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By Joyce Tait & Guy Barker

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Food security has recently become an issue of serious concern because global food supplies are potentially threatened by an impending systemic collapse. An increasing demand for food caused by global population growth and changing life-styles in developing countries, coupled with global climate change and competition with biofuels are combining to create what is being called the 'perfect storm' (Godfray *et al.*, 2010). Moreover, short-term weather patterns leading to floods and droughts - and associated fires - in major grain-producing areas of the world encourage **[OK]** speculation in agricultural commodities and cause wild price fluctuations. Drastic price hikes for staple foods during the past few years have triggered famine and revolts in developing countries, where people are hit hardest (Henn, 2011). **[OK]**

Against this background, basic research **[OK]** into plant, animal and microbial physiology and molecular processes has yielded extensive knowledge about plants, their pathogens and symbiotic partners. Scientists and policy makers are confident that the application of this knowledge could lead to new and more efficient approaches to crop production that will eventually improve food security. In this context, Europe has a particularly important role to play, as it contains highly fertile areas of land and is agriculturally very productive. **[OK]**

However, European countries find it difficult to respond constructively to the challenges listed above, given their divergent opinions on how to address food security issues, particularly in terms of if and how science and technology should be part of the solution. Individuals and interest groups opposed to genetic modification (GM) and related technologies have had an important influence on policy decision-making in agriculture. **[OK]** Unfortunately, the European Union (EU) has yet to develop a coherent approach that allows European citizens to reap the benefits of scientific progress while preventing the domination of decision-making processes by special interests. European regulatory systems, rather than scientific progress **[OK]**, will therefore determine whether technology-based solutions are available as part of the future of agriculture within Europe itself and in many other countries. This essay explores the link between regulation and innovation in the context of food security within Europe and considers the impact of European policy on the ability of other countries to respond to food security challenges.

Foresight and horizon scanning are important tools for developing **[OK?]** government policies and planning. They help determine both the level of investment into scientific research and the policies to facilitate the application of knowledge. Unfortunately, for more than a decade, the prevailing policies in Europe have been either negative or neutral towards innovation for agricultural production. This has led to a situation in which there is both a lack of availability of new GM crop varieties for European agriculture and an unreceptive environment for their application (Wamae *et al.*, 2011).

Two recent Foresight reports from France (INRA and CIRAD, 2009) and the UK (The Government Office for Science, 2011) have dealt with the looming food security crisis. The conclusions that each draws clearly reflect the differences in national perceptions, in particular the expected role of biotechnology in addressing the problems. The French Agrimonde report considered two scenarios. Agrimonde GO, describes a global free-trade economy that permits the rapid diffusion of new technologies and an expanded area of biomass production for biofuels. Mechanised, industrial farming is the norm, supported by GM crops, with plant and animal production controlled largely by multinational companies. In contrast, Agrimonde 1 describes a suite of policy options at national and international levels–including strong regional planning policies to limit the ‘artificialisation of the land'–supported by 'massive aid' and regulated by a new United Nations organisation to avoid distortions in competition and food price volatility. Innovation in this case is seen as a process of 'ecological intensification': an alternative to modern agricultural systems that steers ecological processes rather than controls them. The authors of the Agrimonde report favoured the Agrimonde 1 scenario, perhaps influenced by French public support for small family farms.

While efforts such as ecological intensification are laudable, the required policy approaches have so far eluded the combined efforts of numerous national and international agencies and NGOs. It would therefore be unwise to rely entirely on something like the Agrimonde 1 scenario to guarantee food security. Likewise, the Agrimonde GO scenario is unlikely to exist in the extreme form presented in this report. The rapid diffusion of new technologies, along with mechanised farming and GM crops–whether or not these are controlled by multinational companies–are likely to be needed to meet future challenges in agriculture. However, there is no reason why such a scenario could not include measures to foster biodiversity on non-cropped land areas (Tait, 2001a); indeed, more productive GM crops could actually foster better co-existence between intensive agriculture and biodiversity (Dewar *et al.*, 2003; National Research Council, 2010) and future biotechnologies could be even more effective in this respect if policy was used to drive innovation in that directrion. Ultimately, the French approach –setting up two extreme Agrimonde scenarios with the apparent aim of forcing choices - rarely delivers a viable basis for decision making, although it can influence attitudes.

