The Anthropology of Genetically Modified Crops

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Abstract

By late in the twentieth century, scientists had succeeded in manipulating organisms at the genetic level, mainly by gene transfer. The major impact of this technology has been seen in the spread of genetically modified (GM) crops, which has occurred with little controversy in some areas and with fierce controversy elsewhere. GM crops raise a very wide range of questions, and I address three areas of particular interest for anthropology and its allied fields. First are the political-economic aspects of GM, which include patenting of life forms and new relationships among agriculture, industry, and the academy. Second is the wide diversity in response and resistance to the technology. Third is the much-debated question of GM crops for the developing world. This analysis is approached first by determining what controls research agendas and then by evaluating actual impacts of crops to date.

GM: genetically modified

HT: herbicide tolerant

Bt: *Bacillus thuringiensis*

ISAAA: International Service for the Acquisition of Agri-Biotech Applications

GMO(s): genetically modified organism(s)

INTRODUCTION

The last half of the twentieth century saw a momentous series of developments in microbiology. By the time the structure of DNA was published in 1953, biologists knew that bacteria could exchange genes via small extrachromosomal rings called plasmids. By the early 1970s, biologists at Stanford University had learned to isolate some individual genes, cut them out with restriction enzymes, and recombine them on plasmids to move genes between bacteria (Halford 2003, Lurquin 2001). By 1983, biologists at both Monsanto Corp. and Washington University had succeeded in moving genes into plants, marking the beginning of transgenic or genetically modified (GM) crops.[1] Because the genetic code is uniform across life forms, genes could now be transferred across phyla and kingdoms; the first GM plants contained a bacterial gene. Although this technology has seen limited application in bacteria and animals, its major impact has been in crop plants.[2]

In 1988, China became the first country to grow a commercial GM crop: tobacco, modified to resist tobacco mosaic virus (Pray 1999). In the United States, the first GM crop was released in 1994: Calgene's ill-fated "Flavr Savr" tomato, with a gene altered to delay rotting (Harvey 2004, Martineau 2001). The next two years saw arrivals of the two plant transformations that have overwhelmingly dominated GM plantings ever since: herbicide tolerance and insect resistance. Herbicide tolerance is usually from a gene for immunity to glyphosate weedkiller, allowing the farmer to spray weeds without harming the crop. Insect resistance is via a gene from the *Bacillus thuringiensis* (Bt) bacterium, which produces an insecticide, and these crops are often called Bt crops. Major industrial crops—soybean, maize, cotton, and canola—with one or both traits were adopted by many farmers in the United States and Canada with little initial controversy.

But by the late 1990s, the situation had become much more turbulent. The spread of GM crops had stumbled badly in western Europe, and opposition to GM crops and foods had emerged in many parts of the world. High-profile, highly evocative campaigns were launched both for and against GM crops. By 1999, debates turned increasingly to the developing world; new crops were cast as either an agricultural and public health savior or as an ominous threat. Even though GM crops were being developed almost entirely for large-scale industrial agriculture, and were being planted in miniscule amounts in developing countries, there was a surge of publicity on GM crops for the third-world poor: vitamin-enhanced rice to "save a million kids a year," high-protein sweet potato, virus-resistant cassava, and fungus-resistant banana (Moffat 1999, TIME Mag. 2000). The industry-supported ISAAA (International Service for the Acquisition of Agri-Biotech Applications) began to issue reports emphasizing GM crop adoptions in developing countries. Opponents of genetically modified organisms (GMOs) also favored the discursive terrain of the developing world, where they depicted GM crops as a danger to farmer sovereignty and the environment. The trajectory of controversy has been covered by journalists (Charles 2001, Lambrecht 2001, Pringle 2003) and social scientists (Jasanoff 2005); the refocusing of the debate on the developing world has been examined in anthropology (Glover 2010; Stone 2002b, 2005b).

The latest figures show that by 2009 GM crops had spread to 134 million ha (**Table 1**),

[1] Like so many aspects of this technology, the terminology is contested. *Genetic modification* (GM) is used here because it is a neutral and accurate term for altering organisms at the genetic level; it is also widely used by advocates and opponents alike. The meaning is the same as *genetic engineering*, but that term implies a greater degree of control than exists at some key points in the process. The term *transgenic* is common but inaccurate for the cases in which genes have been altered in place rather than transferred. *Recombinant DNA*, the original descriptor for this technology, is still the most exact term, but it is unwieldy and out of common usage. Corporate media prefers the nickname *biotech crops*, but biotechnology encompasses a wide range of technologies of which GM is only one particularly controversial subcategory. *Biotechnology* here refers specifically to agricultural biotechnology.

