Can GM crops contribute to international sustainable development goals?

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Abstract

Sustainable development is a concept which permeates policy and action at an international, national and local level. A range of international organisations have sustainable development goals[1] and plans and treaties exist to which the majority of the world's nations are committed, for instance to protect biodiversity[2] and reduce the emissions of greenhouse gases[3]. It is against this backcloth that a range of genetically modified (GM) crops have been developed and are being grown in many part of the world. Whilst recognising that there is considerable debate and resistance to the adoption of GM crops in some parts of the world, most notably Europe, in this paper we briefly review the ways in which GM crops are contributing at an international level to sustainable development, focussing on economic, environmental and social perspectives.

Introduction

Sustainable development is a concept which permeates policy and action at an international, national and local level. The Bruntland Commission (1987) defined sustainable development as *"it meets the needs of the present without compromising the ability of future generations to meet their own needs"*. A range of international organisations have sustainable development goals[4] and plans and treaties exist to which the majority of the world's nations are committed, for instance to protect biodiversity[5] and reduce the emissions of greenhouse gases[6].

The potential for sustainable development is challenged by issues such as growing population, increasing poverty and hunger, damage and over exploitation of natural resources and biodiversity and the increasing concerns about the rate and severity of climate change. The Food and Agricultural Organisation of the United Nations has estimated that 800 million people are still short of good quality food.

It is against this backcloth that a range of genetically modified (GM) crops have been developed and are being grown in many part of the world. In 2007, over 10 million farmers in 23 countries grew more than 114 million hectares of GM

[1] UNCED 1992 http://www.un.org/geninfo/bp/enviro.html , MDG7: 'Ensure environmental sustainability' http://www.undp.org/mdg/goal7.shtml , World Summit 2002 http://www.state.gov/g/rls/rm/2002/10836.htm
[2] Convention on Biological Diversity, see http://www.biodiv.org/convention/convention.shtml
[3] United Nations Framework Convention on Climate Change, see http://unfccc.int/2860.php
[4] (as footnote 1)
[5] (as footnote 2)
[6] (as footnote 3)

crops—mainly soyabean, maize, cotton and canola (James, 2007). GM crops have been developed with a range of traits including herbicide tolerance, insect resistance, and drought tolerance, while recent work has focussed on the use of biotechnology to produce nutritionally enhanced food and feed. In this paper we briefly review the way in which GM crops are contributing at an international level to sustainable development, focussing on economic, environmental and social perspectives.

Economic benefits

Reviewing the economic impacts of transgenic crops in developing countries, Raney (2006) notes that, given the availability of suitable cultivars, adoption is dependent on institutional and IPR circumstances, regulatory capacity and input markets. Brookes and Barfoot (2008) report that a common cost ratio applies across all transgenic crops: that is, payments to the seed supply chain (including sellers of seed to farmers, seed multipliers, plant breeders, distributors, and the GM technology provider) is typically about one third of the net benefit. Overall, Brookes and Barfoot (2008) report that the cost of accessing GM technology worldwide in 2006 was US$2,687M, leaving farmers worldwide with net benefit of US$6,915M. Of these totals, farmers in developing countries pay only US$742M for the technology and achieve benefits of US$3,713M.

The most extensive *ex post* studies of transgenic crop adoption have been conducted for insect-resistant (IR) cotton in Argentina, China, India, Mexico and South Africa. Yield improvement, higher revenue and lower pesticide costs are widely reported for IR cotton, in most cases giving significant net benefit after accounting for higher seed prices. Other large-scale GM crops include herbicide-tolerant (HT) soybeans, grown in Argentina, Brazil, and Paraguay. James (2007) reports that in 2007 about 64% soyabean production worldwide is GM and that the cumulative benefits in Argentina between 1996 and 2005 were US$20bn.

Yield

IR and HT crops are not engineered to increase yield directly, but experience has shown that, by reducing losses from pest pressure and weed competition, GM crops in many cases produce higher yields than equivalent conventional crops. In the case of *Bt* cotton, Fernandez-Cornejo and Caswell (2006) reported that increases in cotton yields in the Southeast United States were associated with the adoption of HT and *Bt* cotton in 1997; a 10% increase in HT cotton area led to a 1.7% increase in yield and a 10% increase of *Bt* cotton area led to a 2.1% increase in yield. The same authors quote 2001 US government survey data showing that maize yield was 9% higher for *Bt* maize than for conventional maize.

