop is recalcitrant to breeding. It is sterile and lacks wild relatives i.e. gene flow between this plant and others of the same or different species is not a concern. It is appropriate for demonstrating benefits of GM crops that are safe for the environment and small farmer use. Such demonstrations are needed for traits of interest such as major pest and disease problems including fungal diseases (*Fusarium;* Black Sigatoka*)*, bacterial wilt, nematodes and weevil pests (Atkinson et al 2003, http://www.bioversityinternational.org/fileadmin/bioversity/publications/pdfs/1238.pdf). Nematodes alone cause 30-50% yield loss to bananas. Public funds (USAID, DFID, BBSRC and charities) have reached the position that the crop can be transformed both by African scientists in a national government laboratory and by IITA, a range of technologies have been developed and there is good prospect of them being stacked into major cultivars within the next few years.

5.2. My interests are nematode control and we have technology that will provide control against all plant nematodes. Nematodes may reduce the African harvest by enough food for 25-50 million people a year although this figure is of course influenced by double counting.

5.3. Scientific independence is necessary for African nations to determine when plant biotechnology can underpin an African Green Revolution. The first products developed completely in Africa are beginning to emerge (Sinha, 2007). There is a need for concerted international effort to provide traits and underpin technology such as high throughput transformation systems for all the main calorie and protein providing crops of the food insecure. Transformation capacity is particularly needed by national laboratories in developing world countries and CGIAR institutes.

5.4. Another example need is to develop transgenic and other approaches that reduce the overuse and misuse of pesticides in periurban agriculture throughout the developing world. A particular need is for pests on vegetables. Their control accounts for 30% of all pesticide use and they are often applied close to harvest (Dinham 2003). Their use poses severe risk to both human health and the 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 foodcrop production?

7.1. The time taken for new scientific approaches to progress from being defined in laboratory to making a significant contribution to food security is considerable. A balanced portfolio from UK science with short, medium and long term benefits is required. There is a need to balance the excitement of new science developments against the considerable risk that the subsequent pipeline to the food for the poor has many points of potential failure.

9. What are the potential barriers to the application of biological approaches to enhance food-crop production?

International aspects

9.1. The development of substantially improved crops takes longer than the poor would wish even for well established approaches. The committee should therefore emphasis the need for prolonged research sponsorship by donors when substantial benefits are appropriately targeted by transgenic crops.

9.2. The levels of investment in scientific infrastructure is a key concern in Africa and elsewhere in the developing world. Scientific progress is limited by the duration of extensive field trials to establish benefits and the cost of collecting biosafety-related information. This is an essential activity but needs to be matched to real needs and resources of developing nations (see point 9.5 below).

9.3. The most favourable approach to advance plant biotechnology in SSA is for countries to have a national biotechnology strategy and well-founded national research laboratories (Eicher *et al.,* 2006) populated with trained plant biotechnologists that they can retain. This provides a basis for progress and equitable interaction with international labs (Raney, 2006).
9.4. Non-scientific causes of delay for plant biotechnology include slow progress of national biosafety regulations and guidelines through both legislative and political processes to active use. The national capacity must also extend to biosafety plus regulatory expertise and effective IP management (Raney, 2006).
9.5. Collection of biosafety-related information to assess risks is required for transgenic crops but is should not be used to delay progress severely. The Cartagena Protocol (http://www.biodiv.org/doc/legal/cartagena-protocol-en.pdf) requires revision before transgenic crops that are public goods for global good can be deployed at an appropriate pace and expense. Currently, it represents a substantial threat to the creation of sustainable solutions to food security in the developing world (De Greef, 2004). It deploys the precautionary principle which is used to support public policy action when there is a potentially serious or irreversible threat to health or the environment (Immordino, 2003). Surprisingly, the Convention on Biological Diversity did not apply it in parallel to transboundary movement of living organisms such as alien species that are not genetically modified but are proven to represent substantial ecological risk. The convention could not have been unaware of the issues, given the precautionary approach is adopted in Australia to alien plants (http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A04014 (2004). A recent example of the real risk posed by alien species is shown by the Harlequin ladybird (*Harmonia axyridis*). It was deliberately introduced to USA and parts of the EU for biocontrol of aphids. It suppresses populations of indigenous ladybirds and now poses a real threat to UK biodiversity (http://www.nerc.ac.uk/publications/latestpressrelease/2005-15harlequinhunt.aspn(2005). The Convention on Biological Diversity should act to remove its apparent partiality by defining when the precautionary principle no longer applies to well characterised transgenic traits in particular crops deployed in a defined geographical regions. The reality is that forgoing possible benefits for unlikely risks, invokes the fallacy of thinking that doing nothing is itself without risk to the poor (2003 follow-up to Nuffield bioethics report, http://www.nuffieldbioethics.org/go/textonly/ourwork/gmcrops/introduction.html).
9.6. There is need for The Royal Society to strengthen its input to the framing of scientific aspects of both national and international polices to minimise negative impact. Examples where science input is required are to correct the unwanted aspects of the Cartagena Protocol (9.5) and Directive 2001/18/EC (9.11).

EU

9.7. The uptake of transgenic crops is hampered in the EU by its policies. Key examples are the misuse of the precautionary principle. It should not be applied without defining when that precaution is no longer needed based on improved knowledge.
9.8. Some consider it is an unacceptable form of neo-colonialism for EU to have policies that prevent developing nations from exploring all options to meet the challenges they must face (Bodulovic, 2005).
9.9. The attempt to widen issues relevant to uptake of transgenic crops by considering their social impact is arbitrary when not applied to other changes in agricultural practises. A key example is an attempt to distinguish between the environmental impact of herbicide tolerance achieved by transgenic and other means (Morris, 2006).
9.10. Directive 91/414/EC considers hazards of a risk without reference to exposure. Its application to crop protection is a concern and any extension of that thinking to transgenic crops would be unfortunate. There have been past misdirected concerns generated by studies that centred on hazard without exposure and *vice versa* (Johnston *et al.,* 2006).
9.11. Directive 2001/18/EC is also a flawed document that has the effect of limiting scientific progress. One failure is that it does not recognise the need of researchers to evaluate transgenic plants that is independent of any commercial intent. It should be modified to allow the UK and EU science base to progress. Currently it creates massive disincentives centred on a high proportion of damaged trials, a massive amount of data that must be compiled for trial authorisation and an outcome that can result in invasion of laboratories and expose scientists to personal risk. It demands a risk assessment that makes no formal recognition that the scale of trial influences risk to the environment. Our destroyed small scale potato trial in 2008 included plans for a specialist company to destroy all tubers at harvest. It is hard to image what risk growing 400 potato plants presents to the environment in contrast to the 10 billion grown with their natural hazards each year in UK (Atkinson and Urwin, 2008).
9.12. Currently Directive 2001/18/EC presents a major block to the intellectual freedom of EU scientists. A society that is not able to ensure freedom of its academics to carry out publicly funded and peer-reviewed legal research is facing a problem (Atkinson, 2008). A pro-science approach is identified in Canadian legislation in which small scale field trials are allowed with different requirements than large scale trials (http://www.inspection.gc.ca/english/sci/biotech/gen/pntvcne.shtml). This approach is based on sound science. Such reform must still ensure that public consultation preceded any commercialisation of a new cultivar.
9.13. The negative consequences of EU policies on plant biotechnology are evident from the small number of such trials in EU countries (http://gmoinfo.jrc.it/). The highest number of applications is 23, Romania; 29,

Hungary; 30, Sweden; 55, Germany; 73, France and 205, Spain. The number authorised in the UK is very low (see 9.14).This should be set in the context of the USA were there have been in excess of 13,774 which I believe excludes small scale trials. There have been 144 from Iowa State University alone (http://www.isb.vt.edu/cfdocs/fieldtests1.cfm).

UK

9.14. Within the EU since October 2002, only Ireland, Belgium, Finland, Lithuania, Slovak Republic and Italy have received less trial applications than DEFRA (http://gmoinfo.jrc.it/). UK has 7 of which only 2 were from public sources.

9.15. The UK ministries, chief scientists etc should be more proactive in ensuring that EU policies are soundly based in science and do not hamper future EU crop production and development. One simple example of need for approaches that make food more affordable is that 19 million EU children live in poverty. Sadly 16% of UK children are in this category http://ec.europa.eu/employment_social/publications/2008/ke3008251_ en.pdf).

9.16. DEFRA have failed to counter a situation that is a severe constraint on the UK plant science base. I recommend the committee seeks BERR's view on this issue. A contact can be supplied on request.

9.17. DEFRA's interpretation of the EU regulations is a concern. It has allowed Trojan horses to enter UK procedures that enable activists to raise issues that continually delay progress and so add cost. Key examples are publication of 6 figure Ordinance Survey map locations of sites. They guide activists to 100m of trial locations as occurred for my research earlier this year. I assume the original aim was to inform growers and others in a locality of a planned trial. However, the need to place an advertisement of trials in a national and not a local newspaper supports national campaigns aimed at crop destruction. A more recent example the committee may wish to consider is the current consideration by DEFRA of the need to restrict trials to sites more than 6 miles from an SSSI. Using my own site as an example, this would prevent trials on 95% of a 400sq km area of North and West Yorkshire. It also takes no account of risk analysis in relation to the crop and locality. It is difficult to envisage how many transgenic traits in a crop like potato pose a risk to many SSSI sites particularly those that are geological. This is an example of the concerns expressed in 9.6.

9.18. DEFRA post the content of the public register on the web after removing scientists' names. This has removed any constraint that consultation previously placed on use of the information. It also distributes the information world-wide. The rights of the researcher to carry out lawful research approved and, in my case partly funded by DEFRA, are not appropriately considered with DEFRA's policy risking personal threats from both national and international sources.

9.19. DEFRA is also not fully transparent when concerning applications for deliberate release. Applicants are not routinely provided with any arguments they may receive that argue against allowing a consent. This is a concern given one consulted public body, Natural England, has a negative stance on transgenic crops (http://www.independent.co.uk/environment/nature/natural-england-warns-brown-of-dangers-in-promoting-gm-crops-852341.html). This concern is compounded if this body is helping to define the change to policy indicated in 9.17.

9.20. DEFRA has an advisory committee on releases to the Environment (ACRE) but chooses to ignore the advice it offered such as that on the publication of trial site locations (ACRE advice #39). Such actions undermine the confidence of the scientific community in DEFRA's commitment to science-lead approaches to policy.

9.21. DEFRA should take an active role in countering misinformation from any source such as the claimed risk to honey from transgenic potatoes. Potato offers no nectar and honey bees can not "buzz" its pollen (Celis *et al.,* 2004) and so do not forage in this crop. This alleged risk was used to pressure a trial from progressing in 2007 (http://www.gmfreeze.org/page.asp?id=323).

9.22. Leaving scientists to respond to misinformation is unsatisfactory as the media represents this as advocacy. The interaction of those advancing scientific standpoints and others acting from other viewpoints including personal beliefs are too often irreconcilable.

9.23. A way needs to be found to allow transgenic field trials. A national test centre would meet many needs but might become a focus of activist attention. It is unlikely funding bodies will provide the £100k or more required to protect individual sites. A change of legislation not to reveal locality of small field trials as in Canada would only be effective for trials away from sites belonging to institutes and universities.

9.24. The Environment Minister has called for those that appose transgenic crops to provide evidence of harm to justify their current stance (http://www.telegraph.co.uk/news/newstopics/theroyalfamily/2571514/Prince-Charles-wrong-on-GM-saysminister.html. This view is consistent with that expressed (9.7) on the precautionary principle. Any evidence concerning the risk of transgenic crops should be presented on case by case basis and be based on sound science.

9.25. Re-engaging the general public with the issue of transgenic crops should be considered. The UK GM Nation debate has been considered to have critical flaws in its approach but it did establish that the UK public appreciated that developing countries have special interests (Gaskell, 2004).

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Professor Jeff Bale

University of Birmingham

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

The answer to this question is surely a resounding yes.

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?

The major constraints to increases in food production are abiotic and biotic in nature. Whilst the headline statistics on climate warming usually relate to increases in minimum and mean temperatures, the increasing incidence of extreme events, such prolonged drought and sudden floods can have catastrophic effects on crop yields in a particular year – this can affect both developed and developing countries. The biotic effects of climate warming are now becoming apparent with several examples of key pests advancing their northern range limit by around 50 km over the last 30 years against the backdrop of a 1°C increase in temperature: in the USA, Japan and other examples in Italy and Scandinavia. It seems likely that more species will follow this trend.

There has been a policy of progressive withdrawal of pesticides for a variety of reasons (e.g. ground water pollution) without replacements, and without advances in alternative strategies. The effect of insect pests on crop yields can be devastating, particularly in developing countries, and similar levels post-harvest.

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

A distinction needs to be made here between impacts that *could* increase food production subject to changes in policy and those that are not so subject to policy, but will require other forms of input. In the first category I think that the UK and Europe will have to reconsider its stance on GM technology. There is no need I think to rehearse those arguments here, but the potential to extend beneficial GM traits beyond herbicide tolerance and Bt insecticidal events is great – but it will require a major change in attitude. It is interesting to note the anti-GM cam paign against crops but the relative quiet over GM medicines.

I think that the potential to exploit biological control is also considerable – both with biopesticides and conventional natural enemies, but both of these have their own problems. For biopesticides, there has been expensive over-regulation through EU directives that has classified these agents as if they were synthetic pesticides, and this has hindered the development and marketing of viruses and bacteria that would be valuable agents – a more balanced approach is needed, as this may have now been recognised by the EU. For predators and parasitoids, the potential is enormous, but there will have to be government investment alongside SMEs. The support of Defra for UK horticulture (since the MAFF-DETR merger) has been woeful – this must change if any progress is to be made.

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.

Part of the answer to this question is given above. There is substantial evidence that various forms of biological control can suppress pest incidence, and can be combined with both pesticides and GM approaches. To realise this potential there has to be a more balanced regulatory framework and investment in research. As one UK example – we have no 'classical' biological control schemes i.e. where natural enemies become permanently established in open fields/orchards – the main reason is a lack of over-winter survival. All UK biocontrol is in glasshouses using non-native species, and here, the released agents have to be screened for a *lack* of establishment potential – i.e. we must be certain that any escapes will be killed off by the low temperatures of winter – so as not to affect native fauna – this is in part because of pressure from environmental protection agencies having concern about impacts on native species. Having reached this stage with some very successful glasshouse schemes, the UK has not yet licensed any of these non-native species to be released into poly-tunnels or open fields. If we can be sure that winter will kill off all the released agents each year, what is the problem in promoting inundative biocontrol in UK poly-tunnel crops or even open fields? This system is used in other parts of Europe. And this highlights another issue – a lack of a coordinated policy across Europe, which is a disincentive to industry investment.

A small research investment in proving (i) the effectiveness of the agents, (ii) absence of any non-target effects and (iii) the lack of any carry-over of natural enemies into the following year, could offer a major advance in production of several fruit and vegetable crops grown outside of glasshouses across temperate zones.

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).

I am not well qualified to comment in this area, except to say that current research on GM traits that are targeting insect pests via the plant e.g. phloem translocated aphicides will not be successful without a change in public attitude – biocontrol does not have these problems of public acceptance.

6. Which current/future husbandry or farm management technologies for the enhancement of food-crop production are appropriate for development and dissemination and why? Comments could include information on the benefits they may bring, difficulties in scaling up their use in different parts of the world and time needed to get improved methods incorporated in farm practises.

