Agricultural Biotechnology, Gene Flow and Biodiversity

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A sustainable strategy to nourish the planet and its people must also promote biodiversity conservation. This strategy will have to include reduction in land degradation and unsustainable overuse of fertilisers, pesticides, fungicides, herbicides, and irrigation water. A case can be made for conserving biodiversity as a source of traits for incorporation, by different genetic tools, into food plants and animals, but an even stronger case can be made for a conserved biodiversity to supply ecosystem services that will nourish the planet and its occupants into the future. Biodiversity is under severe threat from many angles. One of the best ways to promote biodiversity is to preserve native habitats. By maintaining or even increasing yields on existing land, biotechnology crops can help to minimise expansion of agriculture into natural areas. It has also been estimated that agricultural biotechnology has changed pesticide spraying so as to greatly reduce greenhouse gas emissions and decrease environmental impacts of insecticides and herbicides. Gene flow from cultivated, including biotechnology-based, crops to and from wild plants is known to occur. The consequences of this flow vary from species to species, but as a general rule, do not pose a significant threat to biodiversity.

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Introduction

The journal *Nature's* editorial of 29 July 2010, 'How to feed a hungry world' (Anon. 2010), said 'producing enough food for the world's population in 2050 will be easy'. This is a very controversial comment—although it did go on to say, 'that doing it at a acceptable cost to the planet will depend on research into everything from high-tech seeds to low-tech farming practices'. That second sentence is starting to sound more realistic, but not too many people—certainly not the Crawford Fund audience—would be as naive as the editor of *Nature* to say that all of our problems will be solved by technical fixes alone. Most people would subscribe to a much more complex set of conditions to be met if we are to feed and clothe the future 8–10 billion. At the very least we will need significant policy and social changes, and new regulatory regimes around food production as well as scientific and technological advances (Tilman *et al*. 2001).

The past five decades

The next 50 years is likely to be the last period of rapid agricultural expansion; thereafter the planet should be in a steady state. To anticipate the next 50 years, it is useful to look back on what has happened during the past 50 years.

The population has more than doubled and world crop production has more than kept pace with that growth—in fact it has almost tripled. An increase in land area of about 27% contributed to the production of that extra food. This amazing increase in yield was achieved by a combination of factors—better varieties, more pesticides, more fertiliser, more irrigation and more mechanisation, as well as an increase in cultivated area (Burney *et al*. 2010). Intensification has had undoubted benefits but, equally undoubtedly, costs. The benefits included sparing wild lands for nature and less malnutrition; some of the costs were more water use, more chemical runoff, more soil erosion and increased greenhouse gases.

The coming decades

To anticipate the changes that are likely in the food ecosystem by 2050, note that currently about 3.5 billion hectares (B ha) are under pastures, 1.5 B ha are cultivated and about 280 million ha are irrigated. There is heavy use of fertilisers, that is 87 million tonnes of nitrogen and 34 million tonnes of phosphorus. Already more than 3.5 million tonnes of pesticides are applied (Burney *et al.* 2010) (Table 1).

In summary, between 30% and 40% of the terrestrial area of the ice-free land is already under cultivation or in pasture. It is estimated (Tilman *et al.* 2001; Burney *et al.* 2010) that land committed to crops and livestock will have increased to 5.3 B ha by 2020 and nearly 6 B ha by 2050. This means that another billion hectares are going to be converted from wild lands, even assuming we are going to make gains through intensification at the same rate as in the last five decades. For example, the area of irrigated land is predicted to double by 2050, and there will be massive increases (three-fold) in fertiliser use, particularly nitrogen (N) and phosphorus (P), if they are affordable. If, as expected, we reach peak oil about 2015 and peak phosphorus in 2035, there is considerable uncertainty about the future availability and thus price of N and P. Crop and pasture legumes are a significant source of fixed nitrogen and have an important role in P availability, and it can be anticipated that more legumes will feature in future intensification of food production. Massive increases in the use of pesticides (up to ten from the current near four million tonnes) are predicted to be required to achieve the yields of food, feed and fibre that are going to be needed to shelter, clothe and feed humanity into the future (Table 1).

