Issues in the political economy of agricultural biotechnology

Journal Item

Issues in the Political Economy of Agricultural Biotechnology

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Agricultural biotechnology is typically analyzed critically by means of a political ecological focus on the science and its ecological implications – agbio science as a radical and 'non-natural', break with 'normal' trajectories for 'new plant science'. Surprisingly, less attention has been paid to a range of key political economic issues, many of which were important in the last big food production technology 'revolution', the green revolution. This paper will focus on three areas of political economy. First, we discuss the corporate drivers of agricultural biotechnology, and examine whether these drivers have already set the technology so that it cannot be changed. Second, we investigate the present economics and technology of genetic modification in plants, and its possible future. Third, we examine empirical evidence for alternative visions of the technology.

Keywords: Biotechnology, agriculture, technology drivers, policy alternatives

INTRODUCTION

Agricultural biotechnology, especially transgenetic agri-biotechnology, is often analyzed critically through the lens of political ecology. The focus is on the science and its ecological implications – agbio science as a radical, and 'non-natural', break with 'normal' trajectories for 'new plant science'.[1] Analyses focus, for example, on the 'introduction' of 'foreign' genes into plants; and on 'terminator' genes that will 'kill' plants after one season. Arguments in this vein also often highlight the monopoly control of big multinationals over both the seed and the linked chemicals used to spray the seeds/plants, leading to monopoly control over the whole planting system and complete commodity chain from field to plate.

Surprisingly, less attention has been paid to a range of key political economic issues, many of which were important in the last big food production 'revolution', the green revolution. There has been less political economic analysis of differences between agrarian producers, notably inequalities among different classes of farmers in access to 'the benefits' of agricultural-biotechnology. Indeed, there has been a strong eco-populist tendency (to use the term of Bernstein and Woodhouse, 2006) to argue that 'Third World' farmers will be disadvantaged by new GM (genetically modified) technology, with little or no accumulation potential for any farmer, anywhere. Instead, all GM technology is portrayed as having

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[1] There are some exceptions, for example the Special Issue of *Journal of Development Studies*, 43(1): 2007, edited by Ronald Herring.

negative consequences, with no potential for productivity or income improvement except by one (Monsanto) or a very few monopolist chemical-seed conglomerates.

A sub-genre of the literature has looked at development dilemmas associated with GM technology. Herring (2007a, 4) summarises some of the key concerns of its critics: 'Opponents of transgenics argue that it is precisely the most vulnerable people who will be at risk; critiques often begin with intellectual property... . Poor farmers, in this view, will be crushed by bondage to multinational monopolists'. He emphasizes that 'these are questions of great consequence and are amenable to empirical treatment', and then posits an opposing argument that 'if [GM] proponents are correct, but critics win politically, the poor would be denied significant opportunities for improving their lives'. He goes on to make the oft-forgotten point that precautionary approaches to slow technology uptake when there are major possible risks is not a costless decision: 'precautionary approaches are therefore not costless: the status quo is hardly risk-free for the world's poor'.

In practice however the debate on transgenics has not followed what Herring calls the familiar 'north-south tectonics'. In the 'north' the US has, in the main, embraced transgenics, whilst Europe has most decidedly not. In Europe, the gains from non-adoption of transgenics are portrayed as not going down a 'doom-laden' technological trajectory with massive ecological destruction.

Would a more political economic analysis of agricultural biotechnology produce a different narrative and point to different options? This paper seeks to suggest at least a partial answer, to this question. We concentrate on the development of agricultural biotechnology from the perspective of how it has evolved, and how its applications reflect corporate power and strategy. We detail the processes of industrial and technological restructuring and accumulation, and consider the science/technology dimensions of this type of production technology and some of the social relations and dynamics of its adoption.

We focus on three key areas of political economy. First, we argue that the economic drivers of agri-biotechnology have been competitive pressures in a rapidly maturing agricultural chemicals industry, with increasing monopolisation, and increased integration of the hybrid seeds industry into the agri-chemicals industry, with implications for value-chain control. At the same time, the big multinational chemical corporations have separated their pharmaceutical from their agri-chemicals businesses, which were tightly integrated only a decade ago. We suggest how the production of GM and linked technological changes reflect particular processes of accumulation, and ask: has this corporate shaping been so dominant that there is no alternative narrative or possible future outcome?

Second, to begin to answer this question requires some analysis of the present economics and technology of GM. The technology of genetic modification of plants is still seen by scientists as in its infancy and rather crude – it is still described as first generation, meaning focused on 'input traits[2]' such as herbicide, insect pest and disease resistance. We

[2] By input trait we mean improvements designed to alter some aspects of production, leaving the end-product identical to a conventional variety. The aim is to make farming and agricultural production more efficient at least for some groups of farmers. Output traits on the other hand change the composition of the final product to enhance its appeal to consumers, such as improved nutritional content (for example, 'golden' rice). The aim is to improve the quality of agricultural products and thus their value. Such 'output trait' modifications are often termed 'second' generation GM products. The term 'third' generation product is used to describe bio-

consider: the implications of the long lead times in the process that turns science to new products; the relationship to the seeds value-chain, that was dominated by Monsanto and later became DuPont's strategic advantage; the importance of present agri-biotechnology to farming; and, the potential of 'second' and 'third' generation technologies. The focus here, then, is: what does GM 'agri-biotechnology' offer in terms of agricultural production? What are its environmental and economic effects and who gains from them? In short, how important is GM agricultural biotechnology for agricultural production now and in the future?

Finally, we examine what evidence exists for alternatives in GM development and adoption, public and private, and argue that there is some scope for alternative approaches to those of the dominant corporation drivers of GM technology.

THE CORPORATE LANDSCAPE OF AGRICULTURAL BIOTECHNOLOGY

Much social and economic research on agri-biotechnology presumes that there is only one, inexorable path for the technology and its impact on farming, namely that determined by a small group of large multinational agri-chemical and seed firms. A major cross-European research project in the late 1990s and early 2000s - Policy Influences on Technologies in Agriculture (PITA) - investigated this proposition with a study of research and development (R&D) strategies in large and small companies in agri-biotechnology, seeds and chemicals and what shaped those strategies (PITA 2001; Chataway et al 2004; Bijman and Joly 2001).

One key finding of that study was that the motives behind many R&D decisions could be linked to the particular and ongoing technology trajectories in individual companies. Rather than assuming a particular rate and direction of investment in innovation, the study carefully analyzed the reasons why individual companies design particular R&D, innovation and merger and acquisition strategies. Whilst much writing about agricultural biotechnology assumes that all private companies, in particular all large multinational companies (MNCs), have common objectives and strategies, this research dug deeper into decision making in companies and in doing so showed their more diverse approaches to strategy.