In some parts of the world 'conservation biocontrol' has been very successful. For example, adult parasitoids often require pollen and nectar to mature their eggs. The removal of hedgerows and lack of weed tolerance by growers has reduced the level of these floral rewards for key natural enemy species e.g. aphidophagous hoverflies. There are some well-studied examples in New Zealand of increased 'natural' pest control if flowers are provided close to crops (even the 'best' wild flower species composition is now known).

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?

I cannot comment here.

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.

Biocontrol has the potential to increase crop yields, especially for pests that are resistant to insecticides. The nutritional quality of such crops will not be affected, but the 'appearance' can be a problem – though not always.

Difficult to assess effects on prices, but successful biocontrol schemes have very favourable cost:benefit ratios.

Biocontrol is likely to be more beneficial to the environment than pesticides – even the selective chemicals, and arguably more beneficial than GM – unless mitigation measures (conserving some weeds) were accepted.

For farmer livelihood, biological approaches would seem to be cost neutral of positive.

Increasing the success of biocontrol would fit well with the sustainability agenda and cross the farmed:unfarmed land transition more than any other technique.

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.

There are several barriers to achieve more of the potential of biocontrol. Firstly, apart from with inundative control (releasing 100,000s of 'non-establishing' agents simultaneously), there is no private sector involvement. Companies will never invest in classical biocontrol if the agent can only be sold once! So, there has to be a recognition that public sector support for research is needed for the potential of biocontrol to be fully exploited. With inundative control, there is great potential e.g. the massive move away from pesticides in the Almeria region of Spain in 2006-7 and the replacement with predators and parasitoids. Companies will link up with universities and research institutes in this area of research.

Secondly, the loss of much of the agricultural research sector in the UK – more than many other EU countries – is not helpful, though there is still ongoing research that could be scaled-up to help overcome problems.

The regulation of biopesticides is common across the EU via a directive, but for arthropods, each member state has its own policy – or no policy. A recent EU project (REBECA) reviewed all of these issues and made recommendations on future regulatory policy - a final report is available.

Sir John Beringer CBE

Response to Royal Society study "Biological approaches to enhance food-crop production"

John E Beringer, November 2008

Responses to questions

Q 1. Yes, if we continue to eat meat. Evidence at present is that as people become wealthier they consume greater amounts of meat. Thus, China and India are likely to need much more food for animals, which we are already seeing and is influencing world food prices. Increasing aridity in many parts of the world is reducing crop yields.

Q 2. Sufficient understanding of agronomy to determine what limits yields and losses during storage and harvesting. I see the major challenge in some parts of the world, such as Africa, will be to recognise limiting factors and apply already known measures to alleviate them. This is as much a political issue as it is one of available skilled agronomists. It is a tragedy that in the 21st century there are large parts of Africa moving backwards in food production and indeed are not safe for their own citizens, let alone those willing and able to help.

The availability of water for food production is becoming a major problem through climate change, use for growing populations in cities, movement of saline water into aquifers, and depletion of deep underground reservoirs. Major challenges are technical, relating to how to manage water, make irrigation much more effective. Biological challenges relate to the need for crops that are tolerant of saline water and also have much lower requirements for water to grow and produce useful yields. Drought tolerance and modified rooting patterns could also be extremely valuable.

Pest resistance resulting from the breeding of crops that are intrinsically resistant to pests is a major target. Of particular importance are mechanisms of resistance that are very general and have very little chance of resistance in pest species overcoming the mechanism/s. For example, wheat does not suffer from potato blight.

The application of mineral nutrients to crops through the use of fertilisers is becoming increasingly more expensive. Improved root architecture to capture available nutrients, possibly allied with enhanced efficiency microbial interactions, both mycorrhizal and nitrogen fixing, offer important avenues for improving yields and enhancing the nutrient value of harvested crops.

Q 3. Recent work has demonstrated that mycorrhizal fungi and rhizobia share common plant pathways for infection. This offers opportunities for enhancing symbiotic interactions and extending the range of plants able to fix their own nitrogen.

It is clear that GM-derived resistance to lepidopteran insect pests has been very effective. As this has been the first generation of resistance mechanisms, there are obviously a number of much better methods in the pipeline.

While I think that GM has been overrated as "the way forward", I do think that it will become extremely important. Moving political and public opinion in Europe to accept the inevitable remains a major task, which is only likely to be achieved if plant breeders produce GM crops that the public can see confer benefits to them.

The massive increase in speed, reliability and reductions in cost make genome sequencing, and analysis increasingly attractive in plant breeding.

Developing an understanding of the genetic control of chromosome crossing over in hexaploid wheat offers great opportunities for enhancing the introgression of genes into this crop and the exploitation of polyploidy in other crops.

Research on how plants differentiate different organs will lead to exciting opportunities for modifying the ability of plants to allocate resources to harvestable components, such as seeds. This could have a big impact in improving the productivity and reliability of existing crops, such as *Vicia faba*, which have the potential for very large yields of protein without the need for fertilizer nitrogen. It could also enable us to have the option of modifying plants that are able to grow under very adverse conditions, such as on saline soils or under drought conditions, to yield reasonable amounts of edible seeds. This could well be much simpler than modifying existing crop plants to grow under these adverse conditions.

Q 4. This has largely been answered in the responses above.

I expect to see nitrogen-fixing non-legume crop plants within 10 years and cultivars by 30.

GM-derived pest resistance should develop rapidly with new cultivars within the next 10 years.

Developing a better understanding of plant root growth and changing rooting patterns will take time, but it is feasible that we could see cultivars within 15 years.

I am less optimistic about rapid advances in drought resistance, but this is as much due to my ignorance as anything else. There are interesting opportunities for developing some non-traditional drought tolerant food plants for commercial use.

Controlling crossing over and enhancing the introgression of genes in wheat and related crops could well yield new cultivars within 10 years.

All these times assume normal breeding times of at least years, as new lines are tested and bulked-up.

Q 5. Nutritional value offers interesting opportunities. For example, vitamin A rice offers great advantages for poor people who have limited access to foods containing adequate vitamin A. Improving lipids, amino acid composition, availability of mineral nutrients, such as phosphate, and a host of other targets are obvious candidates.

Perhaps less obvious is the modification of existing plants grown for human nutrition to make them less hazardous. My favourite example is the legume *Lathyrus*, which grows in very poor drought stressed soils and is fed to desperate people when other food is unavailable. Removing/inactivating pathways producing toxic compounds that cause severe harm to humans would give us a crop that could be used in soils/years when drought is a severe problem.

All crops produce biomass that could be used in local fermenters to produce energy, but the structure of plant cell walls makes them relatively difficult to ferment. Modifications to plant cell wall architecture combined with the isolation and use of enzymes with enhanced abilities to degrade cellulose and lignins could enhance the value of crop remains for biofuels.

Weeds are a massive problem common to all crops. Herbicides have a role, but are expensive and difficult for poor farmers to use. Exploiting the existing ability of plants to interfere with the growth of other plants might enable herbicide-free crop cultivation, but this is probably well beyond the 30 year time limit.

Of more immediate relevance to weed control is the issue of conserving wildlife (butterflies, wild flowers and birds – the things we like to see in the countryside!) because in controlling weeds we are severely reducing biodiversity in agriculture. My guess is that Europe will remain wealthy enough to sustain lower yields of crops and will continue to require agriculture to produce both food and biodiversity. Following the logic of existing trends, it will probably be essential not to produce crops in Europe that are fully pest resistant, or capable of seriously outcompeting weed growth – quite the opposite of what will be required in developing countries.

Q 6. I have little competence to address this question.

Continuing to develop cultivation techniques that reduce problems of erosion caused by wind and water is essential.

There is a major need to tackle the issue of the small farmer and efficiencies of scale. My guess is that within 20 years food will be even more expensive than now and serious shortages will occur during years with low rainfall in grain producing areas. Will we be able to produce enough food in developing countries without more mechanisation of agriculture and larger farms?

Sustainability and the management of land will become more and more important. I do not believe that organic farming is the solution because crops mine soil and without replacing minerals there will be long-term reductions in yield. I also believe that organic farming produces less food per unit area. However, it is a disgrace that after years of debate about organic agriculture we still do not have sufficient understanding of the long-term risks and benefits of different forms of agriculture to be certain of the best way forward. Whatever the result, in the next few decades the imperative in "hungry countries" must be to increase yields per hectare, rather than expect to use the last remaining areas of forest and uncultivated land for crops.

Dr John Bingham CBE FRS

An individual response specific to wheat breading.

For the third time in 60 years wheat breeding is at a cross roads requiring Government decisions. A more detailed breeders' account of the methods, achievements and limitations to date, with an opinion on new opportunities is available as an advanced draft (Bingham and Summers 2009).

The first period began with the expansion of the Plant Breeding Institute to new buildings at Trumpington, Cambridge, in 1954 to 'provide more food from our own resources', lasting to privatisation of the breeding programmes in 1987. Increases in the varietal component of grain yield were much greater than anticipated and bread making quality exceeded industry expectations except in very wet harvest years. For these complex characters breeding was phenotypically based on detailed physiological/biochemical analyses, in essence a continual search for new heritable components and selection tests. It was empirical only in context of the genetic analyses which followed.

Breeding for resistance to the foliar diseases, mildew, yellow and brown rust was frustrated by new physiologic races, despite evidence for more durable resistances. The problem was essentially that such resistances could not be distinguished by symptoms from new race specific resistances introduced by widening the gene pool for yield. Neither was recognition by test crossing successful and, a warning, the few genes deliberately derived from alien species were also overcome, including 2 genes for mildew resistance from the Wisconsin T. timopheevi derived line CI 12633 and the PBI 'systems demonstrator' Compair for yellow rust resistance from Aegilops comosa. Septoria tritici developed as a practically new problem disease in the 1970's. Adverse yield linkages are also likely, as found with mildew resistance derived from Aegilops speltoides.

Resistance to eyespot proved more straightforward with the Cappelle-Despre and Professeur Marchal sources of field resistance still effective but the adverse yield linkage in the Rendezvous derivative from Aegilops ventriosa via VPM-1 has taken 30 years to overcome (or reduce to an acceptable level).

The second period aim of privatisation was principally to stimulate private sector investment. With this change of policy, there was just one Government mistake which should in no way be repeated, the establishment of the Agricultural Genetics Company with first rights to Institute discoveries for its own breeding programme. Fortunately this organisation foundered, possibly because, at the time, there was little immediately applicable research.

The principal gain to UK wheat breeding was in expansion to continental breeding centres, giving a much wider gene pool, and direct access to continental research, in conjunction with the home country selection base essential to our own particular combination of climate and day length. Breeding has also benefited from free exchange between companies of new varieties at the National List Year 1 stage. However, the four largest programmes are now owned by continental companies, with a risk of losing the UK selection base if the arrangements became less favourable.

The outcome has been a remarkable and continuing advance in the varietal component of yield increases in NL/HGCA trials, which, on the evidence marker variance, has further to go (Mackay, 2008).

WGIN and LINK projects have forged an effective partnership for application of new breeding research, and tackling problems as they are identified. As a stakeholder I note, amongst other projects, avid uptake of markers by breeders when they became available, sourcing of new genes from alien species and varieties outside the European gene pool, and searching for genes which may have been missed along the way for protein quality, resistance to harvest sprouting and reduced height.

The third period now opens on the premise that, 'within 10-15 years there will be varieties of wheat entered to National Trials with GM traits too beneficial to withhold'. However, Plant Breeders' Rights at £13½ - 14m annually are geared to conventional breeding and could not extend to GM methods. So, for GM, there should be a chain of responsibility:

1. Joint private/public sector identification of a target trait, taking all other breeding methods and known genes into account;
2. Institute, Government funded, discovery of the necessary gene or genes, and transfer to a hexaploid line crossable to wheat without deleterious side effects, particularly on yield;
3. Use of that line at nil charge by all UK based private breeding

programmes;

4. Scientific publication and worldwide availability of the GM line.

If such funding and co-operation is not forthcoming, international chemical companies will surely re-enter and fill the void, putting the key benefits and gene pool of the private sector at risk. It could well be that a single 'must have' GM gene would be 'dominant', so there should be no commercial restriction by patent or otherwise, to the breeding use of a gene or GM method.

Concurrently breeding targets are becoming wider and more demanding in the face of the need for food security, predictions of faster climate warming, biodiversity action plans and farming regulations, particularly extended nitrate vulnerable zones, revision of RB209 fertiliser rules, mycotoxin appraisal for grain assurance and restrictions in licensing and application of pesticides. The Government did well in obtaining some derogations to the recent EU ruling on withdrawal of a range of pesticides. However, I do have sympathy for householder and bystander apprehensions, having the experience of talking them over in practice, for example severe damage to young growth on a hawthorn hedge in April was due to frost. The message is clearly that resistance to pathogens and insects is now of much higher priority.

The present call for food security has spawned an unprecedented number of top science think-tanks but, despite an evident central role of wheat breeding, none have included a practicing breeder on their working group, certainly not the following four: Science Museum, Dana Centre debate of 22 January: Chatham House – Rethinking UK Food strategy, 2 February (but full cover striking photograph of a bunch of highly bred wheat ears): Sense about science – GM and Plant Science, 9 February (working group of 28!): This Royal Society consultation.

There is no WGIN equivalent grouping to consider more fundamental work, though some wheat breeders and research scientists are well known to each other. Such reconnection is essential in order to make best use of new techniques and to solve intractable problems. The new group would take a fresh look at all links of the chain and allocate responsibilities.

At first sight single seed descent and doubled haploids may appear less efficient than the pedigree system with its much greater numbers of progenies and opportunities to select within segregating F_2 plants. However, these advantages may now be overtaken by rapid cycling and the use of markers to assemble desirable factors in parent lines. GM should be seen as an addition to these methods, not a replacement.

Priorities should include the following targets. I am well aware that some of this work is now in progress but could well justify intensification.

Higher yielding ability, offering the 'luxury', after food security, of a proportion of the land for biomass crops, new nature reserves (possibly including farmland bird reserves), stewardship schemes and indeed organic farming. Any excess grain will help to maintain world stocks. It does appear that breeders are well capable of exploiting the current gene pool. A step-wise increase will require a more efficient photosynthetic process. It would be wise to look again at the higher net assimilation rate of the diploids, though previous results were disappointing, and in view of increasing temperatures investigate now the feasibility of a GM/C4 or similar system for wheat, with the added benefit of more efficient water use.

Increased grain yield, with constant rates of nitrogen fertiliser application, will also improve nitrogen and energy use efficiency, as evident since application rates reached a plateau in 1985.

In view of research in progress it may also be possible to put a timescale on N fixing, though this would need enhanced photosynthesis.

Given the depth of the current European gene pool, including variation for temperature, daylength and vernalisation responses, breeders are well placed to counter moderately drier and warmer conditions as they develop. In fact, all varieties bred for the UK since 1948, and probably much longer, have involved adaptation to 'climate change' in the sense that their lineage is almost entirely from continental European and other countries; of 17 parents introduced to the PBI bread-making programme only 1, Browick, was English. The contribution of the Institutes should be for new genetic variation, especially from alien sources. With much higher temperatures, more wheat will be grown in the North, especially for bread, and there will be a move to maize for animal feed in the South. As maize is a spring sown crop, commercial breeding programmes now based mainly in Europe will be able to provide the varieties needed.

More closely directed and applicable investigations for resistance to fungal diseases, insects and slugs are now imperative, or yield will be lost as pesticides are restricted. The standard has been set by resistance to orange blossom midge as a major achievement in reducing need for insecticides, especially as the insecticide most commonly used was inadequately species specific.

