Focus

Gaining ground

Debating the growing impact of GM agriculture

Over a decade since the first genetically modified crops were developed and grown, their environmental and production credentials are being better assessed as land area under GM crops expands. But the role of GM agriculture in the 21st century is still being fiercely debated. **Graeme O'Neill** reports.

Earth's human population is predicted to peak at 9.4 billion by mid-century. Global food production, therefore, has to roughly double if we are all to be adequately nourished. With most marine fisheries already under severe stress, and the outlook for them expected to worsen as the population rises, the burden of feeding the planet's people will increasingly fall on agriculture.

Forty years ago the so-called Green Revolution's advances in breeding technology gave us the high-yield rice and wheat varieties that doubled global food production, but that was barely in time to prevent widespread famine in Asia. Now, within the next four decades, agricultural production must significantly ramp up again, but against the unpredictable impacts of global warming and environmental degradation on food-producing regions.

So how are we to achieve this?

Doubling the area of land under crops and pastures is not an option. Somehow, agriculture must become more productive *and* more sustainable – seemingly irreconcilable goals in the past.

Today's intensive, large-scale crop and pasture systems depend on high inputs of synthetic nitrogenous fertilisers and pesticides. These have some well-documented and long-lasting effects on both the environment and people. Agricultural and plant genetics scientists argue that recombinant DNA technology (commonly known as genetic modification – or 'GM' technology), and advanced conventional breeding techniques arising from it, such as DNA marker technology, are advancing agriculture, safely, towards higher productivity and sustainability more rapidly than any other approach.

They believe it is agriculture's best chance of speeding the development of more robust, highly productive, pest- and disease-resistant crops and animals, which can appreciably reduce environmental impacts and enhance social capital.

A GM cotton trial in progress. Researchers say GM cotton in Australia has both significantly reduced environmental impacts and raised farm income. Brasil2/Istockphoto

But it is well known that many non-government organisations (NGOs), such as Greenpeace, Friends of the Earth, the Australian GeneEthics Network and the Network of Concerned Farmers, believe gene technology is intrinsically unpredictable, unsustainable, and could have long-term adverse effects on human health and the environment.

These organisations oppose all use of genetically modified organisms (GMOs) in

agriculture and food production, and advocate the replacement of today's high-input 'chemical farming' systems by sustainable farming, based on organic principles. They advocate a move to organic systems employing animal and green manures, and 'natural' pesticides.

Anti-GM sentiment has been strongest among urban consumers in wealthy nations – the focus of the anti-GM movement's highly organised campaigns for a decade. Yet the global area sown with GM crops has maintained double-digit annual growth since 1996, expanding by a further 13 per cent last year, according to the 2006 annual report of the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), which monitors global trends in GM agriculture.

And a decade after the first GM crops were planted, the fog of the war for the debate's high ground is clearing. The anti-GM movement's predictions of dire environmental, health and social consequences remain largely unfulfilled. ISAAA reported that in 2006, the total area of GM crops reached 100 million hectares, and the number of farmers growing them exceeded 10 million.

According to ISAAA, the economic benefit of biotech crops for farmers in 2005 was US$5.6 billion, bringing cumulative benefits between 1996 and 2005 to $27 billion – almost equally distributed between developed nations ($14 billion) and developing nations ($13 billion).

Dramatic imagery has been powerfully effective in public campaigns against GM food.
Lise Gagne/Istockphoto

A decade of GM trials

Australia led the world into agriculture's Gene Revolution in 1988, by releasing the world's first commercial genetically modified organism, a transgenic crown gall bacterium *(Agrobacterium tumefaciens)*. Nurserymen around the world now use it to prevent crown gall disease in young stone-fruit trees.

The world's first GM crop was Californian biotech company Calgene's long shelf-life GM tomato, the Flav'r Sav'r, released in 1994.