[2] Many introductions to plant genetic modification have been published, ranging from brief (Stone 2002c) to moderately thorough (Halford 2003, Lurquin 2001) to more technical (Liang & Skinner 2004).

Table 1 GM crop plantings in 2009. Compiled from James 2010[a,b]

Country	Area (million hectares)	Soybean (all HT)	Maize (mostly stacked)	Cotton (mostly Bt)	Other (mostly HT canola)
United States	64.0	45%	47%	5%	3%
Brazil	21.4	76%	23%	1%	
Argentina	21.3	88%	10%	2%	
India	8.4			100%	
Canada	8.2	17%	15%		78%
China	3.7			100%	
Paraguay	2.2	100%			
South Africa	2.1	11%	89%	<1%	
Uruguay	0.8	88%	11%		
Bolivia	0.8	100%			
Philippines	0.5		100%		
Australia	0.2			82%	18%
Burkina Faso	0.1			100%	
Spain	0.1		100%		
Mexico	0.1	23%		77%	
(minor plantings in 10 other countries)					

[a]Abbreviations: Bt, *Bacillus thuringiensis*; GM, genetically modified; HT, herbicide tolerant.
[b]Crop-specific figures are row percentages, i.e., breakdowns of each country's total GM hectares, not the percentage of the country's entire planting of the crop is GM.

yet they remain largely a technology for large-scale industrial commodity crops; the most common GM crop (by far) is herbicide tolerant (HT) soybean, followed by HT and Bt maize. However, land planted to GM crops has risen in developing countries, led by Bt cotton (Herdt 2006, Showalter et al. 2009). Other GM crops include HT canola, sugarbeets, and alfalfa; virus-resistant papaya and squash; and blue carnations. Bt eggplant and rice may be nearing release in India and China.

What is the real significance of this development in agricultural technology? Notwithstanding claims that this technology was only a logical continuation of scientific progress, the moment that the first gene was inserted into a bacterium was in many senses a watershed. Humans obviously have a long history of shaping the organisms (and ecosystems) around them, but this was the first instance of humans designing a life form at the genetic level. Although the technology is still primitive (compared with what it will be), the power to alter and transfer genes is revolutionary. It is also a power long anticipated by speculative fiction, which had pointedly asked whose interests would dictate how life forms would be designed. Huxley (1932) provided perhaps the best known answer in *Brave New World*, in which life forms were developed according to the interests of corporate sales and state control.

Perspectives on what the impacts of this technology have been (and will be) vary wildly, and a vigorous struggle has taken place over the framings through which it is understood. The framing favored by industry and allied academic proponents is that ever-growing food needs require continuation of the long history of improving plants and animals. But a technology as multifaceted as crop genetic modification lends itself to other framings (Heller 2007, Jasanoff 2005), and anthropologists may gain greater insight from other historic trajectories in which this technology fits.

SSTW: small-scale third world

One such trajectory is the progressive commodification of agriculture; this has been a long-term spasmodic process, with the previous spasm—the adoption of synthetic insecticides with the resulting problem of insect resistance—creating the need now being filled by Bt crops. Another trajectory is the ongoing enclosure of the genome; genetic modification facilitated and was facilitated by patenting of life forms. Closely related is the rise of biopower, theorized by Foucault (1978) as the state's increasing preoccupation with life itself. Another trajectory is the march of neoliberal economics; the Flavr Savr tomato appeared the same year that the World Trade Organization (WTO) was created, with its mandate to globalize trade and harmonize intellectual property (IP) regimes. Another is the continuing reconfiguration of the academy's relationships to both industry and the state; the parallels in the timelines of genetic modification and what is often called academic capitalism are striking.