The needs are so great that the Institute work should proceed on several fronts simultaneously. Makers have the potential to track durable resistance to foliar diseases. However, as such sources may be inadequate, work should also be expanded on transfers from alien sources by induced chromosome pairing and GM. The target has to be for resistance to all foliar and ear diseases otherwise fungicide treatment will still be needed, though reduction from three to one application would be real progress (as said in 1980!)

There is good evidence that GM methods could be very effective in addressing problems of inadequate resistances in wheat or its near relatives. Action must now take the place of argument in the establishment of new projects and expanding those already at an early stage. Resistance to take-all from oats and other species has the promise of increasing nitrogen use efficiency and production on a National scale. It is also likely that resistance to BYDV (Barley Yellow Dwarf Virus) could be constructed, as has been done with some other crop viruses. Present work with aphids as an autumn vector and summer pest could be intensified. Resistance to glyphosate is already on the shelf and should perhaps be reconsidered, at least discussed, in view of the withdrawal of the widely used pre-emergence herbicide isoproturon and difficulty of controlling black grass.

Presently there are no GM commercial varieties of wheat, but they could well co-exist with conventional because wheat is self pollinated to a high degree, with no pollen or nectar complications, there are no wild species in the UK crossable with wheat and the seed is of short longevity in the soil.

Recommendations

1. Top scientists in the public eye should raise the profile of wheat breeding by referring to need, achievements and prospects, thereby motivating more students to become agricultural botanists, as 1945-80.
2. A new working group should be set up between practising breeders and research scientists, at a more fundamental level than WGIN. The objective should be to identify and solve problems that cannot be tackled by conventional breeding alone, ie. Those needing a wider range of markers, induced chromosome pairing or GM.
3. Allocate more Government funding to these particular high priority areas of research. Wheat is the main UK crop, currently producing around 15mt annually, of which at least 5mt, worth around £500m, is directly due to genetic improvement in yield at no additional agronomic cost. Well judged new investment, in cooperation with breeders, offers the prospect of a continued increase in yield/ha, possibly stepwise, in conjunction with reductions in pesticide requirement and agronomic costs.
4. Ensure that actions taken are not disadvantageous to private sector breeders and do not put their current European gene pool at risk.

References

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Bingham, J., Mainstream wheat breeding at a cross roads. BBSRC, Innovation in Crop Science Workshop, exploitation of genetics, January 2009.

Mackay, I. New varieties underpin growth in UK cereal yields. British Society of Plant Breeders, Plant Breeding Matters, November 2008.

Hard copies available of above and other papers.

Viewpoint

Wheat breeding team, Plant Breeding Institute and Unilever, 1954-90. Arable farming with Countryside Stewardship Schemes since their inception, including 'discovery' of an old meadow, subsequently classified SSSI and extended by arable reversion, Norfolk FWAG and BAP.

WARNING: BSAS represents animal scientists in the UK and overseas including those involved in research and development and technology transfer. Our experience in both developed and developing countries leads us to believe that one must take a holistic approach to food production and thus great care must be taken in assessing a single aspect of agriculture such as food crop production. Your report must recognise that such food crop production needs to be reviewed as a proportion of a whole system and a very complex one! The dramatic expansion of crop production for biofuels is already impacting on the resources available globally for food production, and hence on food supply and cost.

As animal scientists we recognise that sometimes food crop production and animal production are sometimes in conflict over land resource but more often and especially in developing countries or with traditional systems are integral parts of a holistic agricultural system. Animal and crop science are essential for **integrating information from the so-called 'biological revolution'** – the dramatic growth in knowledge stemming from new discoveries and techniques in molecular biology, including genome mapping and sequencing in many domestic livestock species - into practical knowledge applicable to whole animals and populations.

Given that a high proportion of the agricultural land in the UK is unsuitable for cropping, due to climate, topography or soil type, but that it is well suited to growing grass, we would welcome [and be happy to co-organise] a wider review covering livestock as well as crop production.

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

Yes. The population of the world is set to increase from 6 to 9 billion in the next 50 years. There is thus the need to increase all food production, in an environmentally and socially responsible way, including food crop production, to feed the global population. Within this global demand there will be specific consumption patterns that need to be considered. For example increased prosperity in SE Asia and China means that consumers are able to purchase more animal products. Global demand for livestock products is expected to double during the first half of this century, as a result of the growing human population, and its growing affluence and in many cases opting for less crop and more animal products[4]. In a free-market system the demand for more animal products will rise as a proportion of total food consumption. Crops can only be grown in certain areas of the world because of constraints on water or temperature. We also expect big changes in the climate globally.[5] This will change the crop production areas unless we can adapt crops to manage different conditions.

2) Question: 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?

Limited land and water supply will be the major limiting factors for food crop production. Competition with energy crop production will also be a major factor. There will be the challenge of better use of both land and water resources through for example did development of drought tolerant crops. The cost of energy is likely to increase and thus the use of fertilizers and energy-intenisve cultivation methods will be constrained further by cost.

Lack of R&D is likely to be a major constraint as governments especially in developed countries like the UK lag well behind acceptable investment levels for both basic and applied research. Most developed countries thought the food security issue solved! Sadly this is not the case. The UK science base has been seriously eroded away over the last 20 years yet we will need those scientists if we are to help with meeting global food demand. This

[4] FAO (2007). *Livestock's Long Shadow. Environmental issues and options.* Food and Agricultural organisation of the United Nations.

[5] See 4th Assessment Report of the Intergovernmental panel on Climate Change; http://www.ipcc.ch/

erosion is especially severe in integrative sciences, like crop and animal production, and at the strategic/applied end of the research funding spectrum. Both of these trends are of particular concern in relation to research aimed at increasing food production.

3) Question: Can you identify recent or imminent scientific developments that will impact substantially on food crop reduction of the next 30 year?s

Crop breeders have for some time been working on producing staple crops such as cereals that can fix nitrogen. The scale of increase of crop production needed to meet global demand will mean many different strategies will be required to increase yields and improve storage. The former will almost inevitably include the acceptance of the need for genetically-modified crops and in due course animals. Drought tolerance, disease resistance and overall resilience are likely to be other important attributes. Harnessing developments from basic science (e.g. genomics) is likely to be important in crop and animal breeding. Obviously GM has the potential to impact on food production, if societal acceptance for appropriate, tested modifications can be achieved.

4) Question: What biological approaches and do you think have potential for food crop improvement over the next 30 years and what benefits would they bring?

Society must accept that improvements take a very long time to deliver benefits. This is not constrained just by research and development but also by the difficulties in applying research results in the field. Social factors are often more important than technological advances. Persuading producers to except new ideas is a very difficult challenge. (See 3 above.)

5) Question: Which traits across species or in specific food crops are appropriate targets for improvement?

Given the scale of increase of population there is a need to concentrate on staple (rice) rather than 'luxury' (peppers) crops and also ones that have multi use (ie can be fed to animals and humans or have residues suitable for animal consumption or energy generation). Thus long straw cereals might be better as the residue straw could be fed to animals or used to make bricks with manure that could be burnt for cooking. Traits that allow production to be increased despite direct or indirect (e.g. disease) challenges of climate change are likely to be important (e.g. see 3 above).

6) Question: Which current/future husbandry or farm management technologies for the enhancement of food crop production are appropriate for development and dissemination and why?

Research and development results are often applied over a larger area than they have capacity for. Thus a research farm will successfully produce a new maize crop that policy makers try to grow across a whole country. Differences of topography, climate and people often mean that this does not work. Adaptation of ideas to suit regional or local capacity is extremely important.

7) Question: Do you foresee any advances in engineering, materials science, chemistry or other non biological sciences that will strongly influence future developments in food crop production?

In developed countries increased use of global positioning and land resource analysis means that adjustments can be made to growing crops that makes best use of the soil and water resource. Extra fertiliser can be placed on part of a field which is low in nitrogen. Less herbicide can be used on that part of a crop clear of disease. Such micro management within small areas will maximise yields.

8) Question: What might be the possible consequences in impacts of biological approaches to enhance food crop production?

Increases in crop yields and increases in quality can be expected. These need to go hand in hand with better storage. World food prices are likely to continue to increase in line with increased demand from a growing population as we expect that production will not be able to keep up with demand. Great care would be required not to damage the environment by the implementation of inappropriate techniques or poor husbandry. The future for farmers is likely to be one where there are larger production units unless governments decide to support rural populations by supporting agriculture.

9) Question: What are the potential barriers to the application of biological approaches to enhance food crop production?

Lack of appropriately resourced research and development to improve both yields and quality. Lack of successful technology transfer mechanisms for large-scale implementation.
We must be realistic in our expectations and timescale for benefits from new technical developments. It is very easy to produce results in the laboratory or on experimental farms but much more difficult to achieve improvements in the field on a national scale.

The British Society of Animal Science

The British Society of Animal Science is a learned society and educational charity concerned with advancing science related to animals, and encouraging uptake of new knowledge for the benefit of animals, producers, food processors, consumers and the environment. Animal science has a vital role in delivering national benefits and in meeting important global challenges, including: living with climate change; meeting rising global demand for livestock products in an environmentally and socially responsible way; underpinning government policy on livestock issues; translating scientific discovery into economic, environmental, animal welfare or social benefit; and integrating information from the 'biological revolution' into practical applications.

British Society of Plant Breeders

The British Society of Plant Breeders is the representative body for the UK plant breeding industry. Formerly the Plant Royalty Bureau, BSPB was formed in 1966 after the UK Plant Varieties & Seeds Act 1964 established a legal framework for collecting seed royalties on protected crop varieties.

Acting on members' behalf, BSPB licenses, collects and distributes certified seed royalties and farm-saved seed payments on the following agricultural and horticultural crops: Cereals, Oilseeds, Potatoes, Pulses, Fruit and Herbage. The Society aims to promote investment in future crop improvement by optimising the return to plant breeders on their intellectual property.

BSPB represents more than 50 members, comprising virtually 100% of public and private sector breeding activity in the UK. The Society promotes members' interests on technical, regulatory and intellectual property matters at a national and international level. A list of BSPB members is included as an appendix to this submission.

Overall, the Society aims to promote innovation in plant breeding by ensuring its members can operate in a proportionate, commercially relevant and cost-effective framework of regulation. BSPB organises a broad programme of statutory and commercial variety trials on behalf of its members.

Introduction

There is an acknowledged crisis in global food production. Demand is beginning to outstrip supply, and with limited land available to bring into agricultural production, the only realistic prospect of producing enough food for a rapidly increasing world population is through productivity growth – producing more crop per hectare.

It is increasingly evident that improvements in plant genetics – delivered through commercial plant breeding programmes such as those operated by BSPB members – will be the single most important factor in delivering the required gains in agricultural productivity.

Interim findings of a recent study by the National Institute for Agricultural Botany (NIAB) suggest that between 1947 and 1982, around half of the yield gain of major UK arable crops such as wheat and barley could be attributed to plant breeding, shared equally with the contribution of other factors such as improved agronomy, machinery or inputs. Since 1982, however, the contribution of plant breeding to yield gain has increased to more than 90%.

An expanding global population is not the only challenge. Climate experts predict that the effects of climate change – including extreme weather events and shortage of water – mean the world's agricultural productivity will rely increasingly on temperate regions such as Europe and North America.

Furthermore, the UK has a unique maritime climate and needs plant breeding to take place here in the UK. To illustrate this point, UK-bred varieties currently account for 95% of winter wheat, 89% of winter barley and 98% of spring barley grown in the UK.

The UK therefore needs strong, locally-based plant breeding to address the challenges of 21st century agriculture.

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

There is an overriding imperative to increase global food production. With increasing population growth and no significant new land areas to exploit there is a real danger of civil unrest and political instability within the world when food supplies are either low or under threat. The UK has a role to play as part of an international approach to sustaining and improving food supplies.

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?

Overcoming political and public resistance to the application of new technologies, such as genetic modification, is essential if the full potential of advances in our genetic knowledge is to be realised and exploited. Within Europe, much mythology and public anxiety continues to surround a potentially valuable technology, already in widespread commercial use elsewhere in the world.

At a more general level, while the UK is blessed with academic excellence there is a divide between academia and the commercial parties responsible for delivering new technologies. Careers in plant science related research are often linked to academic excellence through peer reviewed publications rather than translation into products for commercial and public exploitation.

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

Developments in molecular genetics and multidisciplinary approaches to the identification and understanding of gene function could play a significant part, as could hybrid crops in current self-pollinating species such as wheat. The tracking of traits through breeding programmes using marker assisted selection and technologies such as double haploidy and other tissue culture techniques could lend themselves to faster integration of high value traits - but there is an urgent need to identify high value traits.

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.

Much of the improvements in production have occurred through the integration of a wide range of technologies. There is still mileage in many of the technologies used previously. Biomass increase is a 'must have' in order that it can be portioned. Precision agronomy and the identification of micro and macro environments in which specific genotypes could prosper as well as better defined and targeted inputs would further enhance production.

The development of insect resistance (to a range of pests) through genetic means rather than the use of often unselective chemical insecticides is likely to lead to more stable yields as well as the maintenance of quality. The timescales for any benefits to reach the market place are long and thus there is a need to develop strategies sooner rather than later. The development of high throughput technologies such as double haploidy via microspore culture could have very significant benefits in shortening this time frame.

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).

Insect resistance is important as outlined in (4). The characterization of what determines reduced yields in continuous cropping of cereals as well as improved levels of disease resistance to current threats as well as intransigent targets such as take all could enhance wheat yields in the UK significantly. A longer term objective could be the possibility of improving photosynthetic efficiency, for example by modifying the Rubisco complex. As noted at (4) the time from research to market through a new variety is 10-15 years as a minimum; the research cost is too great and the risk too high for a commercial plant breeder to invest in these targets within the current limits of royalty income.

There does appear to be an element of 'intellectual snobbery' prevalent within certain strands of the academic community – preferring (or encouraged through Government funding) to work within areas of perceived high 'quality' science. There are major gaps in technology transfer from the academic community to the deliverers of key traits – plant breeders.

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.

Biological approaches to enhance food production must be a key part of any strategy to delivering sustainable output of high quality food. However the demands placed upon those 'burdened' with this target are vastly more difficult than those experienced with the development of the first 'Green Revolution'. The 'ideal' is to sustain (and preferably increase) food production with reduced inputs. Targets such as nitrogen and water use efficiency, biomass production (perhaps through the manipulation of the photosynthetic pathways), insect and disease resistance and introgression of traits through related or non-related species need to be addressed.

At present, strategies to confront these targets are sporadic and lack effective coordination. Whilst these may be pertinent to UK plc they do not seem to figure within Government strategies. The benefits of achieving just some of these targets would be beneficial to farmers and consumers, both in prices achieved and stability of supplies. If growers are adequately rewarded the environmental benefits will flow (at least for the majority of farmers) from the custody of the environments in which the crops are grown.

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.

Barriers exist at all levels because there is no agreed common strategy to boost food production and the targets involved are not (yet) perceived to be of high value.

Near term threats include the impact of unscientific or politically motivated regulation, particularly at EU level, ostensibly to protect or benefit consumers. Some of the strategies imposed may well be at variance with an objective of raising food crop output - for instance proposals to remove many known and safe agrochemicals, imposed reductions in the use of nitrogen fertilisers (a major driver for grain output) and over regulation with regard to water quality directives.

Recruitment of young plant breeders to the industry is difficult. In the plant breeding sector the low esteem given to workers within the agricultural community may discourage scientific high flyers from taking this route. In addition, agriculture has traditionally been a poorly paid sector, relying more on individuals' vocational aspirations than on financial remuneration. The industry has a high proportion of individuals who will retire in the next ten years and this will leave a knowledge gap.