The study pinpointed what had recently become a maturing industry, finding it hard to identify radical new ways of increasing profit levels. During the 1990s, many agri-chemical companies were divested from their corporate parents' pharmaceutical subsidiaries. This was a radical departure, since the big pharmaceuticals and agri-chemicals industries were a tightly integrated chemicals-based entity only a decade before. In the late 1990s and early 2000s the sector had also seen increasing monopolization, with Hoechst and Schering (AgrEvo), Rhone-Poulenc, American Cyanamid, Novartis Crop Protection and Zeneca Agrochemicals merging or being acquired to make up what is now the six largest global agri-chemicals companies (see Table 1). Over the same period there was increased integration of the hybrid seeds industry into the agro-chemicals industry, with rapid commodification and thus impact on commodity-chain control[3].

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manufacture of pharmaceutical products such as ingestible vaccines and other 'pharma-crops' containing antibodies and proteins.

[3] For example, the development of the GM seeds market has lifted seeds sales growth very significantly faster than agri-chemicals sales. Between 2000 and 2008, the GM and conventional seeds market rose by 5.9% annually (GM by 19.5% and conventional by 2.1% annually).

Chataway et al (2004) suggested that, as the agro-chemical sector became more mature during the 1980s, multinationals were searching for a new R&D direction. Biotechnology was increasingly seen as one way, if not the only one, to transform their fortunes. Companies increased their technological diversity (Granstrand et al, 1997) as a means to introduce improved and new products. In all cases companies defined themselves as moving towards biotechnology, not merely using biotechnology to develop better chemicals.

A main finding of the PITA project, then, was that companies differed in the extent to which they invested in GM technology as a replacement for non-GM technology or as an addition to other technological trajectories and product lines. The agricultural biotechnology trajectory was the product of a complex political and economic context and of the particular circumstances and decisions made by dominant firms.

In particular, Monsanto adopted a radical position with regard to biotechnology in large part because of the narrowness of its chemical technologies and product base. Table 1 illustrates that Monsanto still remains weaker in agro-chemical sales than the largest European-headquartered agrichemicals firms, but is now easily the world's largest proprietary seed producer. Monsanto was the early leader in plant biotechnology, throwing itself wholeheartedly behind the technology. In a sense it had less to lose from investment in biotechnology than the bigger agri-chemicals firms since it had a very narrow technological base with a large proportion of its profit coming from one chemical - its glysophate herbicide, Round-Up. The R&D strategy of developing GM crops resistant to Glysophate, and also developing GM induced insect resistance based on Bacillus Thurigeinisis (Bt) genes, fitted well with a company that had significant herbicide market share but little presence in insecticides. Monsanto's technological leadership was cemented by its aggressive acquisitions strategy. It acquired a group of seeds and biotechnology companies with investment in 1998 alone more than $4bn. (Monsanto Annual Report 1998, 11).

Most other firms had more to lose from a technology whose main marketing attraction was lower chemical use, since they were predominantly chemicals firms with broad portfolios of agri-chemicals products whose sale volumes would decrease if the claims for GM technology were borne out. Indeed, the value of agri-chemical sales of the top six companies in 2007 (made up of the top ten companies in 1996) with 74 percent of the global market in 2007 rose by just 14 percent, from $25.2bn to $28.8bn, in those 11 years. The other companies moved more slowly than Monsanto and in different ways. Novartis, for example, developed a less radical but broader strategy, based on food and feed chain innovation, the incremental integration of biotechnology, and a focus on crops that it knew well. Zeneca, later to join with Novartis, focused more on output traits than input traits. Its research included nutritional characteristics of cereal crops, and incorporation of effects that it could sell as beneficial to consumers and their health. The prime early example was a tomato paste made from tomatoes genetically modified to ripen slowly in the field and to stay ripe for longer to assist processing and improve flavour (Flavr savr). It was labelled as GM on European shelves and sold well for a period until the anti-GM movement grew. Other companies delayed moves to buy seeds businesses until later. DuPont moved into seeds in a huge way with its take-over of Pioneer Hi-Bred in 1999. Bayer took over Aventis in 2001 and BASF moved late, but fast, into GM with an R&D focus on second and third generation plant biotechnology. Potential products from these plants include those producing starch for technical applications as well as plants with higher levels of vitamins, and with omega-3-fatty acids with claimed potential to prevent cardio-vascular diseases, disputed by some who argue that plant omega-3 fatty acids are less beneficial than those from marine sources.

The PITA project also concluded that Monsanto and other companies' initial aggressive response to concerns about regulation of the technology backfired and fed into increasingly strident anti-GM positions.

To summarise, Chataway et al (2004) identified three distinct strategies among the companies they examined: Monsanto, from an early date, and DuPont later with its takeover of Pioneer seeds company to add to its agro-chemicals portfolio, invested large amounts of shareholder funds in acquisitions – a strategy described by other companies as 'buying the channel to market' for their chemicals. They also invested heavily in building up their technological base in biotechnology. Monsanto in particular, being relatively weak in its range of agri-chemical products, radically changed its innovation strategy towards the seeds part of the commodity chain

Second, other companies (Zeneca and Novartis Seeds that became Syngenta, also Dow and Aventis, later bought by Bayer) tried to capture value in a different way – they invested a great deal in the technology and made some acquisitions to give them a reasonable 'route to market' but they did not invest in seed companies or distribution mechanisms to the same extent as Monsanto and DuPont.

Third, BASF was a late starter in the late 1990s with different strategies, looking for benefits from its agro-chemicals businesses to help it buy into biotechnology bypassing the earlier innovation phase of other companies. Bayer then bought Aventis in 2001 to move from sixth biggest to largest global agri-chemical company, and BASF has recently signed a $1.5bn strategic R&D collaboration with Monsanto to develop higher yield maize, soya, cotton and rape.

Over the last decade there has been further concentration in the industry. For example the top ten agro-chemical companies in 1997 had merged into six by the mid-2000s, the first three headquartered in Europe and next three in the USA (Table 1). Three of these firms also control about half of the global proprietary seed market - Monsanto with 23% of global market, DuPont with 15% and Syngenta with 9%. All six firms are now conducting seed R&D, and all are rapidly increasing R&D spending, whilst agri-chemicals R&D is growing much more slowly.

Table 1 Top six agrichemical companies and their seeds businesses, 2007

Company (HQ)	**Acquisitions and mergers since 1997**	**Agri-chemical sales, 2007 (US$m)**	**Seed sales, 2007 (US$m)**
Bayer (Germany)	Bought Aventis (itself a merger between AgrEvo (Hoechst and Schering) and Rhone-Poulenc) in 2001	7,458	524 (7th)
Syngenta (Switzerland)	Merger between Zeneca (itself a merger between ICI and Astra's agrichemical businesses) and Novartis' agricultural business	7,285	2,018 (3rd)
BASF (Germany)	Bought American Cyanamid (top ten pesticide company) in 2000	4,297	
Dow AgroSciences (USA)		3,779	
Monsanto (USA)	Merged with Pharmacia and Upjohn in 2000. Took over a significant set of seeds companies from the mid-1990s, including leading GM pioneers. Took over Seminis (fifth largest global seed company and the leading vegetable seed company) in 2005.	3,599	4,964 (1st)
Du Pont (USA)	Took over Pioneer Hi-Bred seeds in 1999	2,369	3,300 (2nd)
Proportion of global market		74%	49%

Source: Agrow and authors.