Australian and American cotton farmers planted the first pest-resistant GM cultivars in 1996, endowed with transgenes for insecticidal proteins from the soil microbe *Bacillus thuringiensis* (*Bt*).

In the same year, Canadian canola farmers began growing transgenic varieties engineered for tolerance to the broad-spectrum herbicides Roundup (glyphosate) and Liberty (glufosinate).

In 1997, US and Canadian farmers planted the first pest-resistant GM maize crops containing *Bt* transgenes to protect varieties from pests like the European corn borer and corn root borer.

GM maize has since provided human and animal health benefits by both reducing exposure to pesticides and reducing smut fungi infections in insect-damaged cobs. *Aspergillus* and other smut fungi produce mycotoxins, including fumonisins, one of the most potent liver carcinogens and fetal teratogens[1] known. They have been linked to high rates of liver cancer in Africa, and have been identified as a potential health hazard in organic maize.

In September 2003, the UK's Food Safety Agency ordered British supermarkets to remove six organic cornmeal products from their shelves, after tests showed they contained nine to 40 times the safe level of fumonisins. Twenty *Bt* maize products were all well below maximum safe fumonisin levels.

Bt cotton has conferred a similar advantage for farmers in the US, Australia, South Africa and, more recently, India and China. Before *Bt* cotton, hundreds of impoverished Indian and Chinese farmers, giving up against pests, committed suicide each year by actually taking the insecticides to which the pests had become resistant.

India formerly accounted for 25 per cent of the world's cotton but only 12 per cent of its supply. GM cotton has increased yields by around 150 per cent, trebled small farmers' profits, and reduced pesticide volumes by 80 per cent.

Safety and advantage

International anti-GM groups regard gene technology as imprecise and inherently unsafe. They argue that, given historical examples of unanticipated environmental consequences from scientific research, the precautionary principle[2] should be applied.

1 An agent, such as a virus, a drug or radiation, that causes malformation of an embryo or fetus.
2 http://members.iinet.com.au/~rabbit/prec.htm

Focus

A flowering canola crop at Harden, NSW. GM canola is not yet a permitted crop in Australia.
Greg Heath/CSIRO Land and Water

Scott Kinnear, a Director of Australia's largest organic farming body, Biological Farmers of Australia (BFA), and Director of leading anti-GM NGO the Australian GeneEthics Network, describes science's focus on GM agriculture as a generic solution to the food supply problem as 'crazy'.

But neither organisation opposes biotech-derived breeding and selection tools to accelerate development of new crops with positive benefits for farm economics, the environment and human health – technologies Kinnear describes as 'exciting'.

Gene technology allows researchers to develop novel crops that are impossible to develop by conventional hybridisation or mutation breeding. They can explore beyond the limited gene pools of crops and their sexually compatible wild relatives, and import genes for desirable traits from unrelated plants, animals or microbes. They can also modify gene expression *in situ*, and custom-design transgenes for traits such as virus resistance. But this capability is at the very heart of anti-GM groups' concerns.

Both BFA and GeneEthics oppose all GM crops, and Kinnear says there will be no compromise. 'Our main objection is that the health and safety of GM crops and foods are untested. From the organics perspective, we are deeply concerned at the long-term implications for human health and the environment.'

'It's to Australian agriculture's competitive advantage that we remain non-GM – it allows the organics sector to grow produce without fear of contamination, and conventional agriculture to market itself as "GM-free",' Kinnear points out.

But proponents of GM agriculture argue the competitive advantage issue the other way. In his 2004 report, 'Conservation farming systems and canola', University of Melbourne agronomist Dr Rob Norton estimated that GM herbicide-tolerant (GMHT) canola could provide significant economic and environmental advantages worth AU$135 million annually to the wheat and canola industries.

Dr Norton said GMHT canola offered farmers new options: effective weed control in canola crops, earlier sowing, and replacement of the triazine herbicide tolerant (TT) cultivars that dominate Australian production.[3]

Dr Norton stands by his 2004 estimate; if he is right, the current state moratoria on GM crops,[4] in place from 2004 until at least 2008, have already cost Australian grain farmers around $400 million.