Many of these perspectives on GM crops intersect core anthropological concerns, just as the "move south" of the GM debate did in the late 1990s. Anthropology has played an increasing, but certainly not leading, role in addressing these issues; allied and overlapping fields such as cultural geography, STS (science and technology studies), and especially sociology also have growing literatures, which will be selectively considered here along with anthropology. Some of the issues listed above have yet to receive significant attention, but others have. I focus here on three areas of anthropological interest on which literatures are available: (*a*) the role of genetic modification in the changing political economy of agriculture, (*b*) the cultural and national variation in response and resistance, and most importantly (*c*) impacts in the global south—i.e., smaller-scale, less industrialized, often relatively resource-poor producers, often in developing countries. These characteristics of farmers are hardly isomorphic, but owing to space limitations, I follow Soleri et al. (2008) in lumping them as small-scale third-world (SSTW) farmers.

POLITICAL ECONOMY OF GM CROPS

The industry-favored framings noted above obscure political-economic aspects of the technology by naturalizing GM crops as part of the long history of plant manipulation. This framing responds to claims (by Charles 2006, among others) that science was transgressing realms that belong to God, and to depictions (by Greenpeace, for instance) of GM crops as "frankenfood." The "plant manipulation as progress" narrative is standard in histories of biotechnology from corporate media departments, showing a natural progression from grain domestication to genetic modification (Monsanto Corp. 2001); these are published by grateful newspaper editors as unproblematic backgrounders. In this view, domestication is genetic modification (e.g., Fedoroff 2003, Pinstrup-Andersen & Schioler 2000) and the term genetic modification itself is only a political construction (Herring 2008a). The narrative is often coupled with the Malthusian specter of famine (Scoones 2002; Stone 2002b, 2005b; Stone & Glover 2011), casting hunger as a condition of nature (Ross 1998).

Countering this framing is work viewing the technology in the context of expanding corporate control over agriculture (Lewontin 2000). Central to this literature is concern for commodification in agricultural production. Orthodox Marxist theories of commodification were always an awkward fit on the farm, in large part because farmers produce their own seed (Goodman et al. 1987, Kloppenburg 2004, Mann & Dickinson 1978). Instead, capital has penetrated and commodified agriculture through a history of spasms led by developments in science and technology that "pull away the natural ground from the foundation" of agriculture (Kloppenburg 2004, Marx 1858), obligating the farmer to purchase inputs (Goodman 2003, Goodman et al. 1987, Lewontin 2000). Thus hybrid breeding created seeds that performed well for only one generation, inducing farmers to repurchase seeds (Berlan & Lewontin 1986, Fitzgerald 1990, Lewontin &

Berlan 1986). Hybrids also allowed private seed companies to capture the value from public research at land-grant colleges and agricultural experiment stations (Kloppenburg 2004).

With hybrids, farm mechanization, pesticides, and other agro-technological spasms, the United States has been a leader; this is not only because conditions in the United States favored labor-saving technologies, as induced-innovation theorists argue (Binswanger & Ruttan 1978, Koppel 1995), but because integrating industry into agriculture was an alternative to extracting cheap farm commodities from colonies or neo-colonies (Foster 2002, McMichael 2000).

This process of state-supported transformation of agriculture to integrate industrial inputs is described as "appropriationism" (Goodman et al. 1987), and it fits the rise of GM crops. Just as the state had invested in earlier agro-industrial technologies, the United States has invested heavily to ensure global leadership in integrating biotechnology into agriculture (Busch et al. 1991). GM crops, like hybrids before, bring new mechanisms to prevent seed replanting and for agricultural capital to benefit from public investment—particularly government-supported academic research, largely because of judicial and legislative developments just prior to the advent of GM plants. In the United States, life forms were statutorily ineligible for patents until the 1980 Chakrabarty Supreme Court decision allowed patenting of a bacterium because it had been genetically modified (Hamilton 1993). Patenting was soon extended to plants. These important changes in IP rights are covered well by legal scholars (Golden 2001, Stein 2005; also see comparative analysis in Jasanoff 2005). Economic impacts of these developments have been covered extensively (e.g., Evenson & Raney 2007, Santaniello et al. 2000), as have social perspectives on these changes in IP laws (Bowring 2003, Fleising & Smart 1993, Marsden et al. 2003, Rabinow 1996).