After the early 2000s flurry of merger and acquisition activity and the high drama of the debates over GMOs (genetically modified organisms), recent years have been relatively stable in terms of overall corporate investment and consolidation. R&D expenditure has seen a small increase in volume terms with a small decrease as percentage of sales, around 10 percent, which makes the industry comparatively R&D intensive (Table 2).

Table 2: R&D as a percentage of sales (selected years)

Company	**R&D expenditure ($m)**		**R&D as percentage of sales**	
	2004	**2008**	**2004**	**2008**
Syngenta	809	969	11.1	8.3
BASF	365	325	7.1	9.8
Monsanto	509	969	9.3	8.5
Bayer Crop Science	679	649	11.4	10.2
Dow	335	390 est.	9.9	8.9 est.
DuPont	n.a	660 est.	n.a.	10.1 est.

Source: Authors, from Annual Reports of each company, except for some Dow and DuPont data which were estimated from consultant's reports.

However, the legacy of the debates and decisions of the first decade of this century are very evident in terms of geographical distribution of investment in GM R&D. Opposition to GM in Europe and a virtual moratorium on the use of GM crops has led companies to reassess their plans to develop GM crops for the European market and to lower their R&D in European countries. For example, Syngenta's major research centres are now located in Stein, Switzerland; Jealott's Hill, England; Research Triangle Park, North Carolina, USA but also Goa and Beijing. Syngenta opened its enhanced chemistry centre in Goa in 2006, and in 2008 a new biotechnology centre in Beijing to concentrate on early stage valuation of genetically modified traits for key crops such as maize and soybean in areas such as yield improvement, drought resistance and disease control.

Monsanto's gung-ho strategy has so far paid off. It still dominates commercially available GM crop varieties (Table 3).

Table 3 Number of commercially approved GM crops by company

Crop	Monsanto	Pioneer (DuPont	Bayer/Aventis/ AgrEvo	Syngenta Seeds	BASF
Maize	18	5	4	12	1
Cotton	7	-	2	1	-
Soybean	2	2	4	-	-

NB: These include all the traits for the three most dominant biotech crops, 2008.
Source: www.agbios.com

The number of firms using biotechnology to develop new varieties of plant has decreased. The increase in concentration can be gauged from patent and field trial data. Between 1990 and 1994 five firms accounted for 36.7 percent of biotechnology plant patents granted by the USPTO. The share of the top five firms increased to 80.5 percent between 2000 and 2004. Between 1995 and 1999, 146 firms applied for at least one GM field trial. Ten years later the number declined by almost half to 76 firms between 2005 and 2009 (Arundel and Sawaya, 2009). Big companies are increasingly undertaking research for second generation GM crop products, such as: quality traits (flavour enhancement; better processing and feed quality, including animal feed crops tailored to the nutritional requirements of different species); improved nutrition in crops such as vegetables and rice (eg rice with additional vitamin A and iron; or traits that might lower the incidence of heart disease, often described as 'functional foods' or 'nutriceuticals'. The share of research on second generation crops has steadily increased. For example, field trials on agronomic traits increased from three percent of all field trials in 1990 to 30 percent in 2008 (Arundel and Sawaya, 2009). A potential third generation of GM innovations involves plants being used as 'factories' to develop a wider range of chemicals, including pharmaceuticals and bulk chemicals.

In conclusion, there has been undoubted concentration and commodity-chain integration of seeds, chemicals and biotechnology. The maturation of the agri-chemicals industry has led many companies to divide off their higher profit health chemicals/biotechnology firms and to invest in the seeds part of the plant commodity-chain, so capturing new intellectual property from the combinations. Monsanto's strategy keeps it as the leader in 'first' generation GM crops, leaving other companies to 'catch-up' and attempt to leap-frog into second and third generation technologies. Overall, corporate investment in technology has held up well, given the loss of European markets to GM technologies. This suggests that companies have not been put off the technology. Their determination to dominate key global markets, though, has put them off investing in European facilities.

To our question about corporate concentration, the evidence is strong that a technological-economic pathway has been built with consolidated agri-chemical and seed businesses, focused on a small number of dominant crops (maize, soya and cotton) owned by US and European based multinationals, albeit with Europe becoming a less central location for R&D. This, however, does not mean that alternative technological and socio-economic trajectories are completely absent. Whilst the analysis so far might indicate a straightforward picture of large corporate dominance - and one resulting in an increasingly intensified agriculture under the control of mainly large farmers, there are other more complicated dynamics at play. The following section unpicks some of the complex technological, social, economic and political realities.

THE ECONOMICS AND TECHNOLOGY OF GM

This section examines how agri-biotechnology has affected agricultural production processes[4]. What are the benefits and who gains from its adoption? How important is GM agri-biotechnology for farming?

Crops 'in the ground'

The top three biotech crops in 2008 were: (i) herbicide tolerant soybean (53 percent of global GM crop area) and grown commercially in the USA, Argentina, Brazil, Paraguay, Canada, Uruguay, South Africa, Mexico and Chile; (ii) maize with stacked (multi-herbicide and pesticide) GM traits (20 percent of global area), grown in the USA, Canada, South Africa, the Philippines, Honduras, Argentina, and Chile and (iii) pest resistant cotton (9 percent of global area) grown in India, China, Brazil, Argentina, USA, Colombia, Mexico, Australia, Burkina Faso and South Africa.

These crops are all 'first generation'. The development of 'first generation' GM crops, concentrating on input traits such as herbicide, insect pest and disease resistance, is based on technology which has been the subject of scientific research for a considerable time and could be implemented fairly rapidly.

The fastest diffusion of GM has been in soybean, where GM varieties accounted for 70 percent of global cultivation of the crop in 2008, with recent increases driven by large jumps in soybean production in Latin America. Diffusion of GM into maize began later, but more than doubled between 2003 and 2008, reaching 23 percent of global production of GM. Later approvals for GM in maize compared with soybean in Brazil (approved for 2008 harvest) and China (not approved yet) account for some of the difference. GM cotton diffusion at 47 per cent in 2008 is estimated to grow rapidly in the next few years (Arundel and Sawaya, 2009). A fourth crop (rapeseed/canola) reached 18 percent of global area in 2008, but its expansion is less rapid than the other crops because approval has been slower and the USA is a relatively small producer.

Geography of GM

Despite the rapid spread of GM crops across the globe, and particularly in some developing countries, the area under GM crops is still dominated by a handful of countries. Certainly the geography of GM crop adoption is extremely uneven and has not followed a straightforwardly north-south divide. The USA, of course, has been the first and prime adopter. There, the GM share of total area planted of three key field crops in 2009 was 91 percent for soybean, 88 percent for cotton and 85 percent for maize (Arundel and Sawaya, 2009). Given the small but growing demand for organic and traditional varieties, farmer take-up of GM in those crops is close to saturation in the USA.