Specifically in relation to UK plant breeding, there is a major gap between a rapidly advancing knowledge base in basic plant science and the delivery of new technologies to the market place. A major review of UK crop science in 2004, led by Professor Chris Gilligan, identified a serious imbalance between funding of basic plant science, in which the UK remains a world leader, and support for translating the outputs of that research into relevant crop species and varieties of practical benefit to UK agriculture. Although some crop-specific initiatives have subsequently been established to address the concerns expressed by Professor Gilligan, these have paid lip service to the crop science label and have failed to address the targets important for commercial plant breeders in our major crops, wheat, barley and oilseed rape. These initiatives have not resulted in a flow of material or knowledge suitable for use in commercial breeding programmes, and a fundamental imbalance persists today.

LINK has been a valuable mechanism for funding translational research and the plant breeding industry has used it successfully. But there is now a question mark over the future of LINK and a concern that the sole source of funding for truly relevant projects may cease to exist. The Technology Strategy Board within BERR has failed to bring forward funding calls to which breeding companies can apply, despite having many discussions with industry on the subject. Plant breeders are also frustrated at the Government's failure to engage with the breeding sector. For example a recent high level meeting to discuss Government R & D strategy involved public scientists and the agricultural sector but completely ignored the commercial plant breeders, the only route to exploiting plant genetics to improve productivity and, as the NIAB study referred to earlier shows, the only part of the innovation chain that has produced significant improvements in recent years.

There has been an explosion of new knowledge about the genes controlling many aspects of plant growth, development, metabolism and responses to biotic and abiotic stresses. In addition, progress in molecular techniques and laboratory automation, as well as the development of computing power and revolutionary mathematics open up significant opportunities for the genetic improvement of crop plants.

However, as new understanding of plant biology has progressed, the knowledge-transfer chain has become less functional because the required level of investment for translational activities has not been available.

Plant breeding is a private sector activity. Plant breeders derive their income from royalties, provided for by Plant Breeders' Rights (PBR) legislation. Royalties are paid for the use of seed: on certified seed supplied by seed multipliers (agricultural merchants) and at a substantially lower rate on farm-saved seed (around 50% of the royalty paid for the use of certified seed, with farm saved seed accounting for nearly 50% of all seed use in the major crops). The dynamics of the industry are such that the total income to breeders is relatively inelastic and equates to around £30 million per year.

An inevitable consequence of linking royalty income to the volume of seed sown has been to restrict the total amount of money available at the point of collection, a situation compounded by a trend towards reduced seeding rates and increased use of farm-saved seed. In IP terms, this situation has detached plant breeders from the rest of the value chain, and limited the sector's ability to derive a more realistic share of the genetic value added beyond the farm-gate.

A consequence of the limited revenue streams available from plant breeding is that breeders simply cannot invest in more speculative or long-term targets. Around one third of breeders' income is devoted to research activities, the vast majority of which is required to maintain existing breeding programmes. For some crops, further growth in the proportion of farm saved seed to certified seed use may result in the closure of the few remaining breeding programmes as income will be insufficient to sustain them.

Because of this, the market-based approach to financing near-market and applied R&D is not working, and opportunities to exploit the UK's world-leading, publicly funded research base in plant science are being lost.

There is an urgent need to bridge this hiatus in research activity. Significant investment in publicly-funded translational crop science and pre-breeding programmes is required to ensure public benefit – in the form of enhanced food crop productivity – can be derived from current taxpayer investment in basic scientific research. The role of private sector plant breeders will be pivotal for further exploitation of material developed or characterised through such activities.

BSPB membership

Full Members – Large

DLF Trifolium Ltd
Elsoms Seeds Ltd
Germinal Holdings Ltd (BSH)
KWS UK Ltd
LS Plant Breeding
Monsanto (UK) Ltd
Nickerson-Advanta UK Ltd
Syngenta Seeds UK Ltd
Saaten Union UK Ltd
RAGT

Full Members - Small

Cygnet Potato Breeders Ltd
Senova Ltd

Associate Members – Large

Agrico UK Ltd
Barenbrug (UK) Ltd
Caussade Semences
Danisco Seed
Deutsche Saatveredelung AG (DSV)
Grainseed Ltd
Masstock Arable Ltd
Pioneer Hi-Bred (NE) Ltd
Rijk Zwaan UK Ltd

Associate Members - Small

AFBI
Advanced Technologies (Cambs) Ltd
Caithness Potato Breeders Ltd
David Trethewey Seeds
Enza Zaden
Euro Grass Breeding GmbH & Co KG
Frontier Agriculture Ltd
Harlow Agricultural Merchants Ltd
Harper Adams
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I G Pflanzenzucht GmbH
Irish Potato Marketing Ltd
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John Ebbage Seeds Ltd
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John Turner Seed Developments
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MBM Produce Ltd
Mike Pickford
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Sakata UK Ltd
SCRI (Mylnefield Research Services)
Seminis Vegetable Seeds UK Ltd
Top Green SAS
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TV Seeds
United Oilseeds
Wherry & Sons Ltd

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

There is a need for more efficient and sustainable global food-crop production globally. The global population has a right to a sufficient quantity and quality of food, thus alleviating problems of hunger and malnutrition. Food consumption patterns in some developed countries are unsustainable, both because of the stress placed on the environment and the ensuing health problems experienced by consumers. There is a need for a new equitable paradigm of food production and consumption globally, and a renewed relationship and reconnection with food and food production systems. This may include an increase in global food-crop production, but the focus should be on enhanced production from land already being cropped. The question also raises concerns over population growth and calls are growing for steps to curb population growth, thus reducing pressure on global food-production systems, ecosystem services and resources generally.

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?

A major scientific challenge is to maintain output from conventional farming in the face of rising input costs (fuel, fertilisers, nutrients and seed) and more widespread environmental concerns and regulations. Precision farming is facilitating more efficient and targeted input use, low-cost systems for small farmers in developed countries and farmers generally in developing countries could make a significant contribution to more efficient farming practices, as would more efficient tillage and cropping systems. New crop varieties will also help increase food-crop production and facilitate more efficient input use; pest and disease resistance and water-logging and drought tolerance should be priorities in the face of global climate change.

Research to maintain and enhance soil structure and nutrient levels and optimise carbon sequestration and storage under various cropping systems is required. Evidence in support of more sustainable farming practices is compelling (Pretty 2008) as is the potential role of more sustainable forms of food production in helping protect the environment, conserve biodiversity and build social cohesion (Pretty 2003; Bunting 2007a). The challenge is how to encourage and promote the widespread adoption of more sustainable farming practices, especially when negative environmental, social and economic consequences of many conventional farming approaches are not factored in to policy-making or reflected in commodity prices. This will demand an interdisciplinary approach involving social scientists, political scientists, economists, communication specialists and agricultural scientists, with the interactive participation of all stakeholders, including growers, policy-makers and consumers.

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

Ongoing developments in genetically-modified crops, combined with continued promotion and lobbying by companies and a more rational debate about the use of GM crops in the light of growing evidence of constraints and opportunities.

Increasingly efficient biofuel and biomass crop processing and heat and energy generation systems, combined with research concerning more efficient feedstock production will encourage some farmers to switch away from food-crop production. Policy instruments may be required to ensure sufficient food-crops are grown to permit poor and vulnerable groups to obtain adequate food at a reasonable price.

A strong and growing evidence base for alternative more sustainable land-based and aquatic farming practices (Pretty 1995; Muir 2005; Bunting 2007a; Pretty 2008) combined with growing awareness of problems associated with conventional farming should help facilitate the transition to more sustainable forms of production. However, uptake promotion of more sustainable production strategies is required and further development assistance combined with supporting research is needed to ensure the resulting farming systems are appropriate for particular physical, environmental, social and institutional settings.

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.

Ongoing plant and animal breeding resulting in new varieties and strains could significantly improve food-crops; varieties and strains derived from breeding programmes will be accepted by producers and consumers.

Genetically modified crops have increased food-crop production and helped reduce agrochemical use in certain situations, but in many places there are social and political barriers to adoption by producers. Appropriate safeguards are required to protect the environment and allay public concerns, but in some cases resistance form producers, environmentalists and consumers to GM crops will remain.

Considering aquaculture, domestication of new species could significantly improve food production, creating new opportunities for growers and alleviating pressure on largely fully exploited and over-fished wild stocks.

More efficient water and nutrient management, based on improved varieties and strains, better timing and modes of delivery, including targeted and precision application, better command and control in irrigation systems and where possible better integration of agriculture with aquaculture and livestock farming to make more efficient use of water, nutrient and waste resources (Little and Edwards 1999; Bunting 2008). Integration of aquaculture with water storage, water transfer and irrigation schemes could also enhance food production and make more efficient use of water, land and nutrient resources. At a landscape scale integration of buffer-strips, wetlands and ponds can help trap soil and nutrients that would otherwise be lost, contribute to enhanced flows of ecosystem services and facilitate the integration of aquatic farming systems producing food, biomass or biofuel.

Utilising crop residues, livestock rearing waste and food and drink processing by-products more efficiently could contribute enhance production in food or biomass farming systems, helping reduce pressure on non-renewable resources and limiting environmental degradation.

Widespread adoption of best practices for the use of domestic wastewater in agriculture and aquaculture could also contribute to food-crop and biomass or biofuel production and help avoid negative environmental impacts (Bunting 2004; WHO 2006; Bunting 2007b).

Support for organic, fair-trade and more sustainable farming practices could help enhance the quality of food production and foster more equitable, socially-responsible and environmentally sound modes of production.

Given the expanding area of land affected by salinisation, declining productivity of coastal land previously converted to agriculture and aquaculture and rising number of schemes advocating managed retreat which will result in large costal areas being inundated, a focus on cropping halophytes for fodder, food and biofuel production could help increase direct food-crop production and reduce pressure on land used for food-crop production. Cropping halophytes can also be integrated with land-based marine aquaculture in coastal area to enhance resource use efficiency and limit environmental impacts.
Adopting Integrated Pest Management can also help reduce agrochemical use and improve production, fish culture in rice paddies being one example; however, more work is required to assess the financial, economic and social implications of such practices, as well as potential impacts on carbon emissions and sequestration (Bunting 2007a).

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).

Targets for improvement include:

- yield
- quality for processing
- nutritional status
- pest and disease resistance
- input use efficiency
- drought and water-logging tolerance
- ease of processing and waste minimisation
- reduced carbon dioxide emissions from farm to fork

6. Which current/future husbandry or farm management technologies for the enhancement of food-crop production are appropriate for development and dissemination and why? Comments could include information on the benefits they may bring, difficulties in scaling up their use in different parts of the world and time needed to get improved methods incorporated in farm practises.

- precision farming – more efficient use of non-renewable resources and reduced environmental degradation
- selective breeding for improved strains – approaches are accessible to farmers that will result in improved stock for local conditions
- adoption of sustainable farming approaches (Pretty 1995 and 2008) and low impact, regenerating aquaculture strategies would help enhance production and reduce environmental impacts and degradation (Bunting 2006; Bunting 2007a)
- adopting carbon sensitive agriculture, livestock rearing and aquaculture practices will contribute to lower carbon emissions and enhance carbon sequestration (Pretty and Ball 2001; Bunting and Pretty 2007); appropriate labelling or carbon trading schemes would help producers benefit financially.

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?

- precision farming – enhanced resource use-efficiency
- low cost precision farming and soil and crop testing – more efficient resource use on small farms in developed countries and farms generally in developing countries
- engineering – enhanced fuel efficiency, tillage and cropping efficiency
- bioenergy – improved feed-stock selection and cultivation techniques
- social sciences – improved learning, group-formation, joint analysis and collective action
- political science – improved decision-making and policy formulation

8. What might be the possible consequences and impacts of biological approaches to enhance food-crop production on:

a) crop yields and quality;

Either or both could be enhanced, although a trade-off may be desirable depending upon priorities.

b) world food prices;

Increased food crop production could result in lower world food prices, it could also help stabilise commodity prices and help spread the risk associated with crop failures in particular countries or regions. However, given the apparent pressures on land resources from degradation and conversion to biofuel production and the expected increase in the global population even with substantial increases in food-crop production per unit area, prices may be expected to rise in the medium to long-term.

c) the environment;

Enhanced food-crop production must be balanced with environmental protection and continued environmental flows of water, nutrients and ecological services.

d) the livelihoods of farmers; and

Enhanced food-crop production should not be taken as a guarantee of improved livelihoods for farmers. There will be barriers to some farmers benefiting from enhanced production, some farmers and members of their families may experience greater problems and risks as a consequence of pushes toward enhanced food-crop production.

e) any other areas you think relevant.

A narrow focus on biological approaches to food-crop production may have adverse affects on local communities and society more generally. Failure to include livestock and aquaculture sectors in the development of enhanced food-crop production systems also risks missing opportunities for increased resource use efficiency, environmental protection, enhanced financial returns and reduced risks for producers and wider economic benefits for society.

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.

Awareness and knowledge of enhanced food-crop production strategies may be limited at a local, national or regional scale. Continued subsidies to conventional farming may constitute a barrier to the adoption of more sustainable forms of production. More sustainable food-crop production systems will also be at a disadvantage until the agricultural sector is required to internalise negative environmental costs.

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Ayub Chege

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

The answer is an emphatic YES, as the recurring food shortages, reciprocal trends in population growth and crop productivity, and violently changing climate exemplify.

History of food shortages

Whether one gives it the believers' or the scientists' points-of-view, food shortages- and resultant famines have been with mankind for long, and there is no guarantee that there will be an end soon. What man can do is employ the current knowledge and resource base to minimise the adverse effects attendant with food shortages. Instead of being the victim of famines, man should aspire to be an eventual victor after an unexpected episode.

The Book of Genesis records a severe drought that had affected all the world then. In Egypt, a young Israelite slave named Joseph had put forward his enterprenual policies on food stocking that had been very successful and the pharaoh had promoted him be lord over all his subjects. And that is how the Israelites had escaped famine in Palestine to settle in Goshen, Egypt. Another famine is mentioned during the reign of King Ahab when Elijah the prophet prayed for rain after seven years' drought. The book of Revelations sums up famines in the future administered by the third horseman of the Apocalypse when he measures out portions of grain with a scale at exorbitant prices.

The scholarly world mentions many famines, too. Pre-20th Century has three of the worst famines (food shortages) in history. These are the Great Famine of Bengal, India, of 1769 that decimated 10 million people by starvation, the Great Irish Famine of 1845-1848 that killed between 700,000 and a million people, and the Chinese famine of 1875 to 1878 that killed over between nine and thirteen million people[(1)].

During the 20th Century, an estimated 70 million people died from famines across the world, although most severe in the Asian continent. Spectacularly, an estimated 30 million died during the 1958-1961 famine in China during the ill-conceived The Great Leap Forward[(2)]. China had also suffered other severe famines in 1928 and 1942. Bengal faced a prolonged famine disaster between 1942 and 1945, while several of the former Russian republics have faced several sequence of famines. The African continient also witnessed its share of famines, like the West African Biafra famine of the 1960s, the Horn of Africa Ethiopian famines of 1983-87 and 1991-1993[(3)].

The 21st Century famines are even more graphic. The Horn of Africa is always in the media about food shortages[(4)]. The Southern Africa is also currently facing its worst, after Zimbabwe's food-basket turned dry with the raid of previous large scale farming sector. The combined effects of bad governance/bad policies and a changing climate promise to be even more profound.