The UK Foresight report 'The Future of Food and Farming' (The Government Office for Science, 2011) analyses the predicted pressures on the global food system up to 2050. The five key challenges addressed in the report are balancing future supply and demand sustainably, addressing the threat of future volatility in the food system, ending hunger, meeting the challenges of a low emissions world, and maintaining biodiversity and ecosystem services while feeding the world. The report identifies in broad terms the policy decisions to ensure that the growing **[OK]** world population can be fed sustainably and equitably and recognises the failings in current food production systems. It identifies priorities for action, including **[OK]** investment in new technologies–including genetic modification, cloned animals and nanotechnology–which are regarded as essential and which should not be excluded on moral or ethical grounds. The need to respect the views of people with contrary opinions is recognised, but so is the need to keep open policy options and to make decisions about the acceptability of new technologies in the context of competing risks and the costs of *not* utilising these technologies.

The UK report is more pragmatic in tone than Agrimonde and more accepting of technological solutions to some food security problems. Among many other things, it proposes using technology to improve global food security in ways that will not necessarily lead to environmental devastation. Indeed they could lead to better environmental performance than current conventional farming systems without making unrealistic demands on national and international governance regimes.

The EU has also recognized the problem of food security. It announced an initiative on Agriculture, Food Security and Climate Change, to be led jointly by the National Institute for Agricultural Research (INRA) and the UK Biotechnology and Biological Sciences Research Council (BBSRC) (INRA, 2010; Willis, 2010). It is **[OK?]** one of several Joint Programming Initiatives (JPIs) that pool national research efforts to make better use of financial resources for research; in this case, more than €1 billion annually. However, given the differences in the national cultures and agendas of the two leading partners outlined above, and the diversity of views among the other partners, this JPI may find it difficult to achieve a single voice and deliver the expected improvement in resource use efficiency.

If we were to adopt a more technology-oriented approach to guarantee future food security, it would need to include targeted research on modern crop and animal science, agro-ecology, agricultural engineering and aquaculture management (The Government Office for Science, 2011). In addition, the UK Foresight Report refers to long-term advances, such as the development of perennial grain crops, the introduction of nitrogen fixation into non-legume crops, and re-engineering the photosynthetic pathways of different plants. Consequently, investing in basic science remains an important priority, as does ensuring that the regulatory environment does not unnecessarily constrain the translation of knowledge into new products and processes.

The currently available technologies, particularly GM, are already making a significant contribution **[OK]** to global food production. Outside the EU, the global cultivation of transgenic crops is expanding rapidly. The increase from 1.7 million hectares in 1996 to 148 million in 2010 makes biotech crops the fastest adopted crop technology in the history of modern agriculture, now covering 10% of the world's croplands (James, 2010). Depending on the crop and the farming system, GM crops are already contributing to increased yields, greater ease and predictability of crop management, a reduction in pesticide use and fewer post-harvest crop losses (National Research Council, 2010).

Nevertheless, significantly more research is needed to generate a broader variety of crops to address future changes in farming systems (Fig 1). Current developments already promise [OK] a wide range of improvements related to food security, including yield increases, better nitrogen uptake efficiency, improved heat, salt and drought tolerance, improved root growth, cold germination and timing of flowering. By way of example of how more knowledge and better genetic modifications benefit agriculture, Jiao *et al.* (2010) have developed a new rice variety by mutating a gene that affects plant architecture increasing yield by 10%. Another example is submergence-resistant rice, which could be of substantial benefit to many developing countries.

In addition to GM crops that contain transgenic modification–that is, genes from different species–technological and scientific advances are drastically improving the efficiency of traditional plant breeding (Table 1). In an ideal world, such techniques would be used together with GM and other approaches that provide a suite of techniques from which researchers can pick the one that is best suited to their needs **[OK]**. However, scientists in the EU may find themselves in a situation in which they can only use non-GM techniques because this is more likely to be funded or because the eventual product is less likely to be delayed in the regulatory system or rejected altogether.