Table 1. Projected changes to the food, feed and fibre ecosystem by 2050 (adapted from Tilman *et al.* 2001)

Attribute	2000	Estimate for-	
		2020	2050
Crops (billion ha)	1.54	1.66	1.89
Pastures (billion ha)	3.47	3.67	4.01
Irrigated land (billion ha)	0.28	0.37	0.53
Fertiliser use:			
Nitrogen (M tonnes)	87	135	236
Phosphorus (M tonnes)	34	48	84
Pesticide use (M tonnes)	3.75	6.55	10.1

Exacerbating the risk that it may not be possible to meet future needs in food production is the fact that annual crop yield increases are falling below projected demand (Alston *et al.* 2009). Therefore yields per unit area have to increase or the area of land under cultivation and pastures must expand. This latter scenario would further threaten biodiversity conservation. While food security for humans is identified as absolutely vital to the future, the message needs to be ‘food and ecological security’ (Glover *et al.* 2010). There is a justified concern that if more land is appropriated for direct human use this will have a major negative effect on biodiversity (Cassman and Wood 2005; Glover *et al.* 2010):

The role of GM crops

What role might GM crops play in sparing wild land and thus promote biodiversity conservation? Of the near 1.5 B ha of crops that are currently grown, about 140 million ha were GM in 2009 (James 2009). This amounts to 9% of the total. The 14 million farmers who grew those GM crops amount to about 3% of global farmers. GM crops have been grown for about 15 years—long enough to evaluate what contribution they have made and estimate what they are likely to do in the future.

There have been a significant number of peer-reviewed studies of genetically modified (GM) crops (Carpenter 2010) (Table 2). There are almost 170 reports on yield alone, from both developing and developed countries. Some of these (13 in total) reported that there was a reduction in yield in the GM crops compared to the non-GM counterparts; while a further 31 reported no change in yield.

Table 2. Number of peer-reviewed surveys of yield changes when comparing GM crops with non-GM crops (adapted from Carpenter 2010)

Countries	Positive	Neutral	Negative	Total
Developed	36	18	7	61
Developing	88	13	6	107

A majority (124) reported that there were increases in yield when GM crops were grown. In developed countries, for instance, 36 out of 61 show that there were positive yield gains; 18 showed no gain and 7 reported a reduction in yield. In developing countries—and these countries are the biodiversity-rich areas—88 out of the 107 reports showed gains in yield, 13 were neutral and 6 were negative (Carpenter 2010). Yield gains are a step towards intensification and the sparing of land for natural ecosystems.

The economic effects of these yield gains, when combined with reduced costs of pesticide inputs, can have an impact on poverty. There are almost 100 peer-reviewed studies of the economic impact of GM crops (Carpenter 2010): 71 of those 98 are positive, 11 are neutral and 16 are negative. Most of the positive gains were in developing countries.

Despite these benefits there are risks associated with GM crops which could have negative effects on biodiversity. Herbicide-tolerant crops risk the development of herbicide-tolerant weeds. Insect-resistant crops risk the emergence of resistant pests. These risks are significant and they echo similar risks in conventional agriculture. Management of these new crops requires sophisticated skills that are vital to the long-term usefulness of gene technology for the ecosystems of the future.

Following are examples of the land-sparing and input-sparing effects that GM crops have had over the last 12–15 years, largely in developing economies.

Cotton in India and China

The average yield of cotton increased by about 70% between 2001 and 2008 in India (James 2009). Half of this increase has been attributed to insect-resistant cottons containing genes derived from the soil microbe, *Bacillus thuringiensis* (Bt). The other half of the gain was made by improvements to conventional agriculture. There was a 56% decrease in cotton boll insecticide used between 1998 and 2006 which is cost saving for the six million Indian farmers who grew Bt cotton in 2009. In 2009, seven million Chinese farmers also grew Bt cotton. In China, yield was increased by almost 10% and insecticide use decreased by 60% (James 2009).

Soybeans

Brazil has enthusiastically adopted GM crops and there have been significantly fewer herbicide sprays on their RoundUp-Ready soybeans. Between 1997 and 2008 they reduced diesel and water use, and CO_2 emissions were reduced as a result. Further improvements are expected between 2009 and 2017. Combining (James 2009) GM cotton, maize and soybeans , the projected savings of inputs of diesel and water are over 800 000 tonnes and 105 million tonnes, respectively, with a concomitant reduction in carbon dioxide emissions of two million tonnes (James 2009).