Food-crop production trends

With improved health care, cessations of ethnic/socio-cultural/political hostilities in search of world peace, and improved transport and communications in a more globalised market, it would be expected for populations to grow rapidly whereas forecasts of food shortages can be met more expediently with airlifts. Populations (human and animal) have grown almost geometrically in the run-up to the twenty-first century. As a result, the world's land area suitable for agriculture has gradually decreased, putting a squeeze on the total estimated 3000 million hectares[(5)] to still meet production goals. Nearly all of the productive land is already exploited for agriculture, and man is slowly encroaching onto any other available land.

A finite food production ecosystem has only one way of survival- cultivation year in- year out. Slash-and-burn worked previously in the tropical Africa to replinish nutrients taken up by crops, by changes in land tenure warrants that each confines individuals (or family units) to parcels they assign some ownership. As families increase in size, the parcel(s) of land become increasingly fragmented to subunits that might not be large enough to meet food production needs[6]. Such cultivable soils have long 'grown tired' of continous cultivations that have literary 'mined' soils off nutrients leaving depleted and infertile. This has not been possible leading to food deficits and malnutrition, unlike in the Asian continent where despite the high populations, the green revolution has seen food production outpace population increase[7]. On the other hand, the West has been lucky with inputs from energy, fertilisers, pesticides and irrigation. Greenhouse farming has also catered for any needed exotic species.

The increased demands for energy have created competing use of food-crop products to meet alternative sources of energy. Cereals (specifically maize) and soyabean have been commercially cropped to meet biofuel demand as the prices of oil have risen. The nett decrease in maize (grain and fodder) food source has led to increased demand for other cereals (rice and wheat) thereby skyrocketing their prices too. The rising food prices are hurting the poor and might not benefit all farmers, especially poor farmers who have little effect on price setting.

Changing climate

Man's activities to survive amid declining food production have led to exploitation of fragile ecosystems like arid ecozones, or sometimes wet and cold environments. The consequences have been increased threat to the natural barrier against desertification and the water catchment areas. As global warming and resultant climatic change have tested man with new challenges, the very tenet of human nutrition is no longer guaranteed. Food security can no longer be defined as the assurance of a meal at the end of the day.

Disasters are equally to blame for famines. Droughts and oft attendant pests invasions and disease oubreaks have caused food shortages and famines affecting even the would-be rescure livestock. As the latter often provide manure that helps improve soil fertility and thus improve food-crop yields, droughts come as double blow. Excessive rains like the El Nino and flooding have often destroyed crops leading to the shortages. The sub-Saharan Africa has seen disasters follow each other in quick successions, while Haiti has been battered by a succession of destructive hurricans each year. The Asian continent has suffered devastating floods each monsoon season. Most recent, UK has expereinced heavy summer rains that have delayed harvesting, and farmers fear high yield losses[8].

Signs of the times

Famines are just the tip of food-related maladies like hunger, allergies, malnutrition, low quality, nutrient imbalances, and calory intake- all with significant effect on human health. Apart from the increased consumer food prices reminiscent of the prevailing credit slump and oil 'crisis,' there is greater concern on the food rations as witnessed by the recent food riots that crossed the globe. The direct relationship between food and oil were exemplified when food shortages in Haiti, Cairo and Bangladesh coincided with oil price hikes that saw French truckers and fishermen blocking the English Channel. In other words, both the developing and developed worlds suffered the same.

Isolated cases of children starving to death in UK and other developed countries are on the increase, not due to lack but nutrition transition and socio-cultural breakdown that cannot withstand economic development and urbanisation. The rising costs of living have sacrificed the poorer in society such that even with the plenty, many are living below the poverty line. Prices of basic foodstuffs like bread and milk have risen by as much as 20% in a year following the credit crisis. Unfortunately, there appears to be no end to the woes as even the resourced people across the globe have buckled with the tumbling of share markets.

However, many other food shortages are occasioned by conflicts. Wars like in Cambodia and even in developed nations like North Korea have resulted in famines in the late 20th Century that could have been avoided. And the more recent famine in the Southern Africa following change in policies in Zimbabwe only highlights how far man can go to bring in self-made disasters.

By the 2030

Famines are a mark of poverty[9], and with large populations living below the poverty line, food scarcity would be no surprise. And considering that food production is also a significant source of income to millions whose farming is their way of life, the disparity between continued economic development with starving masses in a rapidly globalising society does not auger well. Migrations will continue to be more desperate and volatile, while food hoarding will be more serious. Therefore, the riots witnessed in 2008 will become more frequent and more violent.

Just like all ecosystems, there is an optimal global carrying capacity above which adverse factors will operate in force to limit further population growth. Food fights will see decimation of many in a free-for-all survival for the fittest-and-meanest individual.

Care International predicts that a hundred billion pounds will be spent this century fighting food emergencies, according to its report to the United Nations' summit on tackling global povert titled 'Living on the edge of emergency: The price of inaction.' These are funds wasted while millions die of starvation if food-crop production could have been stepped up early.

The works of Aid organisations will continue but will not meet the heightened crises. World Food Program, Food for the Hungry International, Oxfarm, CAFOD, Plan International, Food and Agriculture Organisation, etc, will breed more-like organisation in a race to better human livelihoods but will be working against time. This, although a noble act of rushing in with food aid reliefs chasing after the calamities, does not go anywhere towards tackling the problems behind the endemic food shortages.

Firebrands like the UK's Soil Association and enthusiasts of organic farming will eventually tone down once they accept that their principles are based on a fallacy as soils are no longer healthy- clinically and agronomically. Similarly, opponents of genetically modified species will come to terms that there is no true way of excluding biotechnology and agricultural industrialisation in the race against famines and malnutrition. Theoretically, the starving wouldn't care whether their food rations were organic or laced with pesticides or contaminate with GMOs or had covered a thousand foodmiles, and neither would the morally strong object.

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Managing and Researching the Food Crop Production – Nitrogen Connection

- The most urgent need in bringing a Green Revolution to Africa is to increase fertilizer use in sub-Saharan Africa where insufficient supply of nutrients results in continuing decline in soil fertility. In contrast to Africa, Asia's food production has expanded considerably and its success in feeding its larger population has been based on the steadily increasing use of synthetic nitrogen fertilizers. The annual world consumption of N, synthetic nitrogen fertilizer, manufactured using fossil fuels by the Haber-Bosch process, has averaged 83 – 85 million metric tonnes in recent years, with nearly 60% of that amount applied to cereal crops; application rates in East Asia are 155KGN/Hectare, 112 KGN/Hectare in North America and only 9 KGN/Hectare in Africa (Dobermann, 2007).
- Since most of the world's future population growth will be concentrated in a handful of Asian countries, Asia will see further substantial increases in fertilizer use. Because nitrogen is usually the nutrient needed in the highest amounts by staple crops, based on our existing technology the total application of synthetic nitrogen fertilizers will have to increase if the more intensive cropping practices are to be expanded and sustained into the first half of this century. Increased production and more efficient application of synthetic nitrogen fertilizer (the fossil fuel food) are seen as two key determinants of larger harvests for the foreseeable future (Smil, 2000) but application rates will have to be limited in many regions of the world in order to prevent excessive environmental impacts. In North America and Europe where there is an abundance of synthetic nitrogen fertilizer application at an ever increasing cost, food production is sufficient but a large share of the nitrogen applied is lost to the environment and is a major contributor to photochemical smog, fine particulate pollution, ecosystem acidification (including reduced biodiversity), coastal eutrophication and global warming. Nitrogen – related air pollution is linked to higher rates of cardio-pulmonary ailments and there is also concern about the potential health impacts of high levels of nitrate in drinking water.

- Biological nitrogen fixation (BNF) is a major source of fixed nitrogen, especially in systems where legumes symbiotically fixing nitrogen are in crop rotations with cereals. It has been estimated that BNF from cultivated, mainly legume, crops contributes annually approx. 33 million metric tonnes N to agriculture globally. A major central challenge is how to optimise the use of fixed nitrogen to not only produce enough food to meet demand form population increase and expansion of biofuel production but also to minimize the negative impacts of costly chemically fixed nitrogen on the environment and human health – the key need in this respect in developed and developing countries over the next 30 years is to increase nitrogen use efficiency (NUE) and establish symbiotic nitrogen fixation (SNF) in cereals and other major non-legume crops. Recent advances in our understanding of the regulation of nitrogen assimilation in plants and of the interaction of nitrogen – fixing bacteria with cereals and other non-legume crops are indicating that these are both realistic objectives within the next few decades.

- There is currently considerable interest in improving NUE in cereals – estimates of NUE, a measure of plant nitrogen uptake from the soil, have been calculated to be as low as 33%. In most of the earlier NUE studies transgenic cereals did not show improved NUE but recent studies have demonstrated that over expression of specific enzymes such as glutamine synthase can increase grain yields significantly. A study of the over-expression of alanine aminotransferase in rice has indicated that it is possible to improve nitrogen uptake by the manipulation of a downstream step in nitrogen metabolism (Shrawat et al. 2008)

- The demonstration that intracellular nitrogen-fixing root nodule symbioses of legumes with rhizobia, and the non-nodular intracellular root symbioses of legumes and non-legumes, including cereals, with arbuscular mycorrhizal fungi, rely on partially overlapping genetic programs mediated by at lease one common signalling component (Endre et al, 2002; Stracke et al. 2002) has re-stimulated attempts to obtain SNF in cereals. The nitrogen-fixing bacterium *Gluconacetobacter diazotrophicus* which has been shown to fix nitrogen inside sugar cane plants without nodulation (Boddey et al, 2003) has also been shown to intracellularlly colonize the roots and shoots of non-legumes (Cocking et al, 2006). Inoculation of cereals with *Gluconacetobacter diazotrophicus* could thereby provide a first step towards establishing non-nodular SNF in cereals.

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From the ***Program on Sustainable Rice Systems*** of the **Cornell International Institute for Food, Agriculture and Development** (CIIFAD), Cornell University, Ithaca, NY, USA, with supporting statement from the Africare program in Mali

I. This submission on **the System of Rice Intensification (SRI)** focuses on a biological-management innovation that is significantly enhancing production of the world's most widespread food crop, rice. SRI has been validated now in 30 countries around the world (http://ciifad.cornell.edu/sri/), and its methods are being applied to other crops, making possibly broader improvements in food production with more reliance on biological potentials and processes than on external chemical inputs.

SRI methods achieve major increases in the productivity of all the factors used in rice production just by changing the way that plants, soil, water and nutrients are managed. It mobilizes certain biological processes and potentials that already exist within plant genomes and soil systems. SRI experience gives empirical support to the proposition that *biological approaches to food-crop production can be agronomically successful, economically advantageous, environmentally beneficial, and sustainable*.

SRI changes management practices that have prevailed for generations, and even longer. If rice is transplanted, it is best to start with very young seedlings, just 8-12 days old. These seedlings should be planted quickly and shallow, taking care to protect the roots from any trauma or desiccation; singly and not in bunches; and in a square pattern for better exposure to sunlight. There should be no continuous flooding of rice paddies, only keeping the soil moist and intermittently drained; controlling weeds by using a rotating hoe that actively aerates the soil; and applying as much organic material to the soil as possible (Stoop et al. 2002).

II. Generalizing from a large number of evaluations by research institutes, universities, donor agencies, and other institutions, it has been seen that use of SRI principles and practices can have the following results, all explainable with established scientific knowledge (Horie et al. 2005; Mishra et al. 2006).

- **Higher rice crop yields**, usually by 50-100%, and often several times this when farmers are starting from a subsistence level. These increases are achieved with:
    - **Reduction in seed requirements** -- by 80-90%, because plant populations are greatly reduced, giving plants' roots and canopy more room for larger, healthier growth;
    - **Reduction in water requirements** -- by 25-50% if the crop is irrigated; if there are no irrigation facilities, SRI methods can be adapted to ***rainfed*** conditions, with most of the same benefits;
    - **Reduction in costs of production** -- by 10-20%, because there is no need to purchase seeds from new or improved varieties, nor to buy and apply chemical fertilizer if enough biomass and labor are available to provide organic fertilization (compost) instead;
    - Often **reduction in labor requirements** once the new methods have been mastered, although during the learning phase, SRI is initially more labor-intensive, which can be a constraint to adoption;
    - **Increased farmer income** -- by 50 to 200% or more, because production costs are reduced at the same time that output and resulting revenue are raised.

- **Improved grain quality,** and possibly **greater nutritional value**, which remains to be systematically evaluated:
    - **Higher milling outturn** is documented -- by 10-20%, due to fewer unfilled grains (less chaff) and fewer broken grains (less shattering during milling),resulting in **10-20% more edible grain per bushel of paddy** (unmilled rice), which is already increased, as noted above, by SRI methods.
    - **More protein?** Less shattering during milling is indicative of higher protein content, as discussed below. This is quite plausible given the fact that under unflooded field conditions, SRI plant roots do not degenerate (Kar et al. 1974) and they remain functioning throughout the crop cycle, giving the plants more access to nitrogen with which to synthesize amino acids.
    - **Higher quality protein?** While there is little research on this, one evaluation of rice produced with chemical fertilizer (Todorov 1991) has shown that its use can affect the balance among the essential amino acids synthesized, thereby diminishing the biological value of resulting protein. This is a relationship that deserves more extensive evaluation.
    - **More micronutrients?** SRI grains are generally heavier by 5-15%, without necessarily being larger, which means the grains are denser. This could contribute to the reduced shattering of SRI paddy rice during milling. SRI plant roots are much larger and grow much deeper into the soil, to depths of 30-50 cm. This would give them access to greater amounts of micronutrients for plant growth and more nutrient-dense grains, but this too remains to be systematically investigated. Research recently published by Rothamsted scientists shows that rice grown under unflooded soil conditions has 10-15 times less arsenic uptake, a health benefit, and gives greater content of zinc, copper, manganese and magnesium

(Xu et al. 2008). The authors cautioned that not flooding rice fields could lower yield; however, with SRI methods, yield is instead increased.

- Higher **resource use efficiency** – SRI is an unusual innovation in that it increases concurrently the productivities of **land**, of **labor**, of **capital** and of **water**, something unprecedented. SRI makes these different factors of production more productive by mobilizing and utilizing biological resources for various services and processes performed by soil biota, e.g., nutrient cycling, P solubilization, N fixation, phytohormone production, induced systemic resistance (Randriamiharisoa, et al. 2006).

- Less reliance on **non-renewable resources** – Although SRI methods can be used with **chemical fertilizer**, this is not necessary. Compost made from any decomposed biomass can give as good or better yields -- and at lower cost to farmers if they have access to labor and biomass. Because SRI plants are more resistant to pests and diseases (Ngo, 2007), possibly explained by the theory of trophobiosis (Chaboussou 2004), use of **agrochemical means of crop protection** is unnecessary or uneconomic. Rising costs of fuel and fertilizer are undercutting the economic feasibility of input-intensive 'modern' agriculture with its high requirements for energy and water. Few governments can any longer afford to maintain the levels of subsidization of energy and agricultural inputs that they provided in past decades.