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[4] This article focuses mainly on transgenic biotechnologies (GM). However, some data on agri-biotechnology integrates all biotechnology, including non-transgenic breeding methods, such as marker assisted selection and related technologies, tissue culture and biopesticides that use insects or microorganisms to attack plant pests.

However, as is universally known, European countries have not followed the GM route, though there has been significant adoption of non-GM biotechnologies such as marker assisted breeding. In 2008, 92 percent of all GM crops globally were grown in just five countries - the USA, Argentina, Brazil, India and Canada - as shown in table 4. Outside of the 'all or nothing' North America and Europe, take-up has been uneven and data quite difficult to analyze.

In Latin America, Argentina and Brazil are the dominant GM crop producers, and by 2008 nine countries had planted commercial crops, the vast majority either cotton or maize and soybean, mostly grown for animal feed rather than for direct human consumption. By 2005, 65 percent of maize hectarage in Argentina was planted with GM Seeds. The social relations of GM production in Latin America have not been well researched though the geography and nature of the crops indicates that production is by capitalist farmers, including corporate farming enterprises (James, 2008, for Argentina and Brazil).

In Asia, commercial cultivation has been slower. India and China (cotton) and, to a lesser extent Philippines (maize) were the only producers in 2008. In the large Asian countries, indeed, there is a big gap between research and field trials of GM and its use in commercial production. That is, research and development has not translated into significant technology adoption. A number of reasons have been given for this. First, negative consumer opinion towards GM food is suggested by the focus on cotton in India and China (Arundel and Sawaya 2009). Much Asian R&D concerns rice where the next few years will reveal whether GM varieties reach the consumer. The second reason may be the important export markets in Europe, Japan and Korea, where there are very strict regulations concerning GM foods and adventitious presence[5]. This does not seem to affect crops for animal feed – there are large exports of GM maize and soybean from Latin America and the USA to Korea, Japan and Europe, for example. But such barriers to GM foods for direct human consumption may become a factor as GM rice seeds become widely available.

The most recent estimates from the International Service for the Acquisition of Agri-biotech Applications (ISAAA) show that in 2008, some 13.3 million farmers from 25 countries planted up to 125 million hectares of biotech crops. The majority of these farmers, 12.3 million or 90 percent were from 'southern countries', including larger capitalist producers in Latin America, but also smaller producers in China, India, and the Philippines and also to an extent South Africa (James 2008). James estimates that in China there are around seven million farmers growing Bt cotton developed by the Chinese agricultural research system. In India around five million farmers planted 7.6 million hectares of Bt cotton in 2008. Adoption of Bt cotton in India has been rapid, rising from around 10 percent in 2005 to over 70 percent of total cotton in 2008 (ISAAA, 2009). ISAAA argues that pesticide use has also dropped – it reports studies from India of decreases of 39%. These and other data are contested by others, who suggest that smaller farmers have not gained to the same extent as large producers (Glover 2009)[6]. In Africa, South Africa is by far the dominant

[5] One new growth industry arising from GM is that of instrument technology to verify percentage content of GM. The demands in Europe, Japan, Korea, and other countries for no-GM, or very low percentage GM, has led to a new high-tech precision industry that did not exist before.

[6] As an indicator of the 'heat' and polemic associated with research on GM crops: in the same article Glover accused the Reading University group of Morse, Thirtle et al of collusion with Monsanto and Vunisa in South Africa and Monsanto and Mahyco in India, citing their acknowledgement of 'logistical' support. Glover 2009, 36) suggests that 'it is hard to believe that the involvement of Mahyco, Monsanto and Vunisa personnel in the process of selecting research locations, facilitating the researchers' access to the field and directly in the data

GM producer, and also accounts for 82 percent of field trials and thus likely future commercialization. Other countries are beginning to commercialize, including Egypt (*Bt* maize) and Burkina Faso (*Bt* cotton).

Table 4 Area of GM crops by country (million hectares)

Country	**2007**	**2008**
USA	57.7	62.5
Argentina	19.1	21.0
Brazil	15.0	15.8
India	6.2	7.6
Canada	7.0	7.6
China	3.8	3.8
Paraguay	2.6	2.7
South Africa	1.8	1.8
Uruguay	0.5	0.7
Bolivia	--	0.6
Philippines	0.3	0.4
Australia	0.1	0.2
Mexico	0.1	0.1
Spain	0.1	0.1

NB: Limited to countries that produced more than 50,000 ha of GM crops in 2008. Source: adapted from James 2008.

Who benefits from GM crops?

The global value of GM crops in 2008 was estimated at US$ 7.5 billion; accounting for 14 percent of global commercial crop production and 22 percent of the global commercial seed market. 76 per cent of this global biotech market (US$ 5.7 billion) was in advanced capitalist countries and the remaining 24 percent (US$ 1.8 billion) in countries of the South (James, 2008).

Case studies, albeit at small scale, of the economic benefits of Bt-cotton to smallholder farmers in South Africa (Ismael, Bennet and Morse, 2001) and India (Zilberman, Ameden and Qaim, 2007) have argued the potential of GM crops to bring higher yields, more income for those farmers who are cultivating them and also improved health and environmental benefits. A socio-economic study conducted by Huang et al (2005) in Hubei

collection did not have any impact on the data collected and perhaps also on the way it was analysed and interpreted'. These accusations have been vehemently denied and ISAAA has attempted to counter them with further data in its 2009 article. Clearly, more data are required to add light to the heat in this debate.

province on two varieties of rice, GM Xianyou 63[7] and GM II-Youming 86[8], suggested significant benefits of these varieties to farmers. They have reported insect-resistant GM rice yields as six to nine percent higher than conventional varieties with 80 percent reduction in pesticide usage besides reduced adverse health effects. Extensive state-by-state results for cotton in the USA also suggested significantly reduced pesticide use (Marra, Pardey and Alston 2002).

Extensive assessments have been carried out over several years by Brookes and Barfoot, the latest (2009) focusing on the global socio-economic and environmental impacts of GM crops in the first 12 years of their commercial use (1996-2007). They estimated that in 2007, direct global farm income from GM crops totalled $ 10.1 billion representing 4.4 percent added to the value of global production of the four main GM crops: soybean, maize, rapeseed and cotton. Since 1996, there has been cumulative farm income growth totalling $44.1 billion from GM crops. Their latest assessment (Table 5) suggests that ('developing') countries in the south (predominantly Argentina, Brazil, India, China, Paraguay and South Africa) accounted for about 58 percent of total farm income benefits whilst advanced capitalist ('developed') country farmers derived about 42 percent of the benefits.

Table 5: GM crop farm income benefits, 2007 ($ million).