The regulation of GM crops and related biotechnologies has been the trail-blazer for a general shift in policy style in Europe since the 1980s. There has been a move away from top-down *government* to more bottom-up *governance*, with the underlying assumption that this will lead to more democratic decision-making. The governance approach is characterised by **[OK]** the involvement of non-government actors, an increasingly complex set of state-society relationships, and a blurring of the boundaries between the public and private sectors. The role of the state changes from being the main provider of policy to facilitating interaction between the various interested parties (Lyall & Tait, 2005).

Along with the rise of governance as a basis for policy decisions, the 1980s saw a change in the regulation of new technologies for agriculture and food production in the EU. Under the previous *government* approach, regulation had focused on the final product and potential adverse effects on human or environmental health. Starting in the mid-1980s, the precautionary principle–that had originated in German planning law (von Moltke, 1987)–was increasingly advocated as the basis for the regulation of new technologies **[OK]**. An influential report from the UK Royal Commission on Environmental Pollution (RCEP, 1989) supported the precautionary principle as the basis of the regulation of GM crops, in line with a general trend in GM crop regulation in Europe (Tait & Levidow, 1992).

As the European regulatory system for crop biotechnology has been changing, new requirements have been added and their application extended to new areas. For example, even if a new crop variety has no GM traits, the full regulatory system for GM crops–which costs on average €6.8 million–is still applied if the development of the variety involves a GM step (Table 1; Schaart & Visser, 2009). These costs seriously restrict **[OK]** the development of new crop varieties using GM techniques; a situation that would be justified only if there was evidence of a proportionate degree of risk. Moreover, case-by-case regulatory scrutiny has been interpreted to the point that every variety of a crop into which a similar GM event is introduced is subject to the full regulatory regime (EFSA, 2010). Separation distances to avoid contamination of organic and conventional crops with GM produce are governed by a standard which bears no relation to any risk to people or the environment and which was strongly influenced by the organic farming lobby.

The synergistic interaction between the governance-based approach and the precautionary principle has exposed decision-making on the regulation of GM crops to influences from politically motivated conjecture to a much greater extent than ever before. The result has been a much greater restriction of plant biotechnology in Europe than in other parts of the world, despite lack of evidence of any **[OK]** *direct* risks to anything **[OK]** from the wide-scale adoption of GM crop technology. *Indirect* negative impacts, of the type that will arise from any interventions in complex agricultural systems, are usually outweighed by the benefits (Park *et al.*, 2011; Smythe *et al.*, 2011, in press).

The cost and complexity of the EU regulatory system for GM crops, along with the lack of evidence of harm to people or the environment, is generating pressure to change regulatory systems to make them more directly risk-based and take into account potential benefits (Kuiper & Davies, 2010; Schaart & Visser, 2009). However, in Europe and other parts of the world, advocacy lobbyists and individuals with an ideological anti-GM agenda retain considerable influence with policy makers.

Public engagement is seen as an essential component of the governance approach. From surveys to focus groups to citizen juries, GM crops have probably been engaged with more than any other technology, but this has not helped to build societal consensus in Europe. For many of the public stakeholder groups that are involved in the dialogue about GM crops, the conflict is ideological in nature. This makes it much more difficult to resolve (Tait, 2001b) and, in such cases, engagement often exacerbates conflict (Sunstein, 2009).

Notwithstanding, the proposed solution to the on-going impasse seems to be even more engagement. For example, in 2009, the UK Food Standards Agency (FSA) planned to undertake a public dialogue with the aim of helping "…ensure that future government and non-governmental policy towards the availability and production of food which involves the use of genetic modification is informed by a thorough understanding of the public's principal concerns and priorities in respect of such food". The FSA justified their initiative with, among other things, the possible crisis in global food security (FSA, 2010). **[OK]**

The initiative was eventually abandoned in its early stages after two members of the steering committee resigned–one is a member of an anti-GMO NGO; the other is an academic (http://www.sciencewise-erc.org.uk/cms/food-the-use-of-genetic-modification-a-public-dialogue/). These resignations could be seen as politically motivated as both had joined the steering committee with the intention to influence its political context and potentially to create embarrassment for the FSA should they fail to exert this influence. If the dialogue had gone ahead it is likely that there would have been on-going debate, and probably disagreements, in the steering committee over the content of the background materials used to inform the public dialogue, particularly the extent to which it was supported by scientific evidence (Chataway *et al*., 2008).