Commenting on yield increase obtained by *Bt* maize farmers in Spain, Gomez-Barbero *et al* (2008) observe regional differences in yield between *Bt* and conventional maize ranging from -1.3% to +12.1%. They note that *Bt* technology performs differently in the three regions studied, and this variability can be explained by heterogeneity between farmers, differences in pest pressure, agro-ecological conditions and the fact that *Bt* technology may not yet have been introduced in varieties suitable for all regions.

Glyphosate-resistant soyabeans have been grown commercially in Romania since 1999, and were planted on 55–60% of the hectares in 2003. The average increase in soyabean yield was estimated to have been +31% owing to improved weed control, especially of difficult-to-control weeds like Johnson grass[7].

Economic advantage can arise in other secondary effects of GM crops. A glyphosate-resistant weed control package for soybeans has led to changes in rotation and fallowing practices. In Louisiana, conventional practice for many years has been to grow sugarcane for 3–5 years, followed by crop destruction and a fallow period when glyphosate is used to reduce rhizomatous Johnson grass levels. Research has shown that, instead of fallowing, the field can be planted with glyphosate-resistant soybeans and the glyphosate usage will reduce the Johnson grass levels for the subsequent sugarcane crop while at the same time resulting in a profitable soybean crop harvest instead of a non-crop fallow period. (Gianessi, 2008).

Herbicide costs

GM crops have the potential to reduce herbicide costs directly, and also reduce the indirect application costs (Phipps and Park, 2002). Herbicide savings are reported for canola in Canada (Brimner, 2005), where conventional canola required an average of 0.69 kg/ha herbicide over a five year period, compared with 0.34 kg/ha for herbicide-resistant canola. Qaim and Traxler (2005) note that savings of 24% in weed management costs are reported for HT soybean growers in Argentina when compared with conventional soybean weed control programmes based on herbicides. Part of this saving arises because HT soybeans are tolerant to glyphosate, which is usually cheaper than other herbicides. To analyze the farm level effects of RoundupReady (RR) soybeans in Argentina, an interview-based survey was implemented in late 2001. From the survey, Qaim and Traxler quantified benefits to Argentine farmers who had adopted RR soybeans. The use of HT (glyphosate) soybean/ resulted in fewer tillage operations and reduced the time needed for harvesting, and consequently it reduced labour and machinery costs by 14%.

[7] Brookes http://www.pgeconomics.co.uk/pdf/GM_soybeans_Romania.pdf

Environmental benefits

There are a wide range of concerns about the widespread use of GM crops and their impact on the environment (de Jonge 2006; Varzakas *et al*, 2007). However, a range of work also suggests the potential for considerable benefits (Carpenter *et al*, 2002; Phipps and Park, 2002; Brooks and Barfoot, 2008; Strange *et al*, 2008). In a review of results from GM HT soybeans in the USA, Bonny (2008) observes that herbicide use at first declined after a switch from conventional to HT soybeans, with an indicator of environmental impact decreasing from 29.15 in 1994-1996 to 20.4 in 2001, but tended to increase after that, to 23.8 in 2002 and 25.7 in 2006 as glyphosphate was introduced in place of conventional herbicides. Over the same period, the average number of treatments fell from 2.7 in 1995 to 2.1 in 2006.

Green House Gas Emissions

Savings in pesticide and reduction in applications both mitigate greenhouse gas (GHG) emissions associated with cultivation of crops. Further, it is accepted that changing agricultural practice from conventional to low-tillage systems has a net benefit in reducing agricultural energy use. Clewis and Wilcut (2007) report tests which confirm the advantage of weed management in transgenic cotton using strip tillage, compared with conventional crop and tillage. Their data show that economically effective weed management can be obtained in both conventional- and strip-tillage cotton production environments. Glyphosate provides broad-spectrum weed control, high cotton yields, and net returns while requiring minimal inputs of soil-applied herbicides, allowing for full expression of yield potential from the glyphosate-resistant variety.