At the international scale, Kloppenburg (2004) puts these IP rights into a broader pattern of plunder of biological resources of the global south. Brush (1993) examines the spread of new IP rights and the impact of biotechnology on indigenous knowledge before the WTO, whereas Otero and coworkers (Otero 2008, Pechlaner & Otero 2008) and Buttel (2003) examine GM crops in the context of the march of neoliberal economic regimes. Cleveland & Murray (1997) argue that industrial-world IP rights mechanisms are problematic for indigenous farmers, and McAfee (2003) considers IP regimes against the backdrop of the Convention of Biological Diversity. Back in the United States, the Chakrabarty ruling coincided with the 1980 Bayh-Dole legislation allowing results of publicly funded research to be sold into private hands, further weakening boundaries between industry and the academy (Etzkowitz & Leydesdorff 1997b) in the era of "informational capital" (Heller 2001). Genetic modification has therefore been both a catalyst for and a beneficiary of the rise of "academic capitalism" (Slaughter & Leslie 1997, Slaughter & Rhoades 2004), also called the "capitalization of knowledge" (Etzkowitz 1997) or the new university-industrial complex (Kenney 1986). These new relationships have had profound consequences for research priorities in biotechnology (specific impacts relevant to developing countries are discussed below). Further analysis of these evolving relationships among "plants, power and profit" is found in a rich vein of work by Busch and coworkers (Busch 2000, Busch & Lacy 1983, Busch et al. 1991, Middendorf et al. 2000).

The political-economic entailments of GM crops will not be understood for some time, but it is clear that the technology facilitates and is facilitated by key changes in the relationships among industry, the academy, the state, and the farm. Attempts to naturalize GM with assertions like "people have been selecting plant genes for 5000 years [sic]" (Langreth & Herper 2010) seem tantamount to claiming the textile mills of the early industrial revolution to be a simple continuation of the age-old act of making cloth.

REACTIONS AND RESISTANCE

Unlike other categories of biotechnology (such as tissue culture, marker-assisted breeding, and medicine production by GM bacteria), GM crops have often been the subject of heated controversy. Although some have attributed opposition to ignorance (e.g., Braun 2002; see Gusterson 2005), this view fares poorly under scrutiny (Bonny 2003, Bryan 2001, Jasanoff 2005, Priest 2004). Others trace opposition to problems of symbolism, quaint attitudes,[3] or "pagan beliefs" (Bond 1999), and Herring (2009a) attributes European hostility and Asian enthusiasm for GMOs to continent-wide God concepts—all rather unconvincing, although religious perspectives on GMOs are a valid topic (Mirza 2004, Reichman 2004). Citing Haraway's (1997) view of GMOs as a revolutionary form of hybridity, Kwiecinski ascribes anti-GM views to taboos as described by Douglas: GMOs "break the boundaries of fixed, neat categories and thus pollute the entire system of ordering the universe" (Kwiecinski 2009) (although Haraway is more inclined to celebrate the new hybridity).

Discourses and images of "unnaturalness" and disturbing symbols do appear in debates on GM crops (Gusterson 2005), but conflicts over GM crops have also been fierce because there is so much at stake—ecologically, economically, and politically. There has been virtually no opposition to the use of GM bacteria to produce medicines, but GM crops are released into the environment, where their genes will flow and from where they cannot be recalled (Ellstrand 2001, Snow 2005). This technology will produce economic winners and losers (Clapp 2006, Isaac 2002, Wu 2004), and the new niche for the corporate sector in farming stirs deep and long-standing political divisions (Stone 2005b).

These tensions have played out in a variety of ways. If we consider broad patterns of attitudes toward GM crops (and foods), there is no doubt that western Europe has been distinct in its general skepticism (and often hostility). But the European response has been neither simple nor uniform. Development and regulation of GM plants are closely entangled with national law and politics, and an interesting literature has arisen that charts country-specific reactions. Jasanoff (2005) compares framings of the new technology in the United States, the United Kingdom, and Germany, highlighting the uniqueness of the United States's resolutely product-centered approach and exclusion of broader social questions. The U.S.-U.K. divergence on GM crops has attracted particular interest (Gaskell et al. 1999, 2007; Munro & Schurman 2009; Schurman & Munro 2003). Peters et al. (2007) compare U.S. and German attitudes toward institutions. In France, Heller (2006, 2007) traces a history in which disenfranchised smallholders successfully steered the national framing about "quality" and the importance of place. In Hungary, Harper (2004) describes national sentiment driven in part by umbrage over the smearing of the Hungarian scientist who questioned the safety of GM crops. In Norway, Wandel (2005) sees the primary bone of contention being power over labeling. Finucane & Holup (2005) look generally at cultural variation in risk perception and other cultural factors (Finucane 2002) to explain views of GM foods, whereas Gaskell et al. (2000) survey and attempt to explain the widely differing levels of support across European nations.