The strategy adopted in this case by those opposed to GM **[OK]** –invoke democracy and public dialogue, while working behind the scenes to influence the dialogue and its treatment in the media–has been characteristic of debates about GM technology in Europe for the past 10 to 15 years. Stilgoe (2006) has noted that the role of NGOs in stakeholder engagement is often to shape the public debate according to their interests and values. This strategy will continue to be effective for as long as there is no demand, particularly in the media, for more balanced treatment of the two sides of the argument (Tait, 2009).

Pielke (2007) has described four potential roles for scientists engaging in policy and politics: the pure scientist, the science arbiter, the issue advocate and the honest broker. Two of these roles are relevant to dialogues about GM crops in general, the issue advocate and the honest broker: the first focuses on the implications of research for a particular political agenda, aligns with a particular set of interests and seeks to participate in the decision-making process in order to further these interests; the second clarifies possible outcomes related to actions and seeks to expand the choices available to decision makers, but refrains from advocating any particular course of action. The 'issue advocate' category describes the role of NGOs and other advocacy groups, for example industry lobbies, while the 'honest broker' describes the role expected of scientists who advise governments [OK].

Pielke also points to the existence of 'stealth issue advocacy' that allows an adviser to claim to be "… above the fray, invoking the historical authority of science while working to restrict the scope of choice". The European history of policy making and engagement with developments in agricultural biotechnology has been characterised by very effective issue advocacy from NGOs and far less effective issue advocacy from industry, along with a major contribution of stealth issue advocacy generally against GM crops from some members of the academic community. The fact that these strategies have been able to frustrate the recent FSA public dialogue is not reassuring for the future role of GM and other advanced biotechnologies in contributing to food security needs in the UK and the EU.

Another example of the power of advocacy to influence European decision-making on GM crops is the French Agrimonde report. Immediately after its publication, it seemed likely that France would adopt a more liberal approach to GM crops. Marion Guillou, Chief Executive of France's INRA, when asked about the role of biotechnology in food production, cautiously referred to the need for new genetically selected varieties, either GM or produced by classical breeding techniques. She supported case-by-case scrutiny of GMOs, acknowledging that for some GMOs the assessment is undisputedly positive, particularly modifications that provide insect resistance and permit a reduction in pesticide use (Anon, 2010). However, INRA has since announced that it does not intend to make GM plant varieties available for sale in France. Guillou was quoted as saying, "We have no research on GMO innovation anymore, none. […] Since European society does not want to buy GMOs, we had better focus on other technology". http://www.forexyard.com/en/news/French-researcher-halts-development-of-GMO-crops-2010-10-29T080856Z-INTERVIEW (accessed 19 June, 2011)

Thus, governance-based policies, linked to the precautionary approach, have led us to a less democratic and less evidence-based system, in which regulation and restriction of specific areas of scientific activity are seen as a valid response to societal pressures, rather than as a means of dealing with demonstrated risks.

The central concern of the EU should be **[OK]** to enable science and technology to contribute to food security. The relevant technologies must be effective and safe, and their societal acceptability should be determined by a process that is as democratic as possible to balance the interests and values of various stakeholders, as proposed in the UK Foresight paper (The Government Office for Science, 2011). The dilemma in the EU is the ideological basis for most of the opposition to GM and related technologies (Tait, 2001b), which makes it hard to impossible to resolve conflicts and may even exacerbate them (Sunstein, 2009). The experience of the recent FSA dialogue on GM foods, described above, supports this conclusion.

It is difficult to collect evidence of either benefits or risks, given the routine destruction of GM crop field trials by NGOs opposed to the use of the technology (Tait, 2009). It is difficult to develop new GM products that could be beneficial for the environment or contribute to food security when there is a lack of funding for basic research and development to produce such products. It is impossible for small companies to develop GM crops, as is generally advocated by the public, when the cost of regulatory requirements is so high that only large multinationals can afford it.