Another trend that may have contributed to the overall decrease in herbicide use is the increased adoption of integrated weed management programs (IWM) that promote alternative means of weed control, such as rotary hoeing, between-row cultivation and crop rotation, coupled with reduced rates of herbicide application.

Soil quality

The American Soybean Association strongly supports adoption of GM soybeans (Docket No. APHIS 2007-0019), and in particular describes the associated conservation tillage as having a number of benefits:

- widespread adoption of conservation tillage crop production methods has decreased soil erosion due to wind and water by 90% or more, and greatly reduced consumption of fuel required for U.S. soybean production

- population of earthworms subsequently increases in direct proportion to the amount by which mechanical cultivation is avoided
- avoidance of over-cultivation allows natural fungi that grow on plant roots to produce glycoprotein, a protein that sequesters carbon taken in by plants and keeps it within the soil
- glycoprotein helps subsurface spaces to be created which allow water, oxygen, and plant roots to permeate the soil.

Qaim and Traxler (2005) observe that herbicides differ in their mode of action, duration of residual activity, and toxicity. Glyphosate essentially has no residual activity and is rapidly decomposed to organic components by microorganisms in the soil. Christoffoleti (2008) presents results from a reduced-tillage study of glyphosate-resistant (GR) crops that indicate differences in soil biological and chemical properties. Under continuous GR maize, soils maintained greater soil organic carbon and nitrogen as compared with continuous non-GR maize. In China, Liu *et al* (2008) show that *Bt* rice has no adverse affect on rhizosphere soil microbial community composition.

Water

When heavy tillage equipment is no longer driven over minimum-tillage fields, large topsoil particles are not ground-down to smaller particles by abrasion, and are able to absorb more rainfall. In a study of impacts of soil management practices, in which two watersheds were cropped with maize over a twenty year period, Wang *et al* (2008) quantify the benefits of ridge-till over conventional-tillage. The long-term effects of ridge-till reduced surface runoff by 36-39%, and gave a reduction in cumulative soil organic carbon loss of about 65%. The average annual maize yield with ridge-till increased by about 4%.

Cassava is an important crop in semi-arid zones of sub-Saharan Africa. A drought-tolerant variety has proved highly productive in trials in Burkina Faso, Chad, DR Congo and Nigeria. Developed in Nigeria at the International Institute of Tropical Agriculture (IITA), Ibadan, and monitored and reported by IITA, the variety has high resistance to Cassava Bacterial Blight and Cassava Mosaic Disease. The variety also has excellent hosting qualities to *Typhlodromalus aripo*, an effective biological control agent of the cassava green mite. IITA claim that with trained management the variety produces 30 to 50 tonnes per hectare, compared with 5 tonnes per hectare for common local varieties.

Biodiversity

The implications of GM crop introduction for biodiversity are complex; although there is evidence that some outcomes are beneficial. For example, the growing adoption of HT soybeans and no-tillage agriculture in Argentina has increased the use of glyphosate as the main tool to control weeds. This has helped to reduce the density of many weed species, and has increased the density of some others that were previously not always part of the community. As a result, biodiversity has been maintained or even increased, a key factor for sustainability of glyphosate in cropping systems. Use of crop rotation further increases weed diversity, and reduces the weed community specialization and selection.

Field studies of soybean crops in northern and southern regions of USA reported by Scursoni *et al* (2006) indicate that limited use of glyphosate has little long term effect on weed diversity. Some of the new weed species found in the fields sprayed with glyphosate on no-till crops have shown a higher tolerance to glyphosate; in Missouri and farther south, long growing seasons allow weeds that emerge and grow late to escape single glyphosate treatments, and this may reduce crop yields substantially. In contrast, in Iowa and farther north, a single glyphosate application inhibits weeds sufficiently to maintain high glyphosphate-resistant (GR) soybean yields, but still permits expression of high effective species richness. Thus, in north temperate agroecosystems, one-pass glyphosate management systems in GR crops may serve agronomic and environmental needs simultaneously.