Maize

In certain parts of the developed world, e.g. the United States, there has been rapid uptake of GM crops, especially corn, soybeans, cotton and sugarbeet. Cassman and colleagues (Cassman *et al.* 2006)) note that corn yields have doubled over the last 40 years (Fig. 1). Between 1965 and 2005 the average yield of corn in the US went from just under 5 to almost 9 tonnes per ha. Several factors have contributed to this gain and the almost exclusive use of hybrids has been very important. Although these were first developed in the 1930s they really came into their own in the 1960s. Over time more irrigation, increased fertiliser (NPK) rates and conservation tillage, as well as integrated pest management, became significant contributors as well.

Some of the yield gain has been attributed to the adoption of GM corn in the 10 years to 2005 (Cassman *et al.* 2006). They also pose a question about how reduced application (due to higher prices) of nitrogen fertiliser and irrigation will affect the upward yield trend in the future.

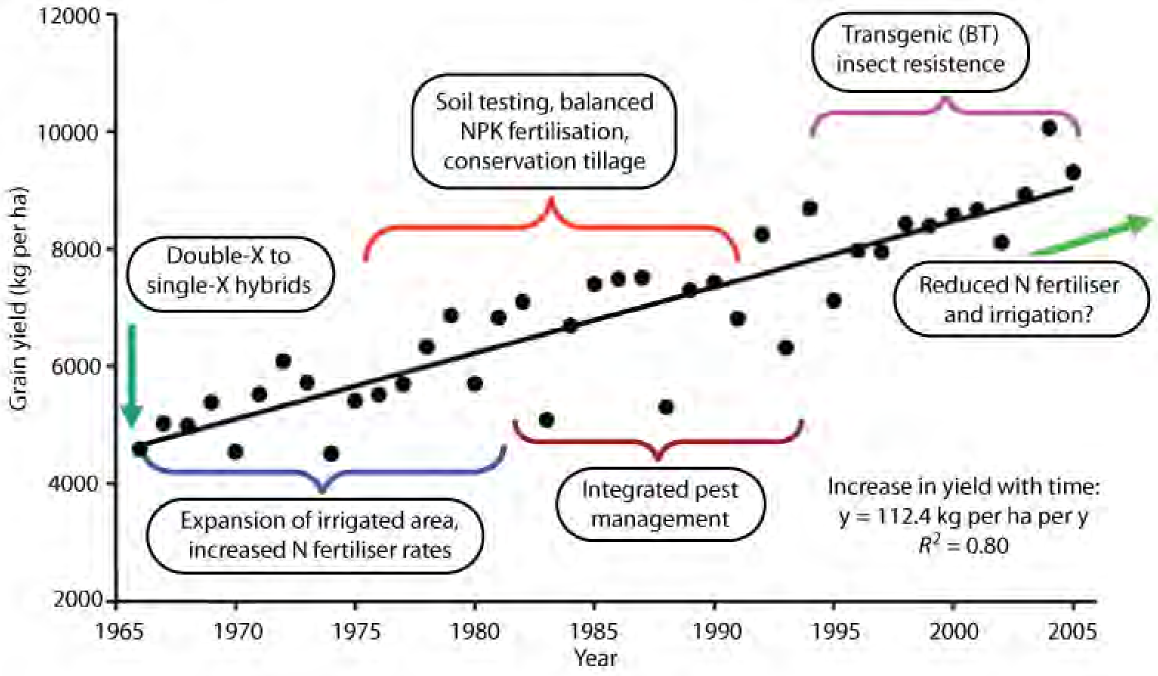

Figure 1. Corn yield trends in the United States from 1966 to 2005, and the technological innovations that contributed to yield increases. Reproduced with permission from Cassman *et al*. (2006) Council for Agricultural Science and Technology (CAST), *Convergence of Agriculture and Energy: Implications for Research and Policy*. CAST Commentary QTA2006-3. CAST, Ames, Iowa.