Crop	**Developing**	**Developed**
GM HT soybeans	2,561	1,375
GM IR maize	302	1,773
GM HT maize	41	402
GM IR cotton	2,918	286
GM HT cotton	8	16
GM VR papaya and squash	0	54
Total	**5,830**	**4,252**

Source: Brookes and Barfoot 2009.

Brookes and Barfoot (2009) estimated that the costs farmers pay for accessing GM technologies (Table 6) across the four main crops was equal to 24 percent of the total technology gains.

[7] Created to be resistant to stem borer and leaf roller; it was developed by insertion of the Chinese-created *Bt* gene.

[8] Also resistant to stem borer but developed by inserting a modified cowpea trypsin inhibitor (CpTI) gene into rice.

Table 6: Cost of accessing GM technology relative to total farm income benefits, 2007 ($ million)

Crop	Cost of technology: all farmers	Farm income gain: all farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology: developing countries	Farm income gain: developing countries	Total technology gain to farmers and seed supply chain: developing countries
GM HT soybeans	931	3,936	4,866	326	2,561	2,887
GM IR maize	714	2,075	2,790	79	302	381
GM HT maize	531	442	973	20	41	61
GM IR cotton	670	3,204	3,874	535	2,918	3,453
GM HT cotton	226	25	251	9	8	17
GM HT canola	102	346	448	n.a.	n.a.	n.a.
Total	**3,174**	**10,027**	**13,202**	**969**	**5,830**	**6,798**

NB: Cost of accessing the technology is based on seed premiums paid by farmers for using GM technology relative to conventional equivalents; Total farm income gain excludes $26 million associated with virus resistant crops in the US.
Source: Brookes and Barfoot 2009.

Although Brookes and Barfoot explain their data gathering methods and analysis in detail, their estimates involve generalisations. Their data, and other data that suggest GM crops bring benefits, are contested by others like Glover (2009, 8) who argue that ‘those benefits are neither as simple, as uniform, as context-independent or as sizeable as they have frequently been depicted to be’. He suggests considerable variability in farmer income from Bt cotton in India, with results to show that some ‘resource-poor’ farmers were doing much worse than others. There is clearly a need for better research on the socially differentiated results of cultivation of GM crops by different classes of agrarian producers.

Technology

Those who championed GM in the early days argued that ‘first generation’ was just the beginning and that the real breakthroughs would come from ‘second’ and ‘third’ generation technologies. Early R&D was almost as much on stress tolerance as on herbicide/pest resistance. However, almost all commercial crops at present are ‘first generation’: either herbicide tolerant, or pesticide tolerant, or a ‘stacked’ combination of these two traits. Second generation products make up a tiny proportion of commercial production, though approval is pending for drought tolerant maize.

The focus on two dominant first generation traits in a small number of crops has led to increasing corporate concentration. An important consideration is that the innovation cycle in agri-chemicals is extremely long: ten to 15 years is not uncommon, thus research being conducted today will take at least a decade to commercial realization. As yet there is no evidence to suggest that second and third generation crops might be technologically and economically disruptive in dramatically transforming farming practices. It is possible that in some applications scale economics might be different. For biofuels, for example, the cost (economic and environmental) of getting biomass (the feedstock for fuel generation) to processing plants introduces limits to the benefits of scale. More generally, the lack so far of more sophisticated and higher generation plant material in terms of both input and output traits, has resulted in lack of applications of traits specifically to address agricultural problems such as drought resistance and anti-salinity.

To summarise, GM crops are increasingly important and can provide decreasing chemicals costs and increasing farm incomes. The benefits so far, however, are associated with a small group of (albeit important) crops, for a relatively small number of farmers, in a few, mostly large, producing countries. Unfortunately, there is a major gap in research data on the differentiated nature of GM production. There are a range of micro-studies concerning the nature of production, which suggest that smaller-scale capitalist producers are important in India and parts of South Africa, but there is no information to support reliable generalisation. Second and third generation crops are increasing as a proportion of field trials, but have not been adopted in any significant extent as yet. And, as yet, research and development as not focused on major agricultural problems like drought.

BEYOND THE DOMINANT NARRATIVES

Given the significant advance of GM technology and the increasing dominance of the large agri-chemicals/seeds corporations in the last decade, it may seem perverse to argue that there might be alternatives. Prevailing criticisms of transgenic crops emphasize the monopolization of R&D by the private sector, largely multinational companies (MNCs) that generate proprietary technologies guarded by strict patents with negative effects for consumers and many producers.

This section examines what scope might exist for alternatives beyond the GM trajectory we have mapped above. We consider three aspects. Are there alternatives that may bring benefits to a broader range of farmers and also to consumers? Can public R&D and investment generate alternatives? And are there ways of delivering benefits in different ways? These are questions typically, if not always, ruled out by dominant eco-populist narratives about agricultural biotechnology.

Beyond the USA to the BICAs

We have shown that, although GM has been taken-up most dramatically in the USA, there has recently been a geographical shift associated with GM crops with India, China, Brazil and Argentina becoming major players. Although the technology is most often associated with large MNCs, the social and economic impact has brought benefits to producers in several large southern countries. Whether benefits can be spread more widely depends to an extent on the development of alternative capabilities.

Our preliminary analysis of recent research from a wider range of sources suggests that this may be the case and that there are other drivers of new plant biotechnology. One pattern features public research and a more public approach to farmer take-up and agrarian futures. Second are explicit attempts to introduce a different politics more oriented to the needs of low income producers and consumers. These alternative approaches have the potential to change the nature of second and third generation crops; to change the geography of GM agriculture (further) away from US and other large-scale, highly capitalized farmers; and to challenge commodity-chain dominance by large corporations, for example, by contesting the intellectual property rights regimes they seek to impose and enforce.. Added pressure by multilateral agencies and a variety of other bodies to address food shortages could add to the momentum behind approaches to bring a wider variety of producers and consumers into a more varied framework of plant biotechnology innovation.

Until recently, there have been some extremely effective political movements against the cultivation of any kind of GM crop, whether publicly or privately funded. On one hand, in a recent incarnation of anti-GM analysis Vanloqueren and Baret (2009) argue that present transgenic and chemical intensive technological trajectories lock out agro-ecological innovations and they go on to argue for a new systemic agro-ecological approach. On the other hand, in the past year there were several high profile reports urging increased investment in agricultural science and in plant biotechnology including GM, for example a Royal Society report (2009). Such reports stress that facilitating increased food production in developing countries is not only important for people who live there but vital for the world economy as prices for food will increase globally if investments in raising the productivity of food farming are not made.

Public research

While the large agri-chemical and seeds MNCs invest immense resources in R&D, especially for new transgenic crop varieties, this recognition tends to mask the important role of public sector research (research institutes and universities), the international agricultural research centres (mostly the Consultative Group on International Agricultural Research, CGIAR) and local, developing country companies. As Pray and Naseem (2007: 194) noted: 'in total, there's more private than public research but the public sector still plays a large role, which sometimes is overlooked in the debates about biotech research.'