Social benefits

The Environmental Impact Quotient considers risks to farm workers and consumers as well as ecological risks (Brimner et al, 2005). *Bt* sprays are favoured by some organic farmers partly because they reduce risks to health associated with insecticides, but they are more expensive and more difficult to apply than conventional chemical insecticides. Icoz and Stotzky (2008) note that the toxins of *Bt* are highly selective; different strains kill different insects, and only those insects. Sunlight breaks down the proteins, and rain washes them from plants. Sprays of *Bt* have to be applied when the target insects are feeding. However, *cry* genes inserted into *Bt* plants by biotechnology are in a form which, when expressed, are already activated. The introduction of HT soybeans, in particular, has changed patterns of use of chemical herbicides. Glyphosate is classified internationally as a toxicity class IV pesticide, the lowest class for toxicity; the herbicides that glyphosate has replaced in soybean cultivation belong to toxicity classes II and III.

For the future, Chu *et al* (2008) have shown that the most potent peanut allergens can be silenced in transgenic plants and that this approach can produce hypoallergenic peanuts.

Aside from economic and environmental benefits, there are numerous incentives to use transgenic methods to enhance nutrition. Newell-McGloughlin (2008) lists examples of developments that improve protein quality, modify carbohydrates and fatty acids, add micronutrients and introduce functional secondary metabolites. She observed that nutritional research has historically been hampered by limited knowledge of complex metabolic pathways; advances in proteomics and glycomics are beginning to reveal opportunities for efficient and cost-effective transgenic contributions to productivity and sustainability. Polyunsaturated fatty acids can be derived from crops rather than fish oils (Napier *et al*, 2006). Work at Rothamstead confirms that transgenic plants can be used to synthesise *n-3* very long chain polyunsaturated fatty acids (VLC-PUFAs), providing a sustainable source of these important dietary components.

Nutrition has already been enhanced via Quality Protein Maize (QPM), developed specifically to reduce malnutrition in parts of Sub-Saharan Africa. Krivanek *et al* (2007) reported that the International Maize and Wheat Improvement Center (CIMMYT) has collaborated with IITA in Ibadan, Nigeria, and National Agricultural Research Systems (NARS) to develop a broad range of QPM cultivars. Breeding and dissemination is making good progress, with commercial cultivars released in 17 countries. Increased protein quality has been demonstrated in clinical studies; evidence from community level studies in Africa is awaited.

Discussion

This paper has briefly reviewed some of the mechanisms by which GM crops could contribute to the sustainable development agenda under the auspice of economic, environmental and social benefits. The 120 million hectares harvested in 2008 by an estimated 12 million farmers suggest that they see clear economic benefits to growing the crop, whether that be via crop yield increases, or reduction in input costs. However, there are potentially much wider benefits via reduced environmental impacts, as well as societal improvements via improved nutrition. Fedoroff[8], in reviewing global food security for the US government, observes that:

[8] http://www.state.gov/g/oes/rls/rm/111147.htm#start

- there is growing competition for water resources; water runoff from the low-tillage systems associated with HR crops is greatly reduced, with corresponding improvement in water use efficiency
- farmers growing GM rice reduce their pesticide use; more than 10% of farmers growing conventional rice in China show symptoms of pesticide poisoning, while those growing *Bt* rice avoid this
- in 12 years since their initial introduction, insect-resistant GM cotton and corn have reduced the amount of pesticide used by almost 290,000 metric tons of active ingredient, with consequently more insects and more wildlife, such as birds, which can thrive along with crops.

These advantages must be balanced against perceived concerns raised by environmentalists, some scientists and members of the general public which mean that GM crops are currently not grown, or indeed included in the diets of humans and animals in some parts of the world, most notably Europe.

Domingo (2007) questions whether sufficient toxicological assessment of GM foods is being carried out, while Munro (2008) considers that coexistence may be impossible without strong regulation of planting patterns. De Jonge (2006) cites a company (un-named) that is a GM provider as one of her examples of a corporate body's failure to engage sufficiently with public concerns; she considers that the corporate commitment is legally, economically and anthropocentric inspired, whereas the majority of the stakeholders' arguments are of ethical and biocentric nature. The company and its stakeholders seem to speak different languages.

However, as the world comes under increasing pressure to feed an increasing world population from a fixed or dwindling resource basis, the prospects offered by a range of GM crops to tackle poverty, hunger and other development issues cannot be sidelined and would appear to have the potential to make a significant contribution to achieving international goals for sustainable development.

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