Europe and the UK have banned triazine herbicides as persistent environmental pollutants – they leach rapidly from the root zone and can contaminate groundwaters and waterways. In contrast, Roundup (glyphosate) and Liberty (glufosinate) bind to soil particles in the rhizosphere and rapidly break down.

Greenpeace International backed the European and UK bans, arguing that safer alternatives to toxic pesticides or pest-management systems should be preferred wherever possible. Yet its Australian subsidiary prefers atrazine-tolerant canola over glyphosate and glufosinate-tolerant canolas.

Greenpeace Australia Pacific and the Network of Concerned Farmers, a rural ally of Greenpeace, also claims GMHT canolas would offer no yield advantage over today's herbicide-tolerant, non-GM TT and Clearfield[5] cultivars.

Without independent, farm-scale commercial trials – currently barred by the moratoria – any yield projection is open to question. But in 2005, Bayer conducted small demonstration strip trials of advanced experimental lines of GMHT canola in Victoria and South Australia. Its hybrid lines out-yielded conventional TT canolas by 32 to 42 per cent. They also yielded 1 to 4 per cent more oil.

Louise Sales, Coordinator of Greenpeace Australia Pacific's anti-GM campaign, says herbicide-tolerant GM crops like canola are grown as monocultures, which are inherently unsustainable. Her organisation has concerns that GM monoculture expansion is not only encouraging wide-scale new land clearing, but also has disruptive effects on ecosystems.

Sales highlighted that farm-scale trials of Monsanto's Roundup-Ready canolas in the UK in 2005 showed a reduction in invertebrates and birds. No similar studies had been conducted in Australia.

She said canola could hybridise with weedy relatives like wild radish (*Raphaneum*) and shepherd's purse (*Capsella bursa-pastoris*), and that broad concerns are still held about GM crops becoming weeds themselves.

Dr Chris Preston, of the Australian Weeds Cooperative Research Centre, points out that non-GM herbicide-tolerant cultivars grown in Australia since the early 1990s carry the same risks.

In a 2004 experiment, CRC researcher Dr Mary Rieger found that hybridisation with wild radish is very rare – among 53 million seedlings raised from GMHT canola, she found only two resistant hybrids.

Dr Preston's own research into herbicide tolerance in weeds has shown that natural herbicide-tolerant mutants occur at a frequency of between 1 in 13 000 to

3 The non-GM triazine-tolerant canola varieties that dominate the Australian industry today were developed from naturally occurring mutants, so they have not been targeted by anti-GM activists.
4 The Federal Office of the Gene Technology Regulator approved commercial cropping of GM herbicide-tolerant (GMHT) canola cultivars in 2004, but the current state moratoria prevent farmers growing it until at least 2008.
5 A commercially registered non-GM weed-tolerant canola breed.

17 000 in weed populations never exposed to herbicides. The frequency of herbicide-tolerant canola/wild radish hybrids is four orders of magnitude lower than these naturally occurring mutants, which have not become environmental 'superweeds'.

Dr Preston indicates that these natural mutants could be used as parents to develop non-GM canola cultivars resistant to glyphosate or glufosinate, which would probably be acceptable to the anti-GM movement. BFA's Scott Kinnear confirms this is the case. The anti-GM movement's objection is to the use of gene technology, not to the trait itself.

Dr Ian Edwards, Chairman of the Agricultural Biotechnology Advisory Group of the national biotechnology industry organisation AusBiotech, said the state moratoria deprive Australian farmers of the opportunity to implement minimal tillage programs that would reduce weeds in following wheat crops, promote soil carbon accumulation and reduce erosion, therefore giving environmental benefit.