The share of public sector field trials in all GM trials has increased a little recently to 21 percent in the period 2004-8 (Arundel and Dawaya, 2009). The public sector does more than its share of field trials on second generation traits than the private with greater focus on agronomic traits and crops with smaller markets.

China, India, Brazil and Argentina are already key players in transgenic technologies R&D. In these countries public sector funding to biotechnology research has been substantial (Herring 2007b; Cohen 2005; Spielman, Cohen and Zambrano 2006). Another source of agri-biotech R&D is the CGIAR system which is estimated to invest some US$ 25 million annually in agbiotech research (see World Bank 2004, quoted in Spielman et al 2006). We use the cases of GM development in China and the CG centres' biotechnology focus to illustrate these public trajectories.

Global data on public sector spending on biotechnology R&D is scanty but studies suggest that in 1999, China spent over US$ 100 million in agricultural biotechnology research (Huang et al 2002 quoted in Pray et al, 2007). In July 2008, China's State Council approved a research initiative to launch a 20 billion RNB (approximately US$ 300 million) programme for GM crops (Shen, personal communication.). Shen's research (forthcoming) makes a persuasive case for China leading in transgenic rice technology, with a range of transgenic varieties under trial. The Chinese government has placed considerable emphasis on the role of the public sector in biotechnology research as Keeley (2006 quoted in Shen forthcoming) has summarised:

> A key feature of Chinese biotechnology policy processes is that biotechnology research and development is overwhelmingly a public sector project. Most research is not carried out by private corporations, and most applications for commercialisation of GM crops do not come from private companies. The majority of risk assessment applications are for technologies that are the outputs of research projects funded by the major public science funding bodies, and carried out by National Key Laboratories in state institutes (particularly institutes under the Chinese Academy of Sciences, the Chinese Academy of Agricultural Sciences and the Agricultural Universities, as well as some other key universities). This is a major contrast with development of GMOs in other countries where most applications come from life science companies.

The case of GM rice development in China (Shen, op cit) illustrates this public sector focus. The China Rice Functional Genomics Programme was initiated in 1999 under the National Biosciences Initiatives and funded by the Ministry of Science and Technology of China. By early 2002 Chinese scientists had completed mapping the rice genome. By 2005, China's biotechnology programme had generated a wide array of new technologies including several GM varieties (Huang et al, 2005). Several of these GM varieties have undergone successful field and environmental trials and four varieties were recommended for pre-production trials in farmers' fields (ibid).

The CGIAR focuses on biotechnology, including transgenic, R&D for developing countries. Table 7 provides a summary of the transgenic research projects at the CGIAR as of 2008 (Okusu, 2009). It shows that nine of the 15 CGIAR Centres were conducting biotech research on some 15 different crops focusing on a variety of traits. Most of these are at various laboratory stages, with only a few that have progressed to field trials and no commercial releases so far. However, the Golden Rice Project under IRRI has begun its first outdoor trials in Asia and approvals for release are expected in 2011.

Table 7: Summary of transgenic research at CGIAR centres

CGIAR Centre	Crop	Trait (resistance)	Research
Bioversity	Musa	Pests (weevils, nematodes); disease	Gene discovery and characterization; transformation
CIAT	Beans	Agronomic	Transformation (particle bombardment and *Agrobacterium*); back-crossing on wild species; biosafety greenhouse
	Cassava	Insect; modified starch; early flowering, Beta carotene	Transformation (agrobacterium) of clones used by small scale farmers; field trials
	Rice	Virus, disease Abiotic stress (flood; acid; high elevation) Drought	Field trials Transformation (agrobacterium) of recalcitrant cultivar with target trait Gene discovery (with CIMMYT and IRRI)
CIMMYT	Maize	Insect (*Bt*)	Gene characterization (target insect specificity); transformation and conventional backcrossing; biosafety containment and confinement
	Wheat	Drought Agronomic	Transcription factor/promoter characterization Genetic molecular analysis for transmission and expression Transformation system development (*Agrobacterium*)
lCIP	Potato	Insect (Bt) Disease	Cultivar development; field trials Cultivar development
	Sweet potato	Virus Insect Modified starch	Cultivar development Gene discovery and characterization Cultivar development; field trials
ICARDA	Chickpea	Disease, abiotic stress	Transformation (*Agrobacterium*)
	Lentil	Disease, abiotic stress	Transformation *(Agrobacterium)*
	Barley	Disease, abiotic stress	Transformation *(Agrobacterium);* variety development
	Wheat	Abiotic stress (salt, drought)	Gene discovery and characterization; Transformation *(Agrobacterium*
ICRISAT	Groundnut	Disease, virus	Tissue culture protocol; small scale field trials
	Pigeonpea	Insect (Bt)	Tissue culture protocol; small scale field trials
	Sorghum	Insect (Bt)	Tissue culture protocol
IITA	Musa	Virus, bacteria, fungus	Transformation *(Agrobacterium)*
	Cassava	Virus	Transformation
	Cowpea	Insect (Bt)	Transformation
IRRI	Rice	Blight, insect (Bt); beta Carotene	Transformation Cultivar development; contained field trial

Source: Okusu 2009

There are collaborative (cross-centre) projects as Okusu (2009, 73) reports:

> The Generation Challenge Program[9] combines genomics with molecular biology tools with the aim of developing improved crop varieties, with a focus on abiotic stress tolerance, particularly drought tolerance. The Harvest Plus Challenge Program[10] breeding technologies, including transformation, aims to breed staple foods fortified in micronutrients such as vitamin A, Zinc and iron.

The CG centres have also championed a range of public-private partnerships for agbiotech research (see Table 8 below). Spielman et al (2006) use the term public-private partnership to mean any collaboration involving both public and private institutions so their data encompass a wide range of initiatives, including many where the private contribution is to 'donate' seed in which intellectual property rights have been registered.

The CG centres' new initiatives have had mixed success. Vroom (2009) analyses the Generation Challenge programme, for example, as an innovation in the ways the CG centres can link upstream science-led genomics research and downstream breeding programmes. The Generation Challenge programme sets out to uncover the genetic mechanism of drought tolerance in crops and thus to contribute to agricultural development for 'resource poor farmers' and in arid regions. This large programme attempts both to do basic science and to build new systems of innovation that include farmers from the very beginning at all stages of the process. Vroom (2009) shows how difficult it is to build meaningful involvement of farmers in upstream science and suggests that it might be more fruitful to acknowledge the difficulties of 'engaging farmers with the basic science' and instead to incorporate the interest of farmers in more downstream activities.