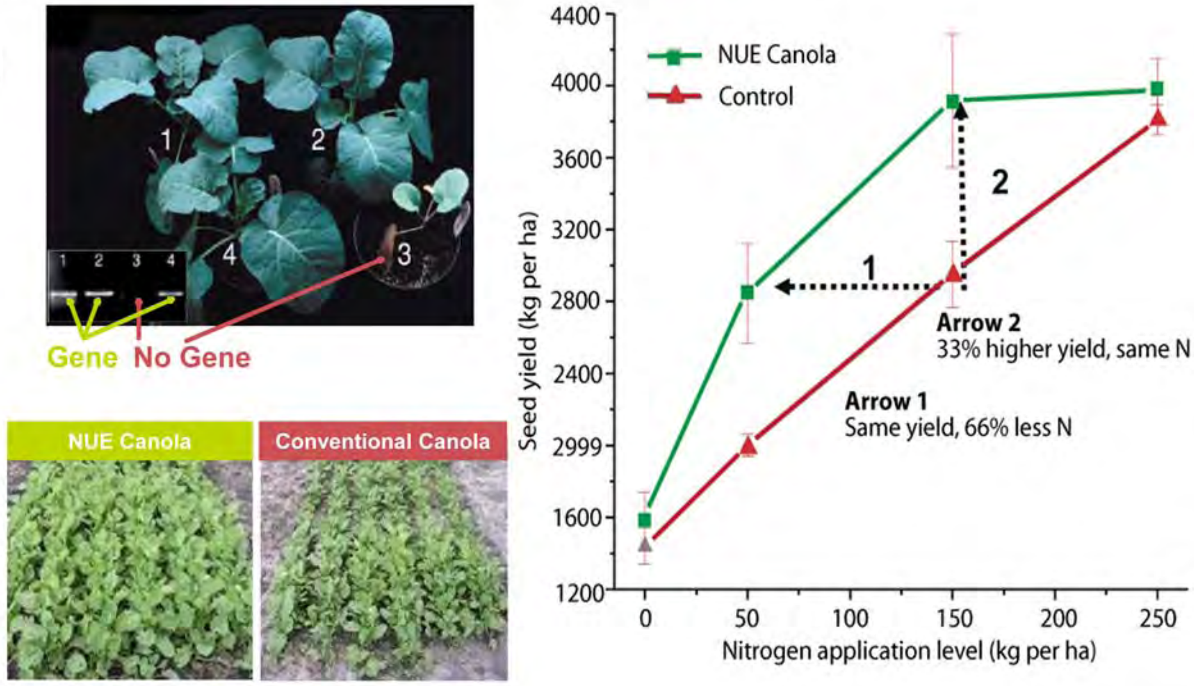

Figure 2. Grain yield in canola with a nitrogen use efficiency (NUE) trait in field trials (Source: Arcadia Bioscience). Reproduced with permission.

Efficiency of fertiliser use

Fertiliser nitrogen and phosphorus have a vital projected role in future food. As indicated in Table 1 fertiliser use is likely to more than double by 2050. Unfortunately, less than half of the nitrogen applied is absorbed by plants and this constitutes an economic inefficiency for farmers. The unabsorbed nitrogen ends up contributing to eutrophication of water and producing additional greenhouse gas.

Conservation of nitrogen (and phosphorus) in the production of food feed and fibre for the future is an area of very active research, using advances in both genetics and in agroecosystem management. One way in which GM may play a role is illustrated by an example from nitrogen-use-efficient (NUE) canola. Scientists at Arcadia Bioscience transferred a gene involved in nitrogen metabolism from barley to canola and, in field trials, showed that the efficiency of nitrogen use was increased such that a yield of about 2.8 tonnes per ha could be produced with 50 instead of 150 kg of N per ha (arrow 1 in Fig. 2) using the NUE canola. Alternatively, a higher yield of nearly four tonnes can be obtained from the same application (150 kg ha^{-1}) of nitrogen to the NUE canola (arrow 2 in Fig. 2). Thus, if this concept of NUE (and in future, a similar approach to phosphorus use efficiency) is transferable to other crops as well as pastures and forestry, GM technology may help with at least one of the major inputs into agriculture.