III. **Sustainability:** Some may question whether SRI production is sustainable without external inputs of inorganic nutrients and energy. So far, we have seen farmers over periods as long as 10 years, relying only on biological inputs, increase their yields rather than experience a decline. What is required for this is that they sustain soil structure and biological activity in the soil by the provision of compost, made from any available biomass. Soil organisms can support the fixation and recycling of nitrogen, which is abundant in the atmosphere, and the mobilization through biological activity of P, K and other nutrients from the soil's unavailable reserves (Bonkowski, 2004; Turner and Haygarth, 2001; Uphoff et al. 2006).
SRI endorsement of organic fertilization is pragmatic, not a matter of doctrine or ideology. Specific nutrient limitations can be redressed by inorganic soil amendments on an as-needed basis with other SRI practices, using such amendments to support, not displace, the functions and services of diverse and abundant soil biota.

Reduction in the requirements of water for irrigated rice has great benefit for the environment, reducing the demands that the agricultural sector makes on hydrological flows and reserves. For this reason, WWF has started supporting the evaluation and extension of SRI in India (Gujja et al. 2007). We find that SRI plants are more resistant to ***abiotic*** as well as biotic stresses. Resistance to drought, storm damage and extreme temperatures adds stability to crop production. Cropping systems in the 21st century are going to have to be able to withstand greater and additional stresses. Our expectation is that SRI methods can help farmers make their crops more 'climate-proof' against the effects of climate change.

By not relying on external, non-biological inputs, the prospects of sustainability with SRI methods are better than with current agricultural production systems. These are petroleum-dependent, needing high energy inputs, chemical fertilizer applications, and agrochemical crop protection. Moreover, in India the insights and practices of SRI are being extended and extrapolated to other crops beyond rice, such as wheat, finger millet, sugarcane and mustard. The key factors are (a) promotion of larger, more vigorous and effective root systems, together with (b) more abundant, diverse and active soil biota. These factors have been largely ignored by crop and soil sciences in recent decades. SRI experience points to the importance and opportunities that these biological 'actors' present for enhancing food-crop production.

IV. **Examples of systematic evaluations of SRI** have produced the following data. The reports from which this information was drawn will be appended for easy access:

- **Cambodia:** An evaluation done for the German aid agency GTZ (Anthofer 2004) based on a random sample of 400 SRI users and 100 non-users in five provinces found an average yield increase of 41% and average income increase of 74%, with no average increase in labor inputs and with reduced risk of economic loss. An NGO study of 120 farmers who had used SRI methods for three years found use of chemical fertilizer reduced from 116 kg/ha before SRI to 46 kg/ha after this period, while the share of households using chemical pesticides fell from 28% before SRI to 2% once its methods were utilized.
- **China:** A team from China Agriculture University (Li et al 2005) evaluated experience in a village in Sichuan province where SRI use had gone from 7 farmers in 2003 to 398 farmers in 2004. SRI yields were 48% higher than conventional practice in 2003, a drought year, and 12% higher in 2004, a more normal year. Water savings were 45%, and fertilizer use was reduced by 11% (despite govt. extension staff efforts to promote its use, for their financial benefit). Overall, costs of production per hectare went down by 8%, conservatively calculated, and income per hectare was 55% higher with SRI using 2002 (lower) prices, and 148% higher at current (higher) prices. Farmer opinions were surveyed systematically, and farmers agreed that ***labor-saving*** is the most attractive feature of SRI.

- **Gambia:** An evaluation by the former director of this country's agricultural research station at Sapu (and now director of research for its National Agricultural Research Institute) found SRI yields to be three times higher than with farmers' usual methods on the same fields: 7.3 t/ha average with SRI practices vs. 2.5 t/ha with farmers' practices, a 192% increase. On-station trials showed an average differential of 6.2 t/ha vs. 1.8 t/ha comparing unflooded with flooded rice production (244% higher yield). The most significant finding was that with SRI practices, water productivity (measured in kg of rice/m^3 water) went up 6-fold (Ceesay et al., 2006).
- **India:** Many evaluations have been done in India. A research team from the International Water Management Institute's India Programme evaluated rainfed SRI in West Bengal state in 2004. It studied a locality where use had gone from 4 farmers in 2003 to 150 the next year. In the village with normal rainfall, SRI yield was 50% higher than with conventional practices; in the village hit by three dry spells, yield was 12% higher than with usual methods, averaging 32% more overall. Income per hectare increased by 75% on average, with 12% less labor per hectare, and 14 times higher productivity of seed (kg of rice produced vs. kg of seed planted). This latter comparison was a critical consideration for the very poor farmers living in these villages (Sinha and Talati 2007).
- **Indonesia:** An evaluation over nine seasons (2002-2006) aggregating 12,133 on-farm comparisons on a total area of 9,429 hectares found SRI methods giving average yield increase of 3.3 t/ha (78%) with 40% less water, 50% less fertilizer, and 20% lower costs of production (Sato and Uphoff 2007).
- **Myanmar:** An evaluation of SRI experience of 612 farmers in northern Myanmar, trained in SRI methods through NGO farmer field schools, followed over a four-year period, showed average SRI yields of 6.5 t/ha on FFS plots and 4.2 t/ha yields on their own fields (not using all SRI methods), which was 3 or 2 times more than farmers' average yields of 2.1 t/ha in the area. There was no increase in cost, so households' ***net income per hectare***, with all inputs and outputs calculated in terms of kg of rice, went from 296 kg/ha to 2,584 kg/ha, a huge increase (Kabir and Uphoff, 2007). Within three years, SRI use had spread to almost 100% in villages once one-third of the farmer received farmer field school training. In the region as a whole (Kachin and Shan States), SRI use has expanded to over 50,000 households within seven years.
- **Sri Lanka:** A research team from the International Water Management Institute(IWMI) in 2004 studied the rice production of 120 farmers randomly selected in two districts, half of them SRI users, half not. Even without using the full set of SRI practices recommended, average yields with incomplete SRI were 50% higher and profitability of rice production almost doubled with the new methods. Water use was reduced, and herbicide use was 73% lower among SRI farmers. Also, famers' risk of economic losses was substantially lower using SRI methods (Namara et al. 2008).

V. **Positive aspects** of the technology have been noted above:

- Higher agronomic and economic returns to farmers;
- Reduced dependence on external inputs and particularly on petroleum-based inputs;
- Reduced water demand which is good for people, who can put the water saved to other uses, and better for ecosystems, which are encroached when water is extracted from surface or groundwater sources for agriculture;
- Less use of agrochemical inputs (fertilizer, pesticides, herbicides, etc.) which is better for soil and water quality and for soil and human health.

So far, **few negative aspects** have been identified. Initially it was believed that SRI was necessarily ***labor-intensive***. But as farmers gain experience, skill and confidence in the methods, as a rule SRI becomes labor-neutral or even ***labor-saving***. We have not seen indications that there will be problems of ***long-term sustainability***, but this should be monitored carefully. If soil nutrient deficiencies develop in the future, it may be necessary to make soil amendments, but these will probably be less, and more benign, than with current agricultural practices.

VI. **Barriers to effective introduction and use**

- **Skills and attitudes:** Old habits and beliefs often die hard. The main barriers to spread and uptake of SRI practices are mental. But as seen below, rapid spread is now beginning.

- **Knowledge transfer:** This is the key to SRI introduction and use, with visible, physical demonstrations of how SRI methods yield more productive ***phenotypes*** from almost any rice ***genotype***: land race or hybrid, local or high-yielding. See videos on SRI produced by the World Bank Institute (http://info.worldbank.org/etools/WBIMM/SSIA/index.htm). Examples of rapid uptake:
  - ***Tamil Nadu state, India***: Evaluations started in 2000 at Tamil Nadu Agricultural University, and extension began in 2004. In 2005, there were about 40,000 hectares of SRI practice; by 2007, according to the Minister of Agriculture, this extent was 430,000 hectares (THE HINDU, 1/1/08: http://www.thehindu.com/2008/01/01/stories/2008010153180300.htm).

- o ***Tripura state, India***: Evaluations also started in 2000-01, with first farmer use in 2002-03 on a trial basis. By 2005-6, 880 farmers were using the methods, and the state government allocated 1/3 of its agriculture budget to SRI extension, putting a dynamic Dept. of Agriculture researcher in charge of the initiative. The next season, there were 73,390 farmers using SRI methods, and in 2007-08, there were 162,485 farmers, with an average yield increase of 1.4 t/ha.
- o ***Himachal Pradesh and Uttarakhand states, India***: People's Science Institute, an NGO based in Dehradun, began working with 40 farmers here in 2006 to demonstrate SRI methods. The next year, 597 farmers participated in further evaluations. In 2008, with support from a Tata Trust and WWF, PSI has expanded SRI use to 12,042 farmers in this poor and marginal part of India.
- o ***Ha Tay province, Vietnam***: The National IPM Program under the Ministry of Agriculture and Rural Development, with assistance from Oxfam America, introduced SRI in this province in 2007, getting farmers to use the methods on 3,000 hectares. In 2008, based on good results and farmer field school methods, SRI use has been extended to cover 33,000 hectares. There are 95,000 farmers using the new methods, having small rice holdings averaging only about 0.4 ha.

Such results show how rapidly SR methods can be expanded when there is institutional support, sufficient (but not necessarily great) funding, and an appropriate philosophy and approach taken to farmers, engaging them as partners in ***adapting*** the concepts and practices of SRI to their own conditions, rather than as ***adopters*** of a fixed technology package.

- **Intellectual property rights:** Knowledge about and for SRI is in the public domain. SRI was developed by a French priest ***Fr. Henri de Laulanié, S.J.***, who devoted most of his life to trying to benefit poor rural households and communities (Laulanié 1993). The NGO that he established with Malagasy friends, ***Association Tefy Saina***, has sought to spread this innovation as widely as possible. ***Cornell International Institute for Food, Agriculture and Development*** (CIIFAD) provides an institutional base for acquiring and disseminating information on SRI experience and promoting research and evaluation of the methods. As an American land-grant university, its mission is to provide and apply knowledge for public interest and advancement. Farmers have also played active roles in spreading SRI knowledge to their peers and have been making further improvements in the innovation.
- **Institutional support:** There has been certain resistance or opposition to SRI from some scientific circles, mostly from international agricultural research centers -- not from the national agricultural research systems unless they were being influenced by IARCs. The **China National Rice Research Institute** and the **Indian Council for Agricultural Research**'s Directorate for Rice Research based on their own evaluations have become supporters of SRI methods. We have found it useful in many instances to have **non-governmental organizations** and **universities** as well as **farmer associations** and **private-sector businesses** involved in SRI dissemination along with **government research and extension** personnel. From the start, SRI has been '***civil-society innovation.***' We try to forge multi-sectoral, multi-institutional alliances to promote SRI when possible (Prasad et al. 2007).
- **Water control:** For best results with these methods, it is important to have capacity to provide deliveries of irrigation water in a timely way at the same time that total volume is reduced. The value of the resulting water savings can easily justify investment in both the 'hardware' and the 'software' of water management.

VII. **In Conclusion:** Much more information could be provided about SRI and about its extrapolation and extension to other food crops. This should be sufficient introduction for the Commission to consider. Reports concerning the country experiences cited above will be appended. As seen from the SRI website maintained at Cornell (http://ciifad.cornell.edu/sri/), SRI represents a unique kind of 'globalization.' SRI is opening up some significant possibilities for a more food-secure and environmentally-benign world that speak directly to the Society's interest in **biological approaches to enhance food-crop production**.

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SRI Experience in the Timbuktu Region in Mali

Africare, Bamako

In the Timbuktu region in Northern Mali, cereal production is in chronic deficit, sufficient for only 4.5 months of yearly consumption for typical households in the area. Three-quarters of the region communes are considered to be "structurally food-insecure," i.e., they face a food crisis at least once every two or three years.

This region, covering 497,926 km^2 (slightly more than 90% the size of France) comprises 40% of the total land area of Mali. The northern three-quarters lies in the Sahara desert, while further south, the climate transitions from Sahelo-Saharan to Sahelian. Rainfall is erratic in the south, ranging from 100 to 300 mm per year, insufficient for rainfed agriculture and making irrigation necessary.

Farmers in the southern part of the region practice either recessional agriculture, utilizing rainy-season flood waters as they run off and are absorbed into the soil, or deepwater rice cultivation along the many river branches, ponds and lakes seasonally flooded by the Niger River using water that is impounded or diverted. The extent of the annual flooding determines the amount of land under cultivation. This varies greatly from year to year. Yields from this traditional agriculture are low: <1 ton per hectare for rice or sorghum.

In recent years, farmers in the region have begun to exploit small-scale, village-based irrigation schemes that give them some assured water supply and a degree of water control. The NGO ***Africare*** has worked for the past 10 years with local farmers in the Goundam and Dire Circles to establish irrigation schemes of 30-35 hectares, the optimal size for irrigation from a single diesel motor pump. Rice yields range from 4 to 6 tons per hectare, with 80 to 100 farmers sharing the land under irrigation in such schemes. Average irrigated crop area available per household is about 1/3 of a hectare (0.83 acre).

These irrigation schemes have helped to improve the food-security situation in the region, and there is considerable potential for increasing the amount of land under irrigation and improving yields. Increasing the total area under irrigation would give more farmers access to land and increase the amount of land available to each one. In 2004, only 1/3 of potentially irrigable land in the Timbuktu region was partially or entirely irrigated, and only 9% had full water control.

With a poverty rate of 77% in the Timbuktu region, exacerbated by the chronic food insecurity and relative isolation, the greatest challenge is to increase food production at acceptable cost, so as to decrease dependence on food aid or on expensive imported food. Finding agricultural production methods that economize on water requirements is essential for further sector development. SRI is proving to be an appropriate and available response.

- SRI is available to any and all farmers willing to learn it, as it is based on knowledge and not purchased inputs. Indeed it decreases their dependency on outside inputs like fuel, pumps, fertilizers, and agrochemicals.
- SRI can reduce production costs: Needing less water per hectare for irrigation means reduced costs of pumping, and larger surfaces can be irrigated with the available water. Lower costs facilitate the expansion of small-scale village-based irrigation schemes, and enhance farmers' net income when production is raised at the same time.
- SRI increases yields per hectare dramatically, about 50% over best present practices, thereby improving food security. Most small farmers have access to relatively small plots. Substantial increases in the productivity of these small surface areas have a major impact on food availability and incomes.
- Greater food self-sufficiency decreases costly food imports into the region. Imported food, even food produced in other parts of Mali, is very expensive due to transport food over long distances on abysmal roads. Rising fuel costs are making transport more and more expensive.
- Long-term build up of productive and healthy soils is achieved through fertilization with animal manure and compost, allowing intensified crop rotation and off-season production of cash crops such as cumin, anise, and wheat. This is a major shift from current practices where no organic matter is applied, and farmers use fertilizer (urea) to achieve an acceptable production. Plots that are low in organic matter need 'quick-fix' chemical applications to produce satisfactorily year to year. Unfortunately, the amounts of fertilizer needed for this strategy rise year by year due to advancing soil degradation. SRI practices break the vicious cycle of soil degradation and chemical dependency, weaning the production system off the need for chemical and

expensive inputs, striving for a new balance between healthy, organically enriched soils and productive crops.

An initial evaluation of SRI methods in 2007 produced a yield of 8.98 tons/hectare, 34% more than the best use of conventional rice planting methods and more than double usual rice yields in the area (4.17 tons/hectare) that season (http://ciifad.cornell.edu/sri/countries/mali/MaliAfricare200708.pdf).