Reactions and responses in developing countries have also been examined, albeit less closely. Pelaez & Da Silva (2008) examine attempts to create a GM-free territory in Brazil. Comparing resistance movements in India, South Africa, and Brazil, Scoones (2008) finds new hybrid networks confronting global issues that are given shape in local political contexts. Herring (2008b) looks critically at GM opposition in India, which he sees as gaining legitimacy from a "reciprocal authenticity

[3]When controversy erupted over the "terminator" technology that uses genetic modification to produce nonviable seeds, a Monsanto spokesman waxed anthropological in attributing opposition to there being "something psychologically offensive about sterile seed in every culture" (Feder 1999).

dynamic" between ex-colonial powers and local global narratives (Herring 2009b). Attitudes in Africa and Europe are also linked in important ways, including use of African food shortages to challenge European opponents (Clapp 2005).

A growing body of work examines differences in the media coverage of these debates. Priest (2001, 2004) considers the ways in which varying attitudes play out in the media, including in Africa, and economists have studied effects of media on consumer choice (e.g., Kalaitzandonakes et al. 2004). Given the range of potent cultural symbols touched by GM crops, the discourse and language in the global debates have been rich subjects. Cook (2004) shows how phraseology used by politicians, journalists, and scientists reflects struggles over the technology; Nelson (2005) traces impacts of academic discourse on public perceptions; Gusterson (2005) decodes the discourse of "frankenfood."

IMPACTS

The available summaries of GM crops' economic and environmental impacts in developing countries (e.g., Brookes & Barfoot 2006, Herdt 2006, Raney 2006) leave unanswered questions of broader sociocultural impacts (Stone 2011). But it is impossible to put actual impacts into context without considering which technologies are being provided to these populations, and what is driving crop modification projects. We therefore divide the discussion of impacts into upstream issues of why GM crops are (or, more commonly, are not) developed for the needs of SSTW farmers and downstream issues of how the crops have actually affected these groups.

Upstream

Thomson (2002, p. 1) opens her book on GM crops for Africa by charging the press with bias for reporting on fears of GM foods but not on how GM technologies are saving Asian children from blindness or African sweet potatoes from viruses. This is a curious charge because no such crops are, or have ever been, in use. In fact, virtually all the world's GM acres are planted to crops developed for industrial farming. The ISAAA's annual reports emphasize the spread of GM crops into developing countries, but even in developing countries the GM acres are planted overwhelmingly to Bt cotton (Smale et al. 2006) and HT soy (Du Bois & de Sousa 2008). A decade after appearing on the cover of *Time*, Golden Rice is still not available (although GM blue carnations and glowing zebrafish are), and the heralded virus-resistant sweet potatoes (Cook 2002) were never released. But could, and will, this powerful technology be used to benefit SSTW agriculture?

There have long been ardent debates on whether the very structure of GM research militated against SSTW technologies (Beachy 1991, Crouch 1991). Biotechnologists have for years insisted that GM crops can and must be part of the feeding of the third world[4] and have been joined by some social scientists (Collier 2008; Herring 2008a,b; Paarlberg 2000, 2008). Paarlberg blames misguided western sentiments for starving Africa by obstructing development of pro-SSTW biotechnologies, based on his belief that African poverty results directly from low labor productivity in the absence of modern science such as GM crops (2008). This view contrasts extensive research on productivity in low-technology smallholder agriculture in Africa and elsewhere (Netting 1993; Pretty & Hine 2000; Pretty et al. 2006; Richards 1985, 1997). Anthropologists with expertise in agriculture in the developing world have generally taken more nuanced positions: Scoones (2002) does not dismiss GM crops but explores hidden assumptions in SSTW biotechnology advocacy; Tripp (2001a,b), although skeptical of some claims by anti-GM campaigners, points to key informational problems with GM crops, along with institutional

[4]For example, "unless we will accept starvation or placing parks and the Amazon Basin under the plow, there really is no alternative to applying biotechnology to agriculture" (McGloughlin 1999).

challenges (Tripp 2009c); Stone (2002b, 2005b) dismisses Malthusian justifications for GM crops but also identifies potentially valuable uses for the technology. Others have found the green revolution to be a useful lens through which to contemplate what a "gene revolution" might be able to accomplish (Brooks 2005, Conway 1998, Parayil 2003, Spielman 2007, Tripp 2009a, Vroom 2009).