The triazine-tolerance trait in today's TT cultivars carries an inherent yield penalty of 10–15 per cent relative to conventional canola. The vigorous seedling growth of Bayer's hybrid GMHT canolas on the other hand makes them more competitive against weeds, and shortens the interval to harvest – traits that reduce their exposure to heat and drought at the end of the growing season.

Rob Norton estimated that this trait would allow canola plantings to be expanded by 160 000 hectares in drier areas. Based on an average yield increase from 1.27 tonnes per hectare (t/ha) to 1.38 t/ha, he estimated that annual Australian production would increase to 295 000 tonnes annually.

GMHT canola would also provide follow-on benefits to the subsequent wheat crop, by reducing weeds and providing a disease break, through the soil-fumigating effect of its root exudates.

In 2005, Dr Stephen Apted, of the Australian Bureau of Agricultural Resource Economics (ABARE), estimated that Australian agriculture stands to lose between $1.8 and $7 billion in higher costs and foregone profits if the states maintain their moratoria on GM crops.

GM cotton's benefits

Even if GM crops can deliver on their promise of higher yields and increased profits for Australian farmers, the current moratoria mean Australia has only GM cotton as a model to indicate whether GM crops will be more or less sustainable than their conventional and organic equivalents.

Dr Ian Edwards says *Bt* cotton has been a real success story in Australia, reducing pesticide use by 80 per cent while achieving the world's highest average yields.

'Cotton uses 25 per cent of all the insecticides used on Earth,' Edwards said. 'The pesticide reductions are a major environmental positive.'

Since 2005, second-generation Bollgard 2 GM cotton cultivars have dominated the local industry. The crop's green tissues – including the developing flowers and leaves – are defended from attack by heliothine caterpillars, cotton's biggest pest, by two independently acting transgenes from the soil bacterium *Bacillus thuringiensis* (*Bt*).

For more than 60 years, organic farmers and home gardeners have used *Bt* spores as a natural pesticide to protect vegetable and fruit crops against leaf-chewing caterpillars. But the organics industry, and anti-GM NGOs, oppose the use of *Bt* transgenes in GM cotton, maize and other GM crops.

Scott Kinnear acknowledges the reduction in pesticide use, but says the figure does not take into account the *Bt* pesticide exuded from the crop's roots, which could have long-term, adverse effects on soil invertebrates, fungi and bacteria.

Louise Sales has similar concerns. 'It's self-evident that if you continue using the same pesticide, you will see resistance.'

She said the toxin could persist in the soil up to 200 days, leading to 'real concerns' about its impact on soil invertebrates.

Sales also said GM cotton was reportedly more water-hungry than non-GM varieties.

She cites a 2002 Greenpeace-commissioned report on *Bt* cotton cropping in China, which found increasing problems with secondary pests, including sap-sucking mirids and jassids, a decline in natural predators and parasites including *Heliothis armigera* caterpillars, the principal pest of Asian cotton crops, as well as signs of emerging resistance to *Bt* toxin.

But Dr Konming Wu, Chief Scientist of the National High-Tech Program on the ecological safety of *Bt* cotton in China, has accused Greenpeace of misrepresenting his group's findings on the ecological impacts of *Bt* cotton.

Evidence for 'emerging resistance' apparently came not from the field, but

Genetically modified cotton plants (left) are able to withstand insect attacks that can devastate conventional plants (right) from insects such as *Heliothis* (far right), the biggest pest of the Australian cotton industry. CSIRO Plant Industry

Nutrition and medical applications

Cotton seedlings in a test crop at the glasshouses of CSIRO Plant Industry, Black Mountain, ACT. CSIRO Plant Industry

Molecular plant breeders in Australia and overseas are developing novel GM crops that are beyond the ambit of conventional hybridisation or mutation breeding, including:

- vitamin A-enriched Golden Rice, to prevent blindness and anaemia in nations where rice is a staple food;
- oilseed crops enriched in omega-3 oils, to reduce cardiovascular disease and conserve marine fisheries – the current source of omega-3 food supplements;
- vegetables and fruits expressing microbial or viral antigens, to orally vaccinate children in developing nations against lethal childhood diseases; and
- crops such as sugar cane and potatoes that will produce high-value proteins, sugars or industrial polymers.

from laboratory experiments in which caterpillars were force-fed *Bt* cotton leaves. No resistant larvae have yet been found in GM cotton fields anywhere in the world.