In 2008, 60 farmers in 12 villages in the Goundam and Dire Circles near Timbuktu are applying SRI methods and comparing it to their conventional practices throughout the 2008 cropping season. Seven Africare technicians provide technical assistance to ensure that the principles and recommendations of SRI are well understood and put into practice, appropriately adapted to local conditions. This is the first large-scale test of SRI in Mali. The varied experiences of these 60 farmers will provide data on SRI performance and potential and will serve as the basis for designing a sound strategy to expand SRI in the Timbuktu region. Two months into the growing season, the results are very positive and give us confidence that SRI innovations can be introduced here on a larger scale. For pictures and narrative, see my blog on this introduction: http://www.erikastyger.com/SRI_Timbuktu_Blog/SRI_Timbuktu_Blog.html

Dr. Erika Styger
Africare, Bamako
September 4, 2008

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

- Yes. The biggest single driver will be population growth. Estimates of global population are that stabilisation will be achieved later this century at between 7-14 bn. Other drivers include changing patterns in diet, diversion of grain to bio-fuel production, and climate (particularly water availability) and environmental change that will potentially threaten crop yields. These drivers have been factored into FAO projections of food supply by 2030-2050 (although there is some political influence on these numbers).
- Note: there are still many other barriers to trade and food distribution that contribute to hunger and which cannot be solved by production alone

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?**

- Replacing the current use of fossil fuels – limited supply and too expensive. This would impact upon fertiliser production, agrochemical production, tillage, crop processing (grain drying etc).
- Increasing food supply will require higher levels of production per unit area due to the limited supply of suitable cropland. To achieve this we need higher levels of NUE (Nitrogen Use Efficiency) and increased N use. It has been predicted that fertiliser N applications will need to increase from around 90 Tg currently to 230 by 2050 (Tilman et al., 2001). This poses major environmental problems because the amounts of N currently added to terrestrial systems are causing significant environmental impacts (Galloway et al., 2002;Galloway et al., 2004) The increase in N applications will lead to a significant rise in GHG emissions (Erisman et al., 2008) and therefore conflict with international agreements to reduce emissions

  NUE is difficult to quantify on a global scale, but there is an index called Partial Factor Productivity which is the ratio of grain yield to fertiliser N applied, and is easily calculated from global statistics and can be regionally disaggregated. Interestingly this index declines as systems become more intensive, and is lower in more "developed countries" than in developing ones (see http://www.regional.org.au/au/asa/2006/plenary/soil/dobermannad.htm). It might be assumed that the greater the efficiency of N uptake, the less the N2O emission (something we could look at in our data). So in trying to increase global food supplies whilst minimising N2O (or GHG) emissions, should we be looking at regionally diverse solutions? In very high input systems we could increase PFP by reducing fertiliser N, whilst conversely we could increase N inputs in regions of the world where inputs are currently very low and still achieve reasonable PFP ratios. Other factors such as climate, water land resources clearly interact, but it would be an interesting analysis.
- Making better use of "waste" materials for crop nutrition (includes food safety issues as well as better prediction of nutrient release characteristics)
- Micronutrient provision – sulphur but also Se, Cu, Co etc etc for both human and livestock nutrition
- Biological/ecological methods of controlling weeds (especially perennials), pests and diseases.
- Adaptation to climate change – development of suitable varieties (with relevant above and below-ground characteristics), new/changing pest and disease issues, cropping systems and rotations, maintenance/improvement of soil organic matter and soil fertility, agronomy associated with ability to grow different crops in a given region
- Education/knowledge exchange – there has been a loss of traditional husbandry skills associated with agronomy and soil management in developed countries. Continued development of appropriate farming systems in developing countries.
- Need for policy and advice to prevent degradation of natural resources (soil, water, air, biodiversity)
- Public understanding of food production
- Interdisciplinary approaches which meet the needs of the combined challenges of food production, environmental protection and adaptation to global change in the context of social and economic structures. Methodology for quantifying and valuing trade-offs.
- Needs Public-Private support – who is going to pay to create and deliver the advances in breeding and technology that we need?

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

- Sustainability traits; delivery of public goods; closed system farming
- Precision farming extended to the use of organic rather than predominantly inorganic fertilisers.
- Development of laser guided hoes and other technologies that will automate non-chemical methods of weed control. This requires the ability to separate crops and weeds in terms of both shape and colour.
- Improved understanding of the relationships between biology and function in soil organisms (micro and macro) will allow more targeted soil management for specific functions e.g. nutrient release from organic matter

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.

- GM technology/MAS - for some crop species, knowledge extensive and could be easily applied within relatively short timeframe – likely to be most successful for relatively simply inherited characters but combined with the power of MAS, could be used for complex characters. Note: caution over the adoption of a single approach to the issues – technological fixes in the relation to enhancing food production in the past have also generated externalities - needs to be placed in a systems context.
- Use of crop mixtures for yield stability, increased resource use efficiency and management of weeds, pests and diseases. Requires a shift in thinking from producers and processors, possibly technological advances in food processing.
- Use of new and innovative crop rotations – inclusion of "designer crops" for example for biofumigation, solubilisation of nutrients etc. Again requires a shift in thinking from a linear crop production focus to a network or systems approach
- Innovative use of different tillage techniques – for example, partial use of no-till combined with conventional tillage for different crops in rotation.
- Better integration of crop and livestock systems to improve resource use efficiency.
- Alternate husbandry in rotations on mixed farms were deemed to be sustainable for over 300 years, but were phased out when economic farming with high input mineral fertilisers and pesticide availability became the expectation. A full return to these systems is unlikely to be realised, but there is a wealth of information to be gained from them to improve on the systems that exist today with a view to making them more sustainable if not as annually productive. Timeline would be dependant on support structures and consumer realisation of the actual costs of food production under these systems.
- Using potential food as a fuel source is a controversial issue, but the use of biomass in anaerobic digesters to generate methane for electricity generation as well as exhaust heat recovery for home heating is available now. The waste from these systems is also still nutritionally valuable as ideally only the carbon derived from recent photosynthesis is driven off. Developing a better understanding of how to best use digester waste to derive the optimal nutritional value from it remains a challenge to science. Provision of the biomass to these digesters faces some challenges too, especially while grain production remains profitable, however, alternate waste streams do exist (food, animal carcasses, municipal green waste, sewage). Exploitation of some of these is currently limited due to regulations regarding potential health issues. Re-evaluation of the extent of threat to human health or re-assessment of the benefits derived from such systems should be undertaken. The technology is available now and all that is needed to implement these systems is more easily secured capital investment plans (difficult under current economic climate), better access to the national grid (difficult on the existing aged system) and local government approvals.
- Biological enhancement of free N fixation through the application of biologicals has been widely applied in some parts of the world for decades. There is evidence of vast benefit of this technology to crops of sugar cane, maize and rice. There remains several challenges to the application of this technology; (i) it remains difficult to match good symbionts, endophytes or associated free N fixers to particular crops, (ii) effective behaviour and outcomes in different environments remains impossible to predict, (iii) several of the previously investigated genera have now been abandoned as other species within the genera are potential animal and human pathogens, and (iv) much of the current work is directed at genetics of these organisms rather than field based practical applications. See http://nfix2008.psb.ugent.be/files/Abstractboek8ENFC.pdf

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).

- Trait desirability and delivery is difficult to address. Global warming, climatic changes, nutrient and water availability, and ownership are likely to be the major decision drivers in this debate. In terms of delivery of whatever traits are deemed desirable then the way in which those traits are introduced is likely to have the largest impact on delivery. Genetic modification allows new traits (e.g. herbicide tolerance and insect resistance) in cotton to be introduced and become commercial within 5 to 9 years, where as conventional breeding for a desired resistance trait in wheat would be based on a 20-25 year program. The continued lack of acceptance of GM by large parts of Europe and the subsequent influence this has on many other nations (Bodulovic 2005) is likely to be the major influence on the rate of introduction of new traits.

- N uptake efficiency; N use efficiency; new pest and disease resistances; resistance to climate-induced stress (eg. improved fertility)
- Resistance to drought or water-logging.
- Ability to access more of the soil profile for nutrients (and water) – requires increased rooting depth and branching.
- Arable crops e.g. peas with earlier maturity allowing them to be grown in shorter growing season areas i.e. further North. Particularly important for livestock production (monogastric and ruminant).
- Plant breeding has predominantly concentrated on yield and the ability to produce yield under good growing conditions. There will be a greater need for reliable production in less ideal/predictable conditions.

6. Which current/future husbandry or farm management technologies for the enhancement of food-crop production are appropriate for development and dissemination and why? Comments could include information on the benefits they may bring, difficulties in scaling up their use in different parts of the world and time needed to get improved methods incorporated in farm practises.

- Overlap with question 4…
- There is a still a need even in developed countries to improve awareness and understanding of soil and manure management. For example, many farmers still treat manures and slurries as waste products rather than products with a fertiliser value allowing fertilisers purchases to be reduced.
- Advisory structures need to be introduced, maintained or even re-introduced.
- Mixtures (with the necessary changes in testing and regulation), inter-cropping and improved rotation design are all important in horticulture and agriculture.

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?

- GIS sensing for both crop and soil
- Engineering should allow automation of manual weed control systems.
- Engineering – automated harvesting of horticultural crops as individual plants ripen and dealing with mixed varieties or even species.
- Engineering - Improvements in design of protected cropping structures to make better use of non-renewables including use of waste heat etc

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.

- Initial conversion to a more biological system might initially reduce yields. Estimates range greatly from a few to 40%, but the same could be said for the current predictions on pesticide reduction under Directive 91/414/EEC. See http://www.pesticides.gov.uk/uploadedfiles/Web_Assets/PSD/Impact_report_final_(May%202008)(1).pdf
- Prices are likely to rise or remain at their current elevated status if real production costs have to be met by consumers.
- The environment would be likely to benefit from enhanced biological farming both in terms of reduced 'waste' going to landfill and reduced excess mineral fertiliser application and the potential for leaching and eutrophicaiton events.
- Farmers are likely to find that expected yield reductions will result in lower profit potential, but gross margins should increase. Bank rates and level of debt carried by a farm would also have an impact on a move into a more biological system.

- It is likely that an agricultural system more reliable on biological processes and applications will result in more diverse crops being taken and possibly alternate animal stocking to be considered. This might very well lead to a more diverse rural landscape than is currently experienced, which may or may not have other associated gains in terms of supported biodiversity and ecosystems functions.

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.

- Public goods must be valued equally with economic/market benefits
- Regulatory controls (PVR/Concept of variety/IP) http://www.genomicsnetwork.ac.uk/forum/events/pastevents/workshops/title,3513,en.html
- Research infrastructure/skills base – there are well-recognised shortages of trained personnel in weed science, agronomy and soil science. Current education systems have resulted in scientists specialising at an early stage of their career and thus there is a critical shortage of scientists with the ability or desire to work at the systems level.
- Long-term research platforms with the facilities for applied research are currently rare. These need to have the backing of effective and efficient sample and dats-archiving.

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CropLife International

CropLife International recognises the serious challenges posed by the need to feed, clothe and provide fuel for a growing population; these challenges will be exacerbated as a result of climate change. Meeting these needs in an affordable, environmentally sustainable way can be effectively addressed through the proper mix of modern and traditional technologies. While technology has an important part to play in achieving food security, it can only bring its benefits to bear in a context of larger change and in combination with other tools and techniques.

A recent UN report said that 820 million people in developing countries suffer from hunger, and this number is expected to increase as the global population grows. It is estimated that food demand will increase by 50 percent by 2030 and meat protein demands will increase in particular. These challenges are further compounded by climate change, where agricultural sustainability may be threatened by drought, changes in rainfall, temperature increases, floods, and soil degradation.

1) Plant science is already contributing to meeting global food needs

Improving yields

Since the 1950's, new technologies, crop protection products, hybrid seeds, and biotech crops have allowed maize crop yields in developing countries to rise more than 160 percent and almost 130 percent in developed countries. Studies in India and China showed Bt cotton has increased yields by up to 50 percent and 10 percent respectively.

Increasing yields also help ensure food remains affordable. Without those gains in yields, world cereal prices would have been 18–21 percent higher in 2000; caloric availability per capita in developing countries would have been 4–7 percent lower and 13–15 million more children would have been classified as malnourished.

While these types of economic benefits are well substantiated, the socio-economic benefits associated with biotech crops are starting to emerge. A study of 9,300 Bt cotton and non-Bt cotton-growing households in India indicated that women and children in Bt cotton households have slightly more access to social benefits than non-Bt cotton growers. These include increases in pre-natal visits, assistance with at-home births, higher school enrollment for children and a higher proportion of children vaccinated.

Improving adaptability

Plant breeding, whether conventional or through biotech techniques, is enabling farmers to grow crops that combat environmental stresses such as insects and viruses, and to control weeds more effectively.

According to the World Bank, in the 1980s and 1990s, improved varieties were estimated to have accounted for as much as 50 percent of yield growth, compared with 21 percent in the preceding two decades. Impoverished consumers and resource-poor farmers have been the main beneficiaries of these yield increases. For example, Chinese farmers planting biotech herbicide-tolerant cotton realised a three-year average yield increase of 24 percent and net income returns of $332/hectare. Farmers who adopted this same biotech variety of corn in the Philippines have seen their net incomes rise by 34 percent on average.

Protecting natural resources

Through yield increases, plant science has helped protect non-agricultural land from encroachment. This is essential to protecting wildlife through the preservation of its habitat, but also important as a means of maintaining carbon sinks. As a result, although the world's population has grown significantly in the last 40 years, the area of land devoted to food production has remained virtually constant. Parts of Asia, for instance, doubled their cereal production between 1970 and 1995, yet kept the total land area cultivated with cereals to an increase of only 4 percent. To continue to limit agricultural encroachment, it is important that science and technology continue to provide solutions for increased productivity.

As well, the combination of crop protection products and biotech crops has significantly helped advance conservation agriculture as a means of restoring and protecting soil and limiting erosion. It is estimated that conservation agriculture can reduce soil erosion by 50 to 98 percent while also reducing greenhouse gas emissions by 80 percent through reduced oxidation of soil organic matter.

2- Plant Science can help meet the challenges of the future

Meeting the challenges of the future requires building on existing successes and bringing about the innovations that can help address new challenges.

Building on existing successes

Focusing on replicating and scaling up existing solutions could help address many of the challenges to food security the world faces. For example, certain key crops in some regions of the world reach only 20 percent of the level of the productivity that is enjoyed elsewhere. Closing only half of that gap in yield would revolutionise the relationship between agriculture and biodiversity, as well as helping to alleviate poverty. This could be done through improved access to key inputs, including fertilisers, seeds, and pesticides combined with better training of farmers to maximise the efficiency of these inputs and ensure safety and sustainability.

Biotech crops have already been taken up at a steady pace over the past 12 years, bringing important benefits to those who have adopted them. Today biotech crops are cultivated in 23 countries around the world, with more countries in the developing world joining the early adopters at a regular pace. More than 11 million resource-poor farmers in developing countries are currently growing and benefitting from biotech crops. In Asia, smallholder farmers are realizing economic gains from growing high-yielding biotech cotton, and in Africa, more countries are recognizing the potential food availability the technology can bring. For the first decade of biotech crops' history, South Africa was the only country growing biotech crops — this year alone, we have seen commercial adoption in Egypt, field trials in Uganda, and field trials are expected in Burkina Faso, Malawi, and Kenya next year, with many other countries following suit and developiong biosafety regulations. Helping build capacity with government and regulatory authorities, as well as with farmers, is an important step to ensure the benefits of biotech crops are scaled up.

The key to improving access to existing solutions lies in setting up successful collaborations along the value chains with the different stakeholders. The industry can bring its know-how and technology, and assist in providing training but it needs partners to be able to reach out to more farmers.

Bringing about innovation

In addition to building on existing knowledge, investing in the development of new products and technologies is a means of improving our response to current challenges and our capacity to meet new ones.