The paucity of GM crops for SSTW farming is partly explained by the incentives and institutional relations shaping research and development. Genetic modification requires a vastly more advanced infrastructure, expertise, and expense than do earlier methods of seed improvement, and most of the basic research and innovation needed to create functional GM crops has been (and will be) done in academic institutions (Etzkowitz & Leydesdorff 1997a). But university research on GM crops increasingly mirrors the research profile of industry (Welsh & Glenna 2006), with public good being defined in a way that promotes university-industry relationships (Glenna et al. 2007). IP laws combine with incentive structures among academic researchers, universities, and corporations with devastating effects for SSTW biotechnology (DeVries & Toenniessen 2001, p. 273). Offerings to SSTW farmers also suffer when the technological regime of genetic modification becomes established enough to lock out competing considerations such as agroecological engineering (Vanloqueren & Baret 2009).

These general institutional relationships have been illuminated by studies of specific institutions conducting plant (and other) biotechnology; a pioneering example in anthropology was Rabinow's (1996) account of the commercialization of PCR (a technology playing a key role in plant genetic modification). Hodges (manuscript under review) follows the struggles over a potentially pro-SSTW technology in an institute collaborating with private firms; Kleinman (2003) observed incentives driving research while embedded in a plant biotechnology lab; Charles (2001) describes interactions between academic and corporate pioneers of plant biotechnology; and Scoones' (2006) fieldwork on the biotechnology frontier in Bangalore examines how public policies interact with public and private research to shape development of GM products.

How GM crop development for SSTW agriculture should proceed is an open question. Virtually all stakeholders claim to be allied with the small farmer (Freidberg & Horowitz 2004), but discussions on research priorities usually occur with little knowledge of the complexities of agro-food systems and how technologies are embedded in social situations (Richards 2005). Collaborations between biotechnologists and social scientists are rare (but see Hall 2005, Richards et al. 2009), although social science provides valuable concepts for envisioning impacts of technological change, such as the technographic approach to how socially embedded technologies are actually used (Richards 2005, Thompson & Scoones 2009). Indigenous biologists may have a special contribution to make in choosing GM crop projects (Holmes & Graham 2009).

Anthropological perspectives have been used to advocate some specific GM technologies for SSTW farms. Cassava, an ecologically advantageous pro–poor crop that is difficult to breed conventionally, would benefit from GM for bio-fortification (Stone 2002b) and virus resistance (Stone 2005b). Bt brassicas (e.g., cabbage) could benefit small-scale vegetable producers (Vroom 2009). Apomixis (plant asexual reproduction) could be a step towards "uncommodification" of seeds (Bicknell and Bicknell 1999, Richards 2004, Stone 2002b), although after years of struggle between competing interests, GM apomictic maize is at least a decade from farmer fields (M. Hodges, manuscript under review).

It is ironic that the two most publicized GM technologies for SSTW farming are not in use at all, common perceptions notwithstanding. Golden Rice is a multigene technology for producing beta carotene (a vitamin A precursor) in the rice endosperm. As its announcement in 2000 coincided with the discursive shift to the developing world, it was lavishly publicized by the biotechnology industry and criticized vociferously by skeptics (Massieu & Chauvet 2005, RAFI 2000). A decade later it remains far from release, despite claims even by biotechnology leaders that it has already helped save many lives (Krock 2009). GM opponents found their own poster child when genetic modification was used to create a gene use restriction technology to produce crops with nonviable seeds.[5] Activists nicknamed this the "Terminator" and used it to depict GM crops as a threat to farmer independence and to impugn industry motives (Steinbrecher & Mooney 1998). This technology too is widely believed to be in common use, and/or to be in all GM seeds, but in reality it never advanced beyond testing.[6]

Downstream

Whatever the potential for pro-SSTW technologies, GM crops have been moving into developing countries, and economists and agricultural researchers have generated a substantial literature on farm-level impacts. Even-handed and thorough overviews of economic impacts are provided by Smale and colleagues at the International Food Policy Research Institute (IFPRI) (Smale et al. 2009). This body of research, in particular on Bt cotton (Smale et al. 2006; Tripp 2009b,d), shows predominantly positive economic impacts although the empirical record is varied and still short-term.[7] But a simple and essentialized summary of the crops' impacts is demanded by many, and this demand is met by two entrenched and contradictory narratives: one of general agronomic failure, especially of the pivotal crop of Bt cotton (critiqued by Herring 2009b), and one of resounding success (critiqued by Glover 2009).