It is ironic that European citizens are unhappy with the dominance of food production by large multinational companies and their focus on global commodity crops rather than the needs of the developing world. Yet, this is the inevitable outcome of a regulatory system that has been applied to plant biotechnologies in response to pressure from advocacy groups (Tait, 2007). The most efficient way to overcome the dominance of multinational companies in food production systems is a regulatory system that is cheaper and faster, but which still assures safety and efficacy. It would enable smaller companies to develop GM crops for niche markets, including markets for the developing world.

However, given Europe's commitment to a *governance* based approach, along with the existence of strong issue and stealth advocacy against GM crops, not to mention the implacable opposition by some NGOs, it is difficult to envisage how regulatory reform could be discussed constructively, let alone implemented.

We could also take a step back to employ more *government* based approaches that require the separation of factual evidence from the political process of dealing with conflicting interests and values. Under the *government* approach, advisers are expected to take a role equivalent to Pielke's honest broker, while the *governance* approach has encouraged issue advocacy. The *governance* experiment of the past fifteen years, involving a more bottom-up, stakeholder led approach to risk management (Lyall and Tait, 2005), as applied to agricultural biotechnology, has not delivered greater consensus in decision making or more innovative products of benefit to society **[OK]**; instead, it may even have prevented these outcomes. The implications of adopting this attitude and the resulting prohibitive regulatory regime have impacted beyond Europe. Many other countries also resist the use of GM crops, because governments fear that they would not be able to export their products to the EU. Unfortunately, this affects a number of developing countries that already face food shortages and whose farmers may actually benefit from growing GM crops.

Europe once had a great deal to offer in terms of an environmentally–oriented approach to agricultural technology, but policy and stakeholder interactions related to GM crops and biotechnologies over the past 10-15 years have so far prevented these benefits from being realised. If Europe is to meet its own future food security needs and contribute to the food requirements of the rest of the world, policy and regulatory changes will be necessary. However, we do not yet have a mechanism for stakeholder engagement that could lead to more democratic outcomes in the context of polarised and ideologically motivated opinions (Sunstein, 2009). We will need clearer strategic thinking on how to implement a *governance* approach under these circumstances if the investments we make in scientific research are to contribute to food security.

Joyce Tait is TKTK and Guy Barker is TKTK. Email: TKTK

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Table 1. Novel Plant Breeding Techniques*

Genetic Modification Technique		GM free end product?
1. Genetic manipulation used as a tool to facilitate breeding		
Virus induced gene silencing	Used for transient silencing of specific genes for functional analysis	Yes
Agro-infiltration	Uses Agrobacterium to achieve temporary and local expression of genes that are foreign to the species, for example to test a plant's ability to resist pathogen attack. Cuttings or seeds that are Agrobacterium free are used for further development	Yes
Reverse breeding	Makes it possible to produce improved F1 hybrid varieties that are free from introduced genes.	Yes
Accelerated breeding	Genetic modification is used to speed up breeding by induction of early flowering	Yes
2. Grafting of non genetically modified material to GM material		
Chimeric plants	E.g. non-GM plant grafted onto a GM rootstock to give improved cultivation characteristics. The harvested part of the plant will not contain any foreign DNA, although RNA transcripts and metabolites can pass into the harvestable parts of the plant	Yes
3 Techniques that involve genetic modification using material from the same species or a sexually compatible species.		
Cisgenesis	Uses DNA from the same species or a cross-compatible species. The regulation of gene expression is unaltered from the native state. The product could be generated by conventional breeding.	No
Intragenesis	Similar to cisgenesis but incorporates new combinations of	No

	regulatory and coding sequences, normally for silencing genes	
4. Genetic manipulation as a tool for inducing specific mutations		
Oligonucleotide mediated mutation	Causes site-directed mutations within genes. Used to knock out or adapt gene function. Plants produced are similar to those obtained through traditional mutagenesis based breeding	Yes
Zinc finger nucelease	Zinc fingers are attached to a protein that cuts the DNA between the recognition sites matched by the fingers. The cell quickly repairs the DNA in doing so knocks out the gene. If a new gene is inserted at the same time as the zinc fingers that scissor the DNA, the new gene can be inserted at the break site. Dow Agrosciences has licensed this technology for creating new crop plants	Yes

*Based on (Schaart and Visser, 2009)

Figure 1. GM Traits in Crops undergoing Trials in the US (1995-2010)