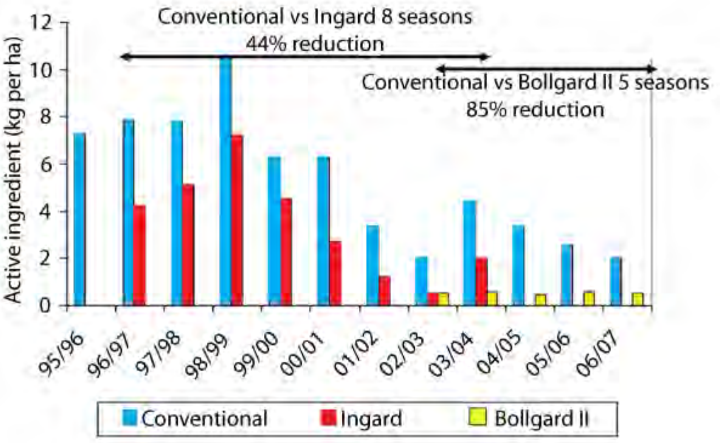

Figure 3. Reductions in active ingredients applied to insect-resistant cotton in Australia in the period 1996 to 2007 (Fitt 2008). Reproduced with kind permission from Springer Science+Business Media B.V.

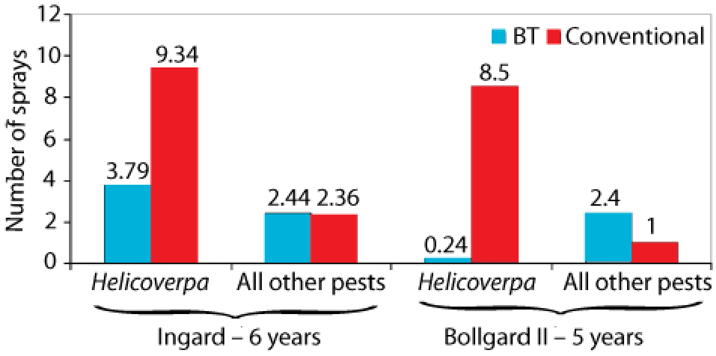

Figure 4. Changes in the number of pesticide sprays applied to insect-resistant cotton ('BT') between 1996 and 2007 (Fitt 2008). Reproduced with kind permission from Springer Science+Business Media B.V.

Integrating pest management

In Australia GM cotton has been grown for over 14 years. A close analysis of pesticide application (Fig. 3) over that period shows the amount of insecticide (as active ingredient) applied to conventional versus two different types of Bt cotton. Ingard was introduced in 1996 and contained a single insect-resistance gene for the control of *Helicoverpa armigera*, the major insect pest in cotton. Ingard was replaced by Bollgard II in 2003 and it contains two different insect-resistance genes for *H. armigera*.

The quantity of active ingredients applied was reduced by 44% for Ingard and 85% for Bollgard II compared to conventional cotton. With Ingard, the number of sprays fell from about 9 to about 4 sprays per season for *Helicoverpa*, with no change in the number of sprays for the other pests that attack cotton. When Bollgard II was introduced those numbers dropped from 8.5 to less then 1 spray per season for the *Helicoverpa* (Fig. 4) but there was an increase from 1 to 2 sprays for the other pests, which took over the vacated niche. The cumulative effect was to reduce 9 sprays down to 2 or 2½ sprays per season.

Similar results have been obtained for insect-resistant maize (Brookes and Barfoot 2008).

The use of less pesticide permits better survival of predators and parasites such as wasps, giving, in turn, better control of secondary pests that are not controlled by Bt. Bt crops are described as living crops, not biological deserts that existed when nine or ten sprays were applied each season. Bt crops are seen as a foundation for long-term integrated pest management (Fitt 2008).

Conclusion

GM crops will be a part of the solution to the dilemma of increasing food, feed and fibre production while at the same time conserving biodiversity. They are not going to solve all problems, and it is worth remembering that they are a relatively minor component (less than 9%) of the total system at present. They have been shown to increase yields around the world, particularly in developing countries, and these higher yields will spare land for natural ecosystems to co-exist with agroecosystems. GM crops have been shown to increase income and thus help reduce poverty in developing countries. They can also help reduce the level of inputs needed to produce the food needed in the next 50 years, thus protecting water and soils. Solving the needs of the food ecosystem of the future will also require new regulatory regimes and political and social changes as well as the technical advances foreshadowed here.

Cooperation and community involvement will be essential in order to successfully address the issues raised at this Crawford Fund conference.

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