The CG centres have begun to reorient their research from more 'science-based' to more 'farmer-oriented'. For example, Puente-Rodriguez (2008) has studied CG research on molecular markers and local potato diversity in Bolivia. He analyses what he sees as two contradictory approaches to this research: biodiversity understood as *raw material* and as *cultural material*. The former is a genomics that uses local potatoes as raw materials without any intrinsic value and in which farmers' varieties can be freely used as breeding inputs to develop commercial varieties, while the latter is a different type of genomics which handles native varieties as final entities constructed by farmers. Puente-Rodriguez suggests that both approaches are being used in the Wiphala project to develop native varieties for commercial purposes - an attempt to connect genomics and Andean small scale agriculture to produce a new genomics.

Finally, Vroom (2008) describes attempts by a public-private partnership to produce 'pro-poor' transgenic cabbages in India that involve redesign of the technology, based on Bt brassica but with strong local 'stewardship' of the varieties. The research at least shows that there is some room for manoeuvre.

[9] See http://www.generationcp.org

[10] See http://www.harvestplus.org

Table 8: Public private partnerships in the CGIAR on agribiotech research, past and present

Research topic/project title	**CGIAR Centres**	**Partners**
Apomixis	CIMMYT	Pioneer Hi-Bred International (Du Pont); Syngenta; Limagrain (France); others
Golden Rice Humanitarian Board	IRRI	Syngenta; Rockefeller Foundation; Swiss Federal Institute of Technology; others
HarvestPlus	CIAT; IFPRI	Syngenta
Unlocking crop genetic diversity for poor people	CIMMYT; IPGRI; IRRI	MAHAYCO; Bayer Crop Science; Pioneer Hi-Bred International (Du Pont); national and international agricultural research organizations; advanced research institutes etc
Agronatura science park	CIAT	Private seed companies; Colombian university biotech laboratories, Colombian national commodity research centres etc
Potato/sweet potato transformation	CIP	Plant Genetic Systems; Axis Genetics; Monsanto
Genomics for livestock vaccine research	ILRI	Merial; The Institute of Genomic Research; others
Bt Genes for Rice transformation	IRRI	Novartis; Plantech and a consortium of public research institutes
Positive selection for cassava transformation	CIAT	Novartis
Biotech Incubator	ICRISAT	Private biotech companies
Fish Genetic Research	World Fish Centre	A private biotechnology company; GIFT foundation international
Research on mimitop-virosome approach	ILRI	Pevion Biotech
Enzyme-linked immunosorbant assay (ELISA) for tick-born diseases	ILRI	Savanona Biotech

Source: Spielman, Cohen and Zambrano 2006

The findings of Cohen (2005) on the role of public sector research in the development of GM crops in the developing countries map multiple trajectories of biotechnology research and also demonstrate that developing countries are not just consumers of R&D developed in the North but are also actively engaging in transgenic research. Cohen has reported on a study of some 201 transformation events of 45 different crops in 15 countries in Asia, Latin America and Africa.[11] The largest number of events (109) was carried out by seven Asian countries (China, India, Indonesia, Malaysia, Pakistan, Philippines and Thailand), followed by four African countries (Egypt, Kenya, South Africa and Zimbabwe) with a total of 54 transformation events and four Latin American countries (Argentina, Brazil, Costa Rica and Mexico) for which 38 transformation events were reported. It is striking, perhaps, that the *World Development Report 2008* (World Bank 2007) exhorted greater public sector engagement in agricultural R&D in developing countries, largely to make up for what it judged to be a failure of the private sector to do enough to produce improved crops for poor farmers (Woodhouse 2009). In late 2009, the Gates Foundation committed a further $120m to agricultural development, mostly in Africa, citing the need to assist small farmers.

Technology access, regulation and economic benefits

One important question in considering this more complicated picture of who benefits from GM is what different classes of farmers in developing countries gain from the use of these plant biotechnologies. Although it is hard to build a comprehensive picture of the differentiated nature of GM technology adoption, there is significant pressure at least from some capitalist farmers, larger and smaller in scale, in some developing countries to become a part of the process of development of GM crops.

A dominant criticism of transgenic plant technology concerns intellectual property rights (mainly patents) in seeds with the effect that farmers are likely to be held 'hostage' by MNCs with devastating effects on developing countries. Examples from Bt cotton in India suggest that 'farmers' are not the 'passive, helpless victims of technology' they are so often framed to be but rather 'active, powerful users of technology' who are not only able to 'pick and mix' the range of technologies available to them (Herring, 2007b) but can pull enough clout to influence policy decisions. Besides, farmers continue to innovate, to adapt the technologies to their settings and as the Indian story shows, have come up with their own 'varieties' which they are able to replicate.[12]

Shen (forthcoming) has noted that the controversies surrounding the GM debate has slowed down, perhaps even derailed, adoption of GM rice in China. In response to the mounting international pressure from anti-GM campaigners, the Chinese government established a biosafety technical committee (consisting only of scientists) under the Ministry of Agriculture. In 2004, a new higher level pan-ministerial committee was set up to oversee biosafety issues, which has not approved any variety of transgenic seeds so far. Shen suggests that this committee is hostage to international organizations championing opposing views on GM technologies. This apparent regulatory bottleneck notwithstanding, Chinese farmers are

[11] An event defined as a stable transformation i.e. the incorporation of a foreign DNA into a living plant cell (by a single institute) thereby providing a unique crop and trait combination.

[12] At the same time, we must acknowledge that Herring's argument is highly controversial in India, and that the 'farmers' in his case studies appear to be small-scale capitalists. One key question, then, which Herring and his co-workers have not researched is whether the adoption of GM crops (principally cotton in the case of India) reflects, and indeed further intensifies, tendencies of class differentiation in the countryside.

reported to have planted GM rice in Hubei province without approval. Jia Hepeng (2005), quoting Greenpeace China, claimed that GM rice seeds were being sold and grown illegally in central China's Hubei province, contrary to an official government ban. Greenpeace China claimed that 19 out of the 25 samples collected from the local rice market were confirmed to contain DNA genetically modified by a Germany-based laboratory Genescan and could have originated from one of the Chinese universities. Apparently, these claims - similar to those about the use of 'illegal seeds in India' (Herring, 2007b) have been confirmed by many organizations in the West as well as media reports in China (Xiaobai Shen, personal communication). A similar incapacity to impose controls was ecountered by the state government of Rio Grande do Sul state in Brazil when it tried to prevent cultivation of GM soya in 2000-1, in line with EU bans on GM soya imports, but GM seed coming across the border from Argentina enabled farmers to circumvent the ban (Philip Woodhouse, personal communication).