GM cotton experts have also criticised Greenpeace's summary of the Chinese findings, pointing out that the decline in parasite and predator populations reflects the virtual absence of caterpillars in GM cotton crops – the same trend has occurred in Australia.

Similarly, the proliferation of sucking pests like mirids and jassids, which are not controlled by *Bt* toxin, reflects the broader benefits of reduced use of broad-spectrum pesticides on non-target invertebrates, including predators.

Australia's cotton industry introduced doubly protected Bollgard 2 cultivars in 2004–5, which are expected to delay the emergence of resistance indefinitely.

CSIRO cotton breeder Dr Greg Constable, of the Cotton Catchment Communities Cooperative Research Centre in Narrabri, NSW, says *Bt* cotton is typically more water-efficient than conventional cotton. The *Bt* endotoxin protects the early flowers and developing bolls against damage, so the crop matures earlier and in fact requires fewer irrigations.

The Cotton CRC reported in the *Journal of Experimental Agriculture* last year that Australian *Bt* cotton cultivars have reduced the crop's overall environmental impact by 75 per cent.

Dr Constable's CSIRO colleague Dr Gupta Vardakattu measured the level of *Bt* toxin in the soil beneath cotton crops, and found it degrades rapidly, reaching almost undetectable levels within just eight weeks (56 days).

He found differences between soil organisms in the root zones of GM vs non-GM cotton, but none attributable to *Bt* toxin. Dr Vardakattu explained that rhizosphere ecosystems also vary widely between different crops, and in different soils.

He reiterated that the organic farming industry has used *Bacillus thuringiensis* as a biocide to control crop pests for 50 years.

Dr Constable says GM cotton has produced economic and social change in cotton-farming communities. Aerial crop-spraying companies and pesticide suppliers have downsized, and demand for costly manual labor to weed cotton crops has declined – but *Bt* cotton has had significant occupational health and safety benefits by reducing workers' exposure to pesticides, sunburn and skin cancer.

A recent study by economists Graham Brookes and Peter Barfoot, of PGS Economics in the UK, found that in 2005 the reduction in greenhouse gas emissions due to low-till GM crops that better sequester carbon was equivalent to taking 4 million cars off the road.

Broader impacts

In an article in *Seedling* in January 2006, Miguel Altieri, Professor of Agroecology at the University of California, Berkeley, and Walter Pengue, Professor of Agriculture and Ecology at the University of Buenos Aires in Argentina, detailed the problems of GM soy.[6]

They said that in developing countries, GM crops are grown mainly for export by big farmers, not for local consumption. They are used as animal feed to produce meat, consumed mostly by the wealthy.

Explosive expansion of soybean production in Latin American countries including Argentina, Brazil, Bolivia, Paraguay and Uruguay has been accompanied by massive transportation infrastructure projects that destroy natural habitats over wide areas, well beyond the deforestation directly caused by soybean cultivation.

In Brazil, soybean profits had justified the improvement or construction of eight industrial waterways, three railway lines and an extensive network of roads to bring inputs and carry out produce.

'These have attracted private investment in logging, mining, ranching and other practices that severely impact on biodiversity that have not been included in any impact assessment studies,' Altieri and Pengue said.

More information:
Cotton Catchment Communities CRC: www.cotton.crc.org.au

ABARE: www.abareconomics.com

Biological Farmers of Australia: www.bfa.com.au

Greenpeace Australia: www.greenpeace.com.au

6 Altieri M and Pengue W (2006). GM soybean: Latin America's new coloniser. *Seedling* (January), 13–17. www.grain.org/seedling