The industry has been at the forefront of innovation for decades. Existing biotchnology-derived crops, such as herbicide tolerant and insect resistant crops have already contributed to improving production. But plant science firms are already carrying out research that will develop seeds that produce plants that have increased tolerance to drought, heat, and soil salinity. Researchers around the world, both in public and private institutions, are working to develop crops that can survive — and thrive — with less water. New products can take a long time to come to market, but the industry is now very close to being able to launch some of its first stress-resistant crops.

Besides improved seeds or climate-tolerant crops, biotechnology can also contribute to addressing health challenges aroung the world. Over the past fifty years, the increased availability of fresh produce has been crucial in helping people diversify and improve their diets, contributing to improving their health. There are still too many people who do not have access to basic staples in sufficient quantities, let alone enough fruit and vegetables. Although this is not solely a matter of quantities produced, with a growing population and changing climate, meeting the goal of improving people's access to varied, safe and affordable food is becoming a greater challenge. In addition to helping raise productivity and protecting crops, innovation could help produce better crops with specific health benefits. Fruits, vegetables, and grains fortified with vitamins, antioxidants, and minerals can help address health risks around the world. Nutrient-enhanced crop varieties will enable farmers to produce crops that are more healthful and provide consumers with additional nutritional content.

Combined with improved seeds and crops, research is allowing the industry to also develop better crop protection products. Improved formulations and application methods can help make these products more effective and safer. This is particularly important as many farmers may have access only to limited inputs, so ensuring products are always as efficient and safe as possible is an important part of helping farmers feed their families and communities.

3- A holistic approach

The methods offered by the plant science industry do not conflict with traditional agricultural techniques. CropLife International believes that modern technologies should be integrated into other styles of farming, ensuring farmers have access to the best tools for their land and choice of production systems. We need complex solutions to complex problems, and this requires broadening the range of choices available to farmers rather than limiting it. The products and technologies made available by plant science should not be seen as 'stand alone'. To ensure sustainability and to maximise their potential, they must be part of an Integrated Crop Management (ICM) approach to farming.

No matter how innovative or useful the products our industry offers, the measure of their success is in ensuring not only their successful development, but also their uptake by those they can benefit. Tools are only useful if they can be used. This requires better public-private cooperation and a strong political commitment.

Appropriate policy that encourages research and the subsequent dissemination of the technologies and strategies must be implemented. Such a framework would include access to new technologies and inputs that will make it possible to increase productivity sustainably.

In addition to products and technologies, also needed are:

- support for research;
- development of appropriate regulatory infrastructure to approve new biological approaches in a timely manner;
- extension and agronomy programming;
- training in responsible and effective handling and use of products;
- enforceable regulations that protect intellectual property, without limiting farmers' access to technology; and
- trade policies that facilitate access to goods, services, information and markets.

In addition to providing farmers knowledge and inputs to improve productivity, investments are needed to provide access to markets so that farmers can profitably sell their increased production. There must be investment in research and extension services in the public sector, in education, in basic infrastructure such as roads, in ICTs and financial services. Partnerships will be essential to bring together the financial means, expertise, and knowledge necessary for these investments to occur. Without such investments, farmers will not be able to benefit from the tools, products and technologies made available through plant science.

Department for Environment, Food and Rural Affairs

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

There is a broad consensus that rising global demand for food means that global agricultural production needs to increase. The global population is growing at the rate of about 6 million each month and is projected to reach around 9 billion by mid century. FAO, World Bank, IAASTD and OECD all estimate that global food production needs to rise by the order of 50% by 2030, and in effect double by 2050, to meet the demand of a rising world population. There is also a trend in developing countries, as they become more affluent, for a greater demand for meat and dairy products, putting further pressure on the production of grain and other commodities used to feed livestock. Climate change, increasing volatility in global commodity and food prices, higher energy, oil and fertiliser prices and alternative pressures on land most notably for biofuel production also affect how and where food may need to be produced in future and the resilience of food supply chains. Ultimately, global food supply underpins UK availability and prices.
At the same time, there continues to be a need to limit the negative impacts of farming and food production on the environment, including devising strategies to mitigate and adapt to climate change, minimising greenhouse gas emissions per unit of product, preventing pollution and the degradation of natural resources and protecting biodiversity. Especially in developed countries, these aspects are an increasing influence on food purchasing and consumption and indicate the need to develop sustainable farming systems that balance requirements for food production, environmental considerations and societal acceptance.

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

There is a vital role for agricultural science and R&D on crop improvement generally, through breeding, husbandry and crop protection, both in developed and developing countries. However, increasing food production needs to be managed in an environmentally sustainable way, avoiding pollution, habitat or biodiversity degradation associated with intensification, and conserving natural resources for the benefit of future generations. It is essential that reductions in environmental and climate change impacts in developed countries are not negated by the effect of simply moving production elsewhere. Future challenges from climate change include water scarcity across many regions, although northern Europe may be favourably placed for cereal and other arable crop production. The UK (as part of the EU) is subject to these global considerations and has a contribution to make by encouraging a thriving and productive domestic agricultural sector, responding to market demands and to consumer concerns and requirements, that continues to produce a significant proportion of our food. Currently, the UK is 60% self-sufficient (over 74% in foods that can be produced in this country) - *Defra 2008: Ensuring the UK's Food security in a changing world.* However, self-sufficiency does not protect against adverse weather events, crop failure or disruptions in supply chains; maintaining some diversity of food supply can contribute to food security and international markets for developing countries require consideration.

UK farming therefore will need the capacity to respond to these future climate change, market and price volatility challenges while at the same time seeking to minimise the environmental impact of food production. Central to this will be more efficient resource use in the production of commodity requirements e.g. improving useable yield and quality while reducing inputs and overall greenhouse gas emissions per unit of production and reducing waste.

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

Although global food demands are rising, on-farm yields of many crops do not seem to be keeping pace; increased production would therefore require more good quality land in cultivation (likely to be in short supply). Until now, ongoing development of higher yielding varieties and better crop management has produced incremental gains per hectare. Historically, crop improvement through breeding, better husbandry and protection from losses from pests, diseases and weed competition has largely used empirical approaches but with increased genetic, biochemical and physiological knowledge it will increasingly be possible to understand interactions and trade-offs between efficient resource use and productivity and to target improvements. On this basis, it should prove possible to raise yields towards their theoretical biological limits, aided by innovations in agronomy, systems design or methods of reducing the impacts of biotic factors (pests, diseases, weeds). In particular, the ongoing expansion of knowledge of plant genetics and biotechnology (genomics, gene mapping, use of genetic markers etc) is allowing the more rapid selection of pre-breeding material with agronomic or environmentally desirable traits and its use by commercial breeders in developing high yielding but more resource efficient crop varieties. Breeding for durable host plant resistance to crop diseases and pests can reduce the dependence on pesticides and allow development of integrated pest management (IPM) approaches e.g. in combination with biological control methods and more targeted use of lower pesticide doses. The development of resistance to certain pesticides is diminishing the effectiveness of control measures. Further developments in IPM are needed, especially if changes in EU pesticide regulations result in fewer approved products for future use. Climate change and trade liberalisation may lead to new disease and pest problems, including any associated with new crops, that control measures will be needed to combat.

Genetic modification (GM) could, in time, make a significant contribution to crop improvement. Realisation of the full potential of this technology will depend on it successfully delivering a range of new crop traits, going beyond the existing herbicide-tolerant and insect-resistant GM varieties that are grown extensively at present elsewhere in the world. It is known that new GM traits such as drought-tolerance and disease-resistance are currently being developed. If these work and have no adverse impact on people or the environment, their responsible use could help to make crop production more efficient and sustainable. Of course, GM will not be the only way of achieving crop improvements. Traditional breeding can be targeted, and to an extent accelerated, by many of the technical advances associated with the expansion of crop molecular genetics and biotechnology, such as marker assisted breeding. However, it is conceivable that it may only be possible to produce certain traits using GM, or that this approach may be the most efficient and quickest means of doing so.

GM crops and foods are subject to specific EU regulations (see annex). The current operation of these reflects the controversial nature this technology has assumed within Europe, which has influenced its public acceptability. As yet there has only been relatively limited commercial GM crop cultivation in the EU, with none in the UK since those crops/traits approved have no agronomic advantage in the UK.

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 benefit from these approaches to be seen.

Genetic and crop management improvements could increase yield potential by breeding and agronomic practices, reduce losses and meet quality and other standards required by purchasers/consumers; and provide technical innovation and economic optimisation of farming systems (including precision farming, integrated crop management, maintenance of soil physical, chemical and biological properties, higher energy efficiency in cropping systems and increasing efficiency during food processing to avoid waste e.g. through greater use of co-products or developing new products). The more fundamental R&D supported by Research Councils will underpin and contribute to this progress provided adequate translational research is encouraged and maintained over the next 10-30 years, leading to practical application by the farming community. Examples include: improved understanding of nitrogen use physiology in crop species, leading to improved use of fertilisers, and organic manures (in short term) and development of N-fixation in non-legume species (longer term); improving water management by breeding and in cropping and irrigation practices; greater utilisation of traits from model plants, wild relatives and cultivated crop genebanks in crop breeding through conventional breeding (medium term) or potentially genetic modification (longer term); ensuring effective crop protection in the long term by integrated crop protection supported by better understanding of pesticide resistance and increased use of natural enemies/biological control.

The scientific challenge of delivering the global productivity is ambitious and should not be underestimated. Biological limits may restrict the continual improvements in yield that have been achieved over the last 50 years. In addition to scientific approaches there is scope to increase overall productivity and efficient use of resources in developing countries by better dissemination of existing and new knowledge and measures to reduce wastage in the food chain.

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).

For our most widely grown arable crop (winter wheat) there are a number of potential improvements largely through genetics, but also supported by agronomic practices: better nutrient use efficiency by the growing plant and its root system (reducing fertiliser application and better utilising soil reserves and organic manures); water capture (adapting to water stress and shortage closely linked to climate change); physiological improvements optimising growth and partitioning of dry matter to grains (through early development, delayed senescence, better light conversion) and durable protection against diseases and pests. Similar improvements to nitrogen conversion, rooting, light conversion by the crop canopy, durable protection against pests and diseases and reduced harvest losses are feasible for oilseed rape, the main break crop in cereal-based arable rotations. In the next decade, modest yield improvements exploiting varieties in development and better uptake of crop management practices are feasible (e.g.10% winter wheat; 15% oilseed rape). Significant productivity and resource use efficiency improvements, without environmental detriment, for all crops over the longer term would require a substantial investment in R and D. Improvement in vegetable and fruit crops could contribute to better nutrition and human health (e.g. as part of "5 a day" diet items).

Which current/future husbandry or farm management technologies for the enhancement of food-crop production are appropriate for development and dissemination and why? Comments could include information on the benefits they may bring, difficulties in scaling up their use in different parts of the world and time needed to get improved methods incorporated in farm practices.

See above (and next section).

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?

Further advances and uptake of technological advances in GPS mapping, sensor technology, sampling, data collection and automation, supporting "precision farming" will continue to contribute to more efficient management of soils and crop inputs and reduction in waste. Similarly, improved decision support tools will be produced for use by farmers and advisors. The potential expansion of non-food crops (for energy or renewable materials) may compete with food production but there are also opportunities in these areas for greater use of co-products from food crops. The potential for nanotechnology, robotics and novel technologies for energy use efficiency, refridgeration, food processing and preparation, including advances in nutrition, diet and health will also impact on primary production.

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; e) any other areas you think relevant.

Increased production of key food items grown in the UK could be achieved by enhancing crop yields per hectare, without an increase in area of cultivated land. This would need to be through optimising use of nutrient, water, energy, crop protection inputs (per unit of product) in order not to increase the environmental footprint of agriculture. More intensive farming could increase risks to biodiversity but, with greater yield per hectare, some (poorer) land might be released for farm habitats to offset losses. Effects on world food prices would depend on fluctuations in global markets but reduced dependence on inputs (also subject to world prices) would improve UK farm profitability and competiveness with overseas producers. Genetic improvement of crops, either by conventional breeding or through GM , is able to raise the quality of produce or products for higher value markets and also contribute to nutritional content and health of human or animal diets.

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.

Sufficient public and private R&D investment, especially research to ensure more basic or strategic work can be taken forward into practical application. Defra LINK programmes have been involved in addressing areas of joint interest defined by industry but additional collaborative R&D would be needed to enhance food production while reducing environmental impacts and adapting to climate change or developments in international trade. There is ongoing discussion with the Technology Strategy Board to broaden the basis of collaborative R&D funding across the range of government interests and industry in the agri-food chain. Pre-breeding work leading to crop varieties with public good benefits (resource-use efficient; reduced environment footprint; resilient to climate change; improved nutritional quality; durable resistance to diseases) has been supported through Defra's crop genetic improvement networks but needs to be taken forward by projects involving public-private partnerships with commercial plant breeders.

Profitability in the market at levels high enough to cover costs of new variety development is an issue with plant breeders. Current returns (plant breeders rights etc) do not always allow small firms to benefit from additional investment in genetics and biotechnology. Some breeders would like GM to be a commercial option and feel regulation is a barrier but they are also conscious that in UK and EU there will be no immediate market until there is broad societal acceptance for GM crops or food.

New crop protection options will also be necessary to combat loss of efficacy from pesticide resistance and in response to new pests and diseases, especially if EU regulations under review further reduce the number and types of approved products.

The adequacy of the skills base will be important both in the interdisciplinary activity essential for conducting the work to integrate improved crop genetics, physiology, soil science and crop management and for subsequent knowledge transfer to farmers and advisers. The agricultural scientific community or employers may need to raise esteem in society generally, and career prospects, for those working on exploitation and delivery of science rather than in fundamental research.

EUROPEAN UNION (EU) CONTROLS ON GM CROPS AND FOODS

1. Under EU law, genetically modified organisms and foods or feeds made from them cannot be released into the environment or marketed without prior official consent. The cultivation of GM crops for research or trial purposes is controlled by EU Directive 2001/18. Decisions on whether to approve such releases are taken at national level. The commercial import or cultivation of GM food or feed crops, and the marketing of the food and feed products made from them, is controlled by EU Regulation 1829/2003. In this case, approval decisions are taken at EU level, using a system of qualified-majority voting.

2. The general principle of the EU controls is that GM crops or final products will only be approved for release if a risk assessment indicates that there should not be any adverse effects on human health, animal health or the environment. In the case of final food or feed products, there is also a specific requirement that the product in question must not be nutritionally disadvantageous to humans (in the case of food) or animals (in the case of feed).

3. Anyone applying for approval to release a GMO or market a GM product has to provide a comprehensive dossier of risk assessment information. This must address the detailed assessment criteria laid down in the legislation, which cover all the conceivable safety factors that might arise. If the application dossier is for commercial marketing of a GM food or feed product it is evaluated by the European Food Safety Authority (EFSA). If the scope of the application includes commercial cultivation of a GM crop, EFSA will normally ask a Member State competent authority to lead on the evaluation of environmental risks.

Difficulties with the EU regime

4. There is no political consensus in the EU on the issue of GM crops and foods. Because of this, the assessment and decision-making process for GM products operates very slowly. EU votes on GM marketing applications are normally inconclusive, with no clear majority of Member States either for or against. On average it takes about 2 years to secure an EU approval, and some applications to cultivate GM crops have been stuck in the EU pipeline for much longer. Defra has been arguing for the operation of the EU regime to be streamlined as far as possible, so that unnecessary and unjustified delays can be avoided.