These examples raise some interesting issues about the effectiveness of regulatory regimes in developing countries. First, regulatory costs are highest for GM plant varieties, ranging between UD$ 0.4 million and US$ 13.5 million per variety. Each new crop release is estimated to cost between US$ 1.2m and 3 million (OECD, 2009). These high costs can focus research onto a narrow group of key crops. Such costs might influence the ability of farmers to adopt GM technologies. There is some evidence, however, that intellectual property regimes can be subverted by producer resistance. Roy, Herring and Geisler (2007) record that in September 2001 a massive bollworm infestation struck Gujarat and devastated all hybrid cotton varieties except Navbharat 151 (NB151), an unapproved locally produced *Bt* variety. Following investigations, Mahayco-Monsanto Biotech Ltd (MMBL) determined that NB151 contained the *cry1Ac* gene for pest control patented by Monsanto. MMBL charged that Navbharat Seeds Limited (a local company) had been selling NB151 illegally for the previous three years and demanded punitive action against it. India's Genetic Engineering Approval Committee (GEAC) consequently issued orders to the Gujarat Biotechnology Coordination Committee to 'burn all illegal plantations, sequester the crop and sterilize the fields'. However, the orders were never implemented due to resistance from farmers and the Gujarat state government.

Herring (2007b, 133) noted that 'appropriately enough, Gujarat's decision to do nothing to enforce the order was announced in Delhi by the Union Minister for Textiles' emphasizing the influence of political disputes surrounding the emotive issue of the Bt cotton ban. Interestingly, both the Union Minister for Textiles and the Chief Minister of Gujarat pointed an accusing finger at a different target: the pesticide industry lobby group for its 'interest in depriving farmers of the benefit of technology'. Farmers became the victors in this stand-off when the state and national governments declared that 'farmers' interests wouldn't be harmed'.

The farmers' victory in Gujarat provided the much needed push for the immediate approval of Bt cotton in India. As Herring (2007b, 134) recounts:

> On March 2002, farmer representatives led by Sharad Joshi – a member of the *Kisan* (agriculturalist) *coordination committee* (KCC) – threatened to launch a civil disobedience movement if *Bt* cotton were not approved by Delhi. KCC representatives from cotton-growing states across India – Gujarat, Maharashta, Punjab and Andhra Pradesh – rallied for immediate approval, and threatened to cultivate

transgenic varieties whether or not the government approved. The following day, 26 March, the GEAC approved three varieties of the Mahayco – Monsanto Bt cotton.

The case of *Bt* cotton in India is a clear demonstration of the countervailing power of (rich) farmer unions in their struggles against the imposition of corporate power and strict (official) regulation of technology. If farmers are properly mobilized, they can influence political/regulatory decisions in their favour, depending on what their interests are. In this case, they 'forced' government to expedite the approval of transgenic varieties. Of course, this influence could also be used to 'stop' the approval of the technology if the farmers' interests are threatened.[13]

Herring (2007b, 134) states that 'It is clear that a cottage industry of transgenic pocket breeding has grown up around descendants of the original Navbharat 151 seeds'. This 'cottage industry has grown due to the challenges that farmers faced following the ban of the NB 151 in 2001'. He continues:

> Given the high cost of official seeds and the scarcity of the very effective NB 151, farmers themselves began breeding new transgenic hybrid varieties. They use Navbharat 151 seeds for the male contribution and a local variety suited to their agronomic conditions as female. From this process, a new Gujarati word has been hybridised: 'Navbharat variants'. ...These locally backcrossed hybrids made by farmers are sold by local merchants. … . There are as well farmer-to-farmer transactions of modified and crossed transgenic seeds with no names.

This kind of innovation appears to be in the interests of some farmers, but is resisted by those MNCs who argue that they have invested heavily in R&D and will fight to hold on to intellectual property rights for transgenic varieties. Indeed, intellectual property rights issues will be a continuing battle-field for change both from those fighting for 'open source' (see Kloppenburg in this special issue) and those insisting on tightening rights as new molecular GM traits are stacked into products.

In summary, in the face of increased corporate concentration and integration of the agri-chemical seed commodity chain, there is evidence of publicly funded R&D that focuses more squarely on agronomic traits, some concerning key issues like drought and saline resistance and nutrition. There is also evidence of alternatives to corporate patenting restrictions, from the major research programmes of China and the CG centres, resistance from farmers to restrictions on GM crop breeding, and GM seed replication and use.

CONCLUSIONS

The commercialization of the first generation of GM crops has brought concentration and commodity-chain integration of seeds, chemicals and biotechnology. Agri-chemical companies have invested into the seeds part of the plant commodity-chain, so capturing new intellectual property from the integration of GM seed and chemicals. Monsanto's radical

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[13] We have focused here on farmers who have pushed for GM crops to be made available to them, but there are others who have mobilized against the planting of GM crops, as reported by Scoones (2008) and Newall (2008). Their research has shown that anti-GM alliances are made up of diverse and changing groups. Such alliances, they suggest, are less concerned with the pros and cons of a particular set of technologies than with inserting GM into a wider debate about 'the future of agriculture and small-scale farmers, about corporate control and property rights and about the rules of global trade' (Scoones 2008, 315).

strategy has kept it as the leader in 'first' generation GM crops, leaving other companies to 'catch-up' and attempt to leap-frog into second and third generation technologies. The large companies have stuck with GM technology in the face of massive resistance in Europe. Their determination to dominate it in key global markets, though, has lowered their investment in their European R&D bases.

GM crops are increasingly important but the benefits so far are associated with a small group of (albeit important) crops, for a relatively small number of farmers, in a few, mostly large, producing countries. In the US, the market for GM in soybean and maize is close to saturation. Publicly funded R&D is partly directed to key agronomic issues like drought and saline resistance and nutrition, but there has been no commercialization to date. There is also evidence of alternatives to corporate patenting restrictions, from the major research programmes of China and the CG centres to resistance from farmers to restrictions on GM crops breeding.

There has been little research on the class differentiation of GM producers. Those, typically better-off farmers and agricultural corporations who take up GM do so because they obtain improved economic benefits. There is a range of (contested) micro-studies which suggest that smaller-scale capitalist producers are important in India and parts of South Africa in taking up GM crops, but no generalizable information. We would emphasize, however, that debate about the potential of GM to raise productivity in farming should not be deflected by the classic populist preoccupation with what is best for, or can 'save', the poorest farmers in the South. To make this the principal criterion for assessing any technical change (and indeed social change) in agriculture is to undermine our understanding of the history of agricultural advances in the modern world, in the same way that the anti-scientism of more radical 'eco-populism' does.

To go beyond these conclusions suggests an urgent agenda of future work that addresses the weaknesses of research to date. There is a serious lack of evidence on the class differentiated nature of GM technology take-up and benefits. The critique of GM is typically limited solely to biotechnology in agricultural production and homogenizes 'farmers' versus the myriad ways in which different classes of farmers organize their production and reproduction (Woodhouse 2009). A second weakness is the need to address the ways in which changes to intellectual property rights and other regulatory issues might open up innovation in GM and related technologies to broaden both the range of GM crops available and their delivery and accessibility to various categories of farmers.

The 'corporate' drivers of GM have focused their research on existing technological characteristics – two traits dominate. But as the technology becomes more widely applied, trajectories are being influenced by other forces, including those of governments and farm lobbies in the larger 'middle-income' countries. Our evidence suggests that GM technology is not determined into some indefinite future, that its control and direction can be changed as it evolves into new generations.

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