An anthropological purview extends beyond yields to broader impacts on farmers and their practices (Stone 2011). As debates on GM crops turned to the developing world, biotechnologists pressed the case that genetic modification was especially suited to SSTW farmers because it was a self-contained technology that could aid cultivation without altering agricultural practice or even being understood by the farmer. In *Nature*, Kenyan biotechnologist Florence Wambugu (1999, p. 16) wrote that "[t]he great potential of biotechnology to increase agriculture in Africa lies in its 'packaged technology in the seed,' which ensures technology benefits without changing local cultural practices."[8]

However, many researchers who actually study agriculture are less inclined to see GM seeds as a "no-brainer" self-contained technology. Soleri et al. (2008) show that less market-oriented farmers use a more nuanced set of criteria for seed selection. Chataway (2005) and Tripp (2001a, 2009c) show that, far from being independent of agricultural practices and institutions, impacts of GM seeds are closely tied to a range of institutions involved in farming. Byerlee & Fischer (2002) show how prospects for GM technology in SSTW farming vary with indigenous research capacities, and Hall (2005) contrasts examples of progress in pro-SSTW biotechnologies in Asia and Africa. Indeed a key reason that GM seeds have had such varied impacts, and have raised such a wide range of questions, is the great variation in agriculture-related institutions and practices around the world. We have noted how many aspects of GM seeds are country specific, and

[5]This particular technology was developed by the U.S. Department of Agriculture and licensed to Delta Pine & Land, a cotton seed company. It was not the technology per se that initially caused uproar, but the 1998 announcement that Delta was being bought by Monsanto Corp., the *bête noire* of environmental movements (Charles 2001).

[6]It is interesting that many people who are disturbed by so-called terminator technology, which is not in use, are unaware that nonreplantability is the hallmark of hybrid seeds, which are widely used in industrial and SSTW farming.

[7]The research is also not free of biases. For instance, most Bt cotton studies comparing adopters and nonadopters suffer from selection bias because early adopters are not a random group but rather a sample biased toward successful farmers (Crost et al. 2007, Stone 2011).

[8]This narrative reached an apogee when biotechnologist Bruce Chassy explained that GM seeds were not too complex for farmers because "[g]enetic farming is the easiest way to cultivate crops. All that farmers have to do is to plant the seeds and water them regularly" (Thaindian News 2008). This statement, probably stunning to anyone who has actually studied farmers, was reprinted by biotechnologist C.S. Prakash (2008) as being from "a fellow biotech expert."

a survey of literature on downstream impacts can be organized along country lines.

Argentina and Brazil account for the great majority of the GM acres in developing countries (**Table 1**). Argentina has been featured in industry publicity that often elides "small farmers" with "developing countries"; in reality, most GM acres in Argentina are planted to commodity soybeans on highly industrialized farms averaging almost 500 ha (Qaim & Traxler 2005, Teubal 2008). Widespread adoption of GM soy has been eased by Argentina's weak IP protection (Raney 2006, Trigo & Cap 2003). Argentina also offers an intriguing contrast to other areas of the world (including in Latin America) where civil society ferment has impeded biotechnology; here the technology has been "secured in material, institutional and discursive arenas of power, producing a particular expression of 'bio-hegemony'" (Newell 2009). Brazil, by contrast, has seen social struggles over regulation (Pelaez & Schmidt 2004), which have important variations among regions (Jepson et al. 2008).

An extensive literature has been published on GM crops in Mexico. Social issues in small-scale Bt cotton farming are an interesting topic here: Traxler & Godoy-Avila (2004) consider how IP enforcement affects cotton farmers' seed saving, their relationship to gins, and the gins' relationship to Monsanto Corp. But the major issue in Mexico has been flow of transgenes into farmer varieties of maize. In 1998, Mexico banned planting of GM maize out of concern for gene flow into the many landraces in this center of diversity. In 2001, ecologists Quist & Chapela (2001) reported transgene contamination in landrace seeds and also asserted that the transgene had unstably integrated into the corn genome. Furor followed (more over the second claim than over the more important first one), including unusual attacks on the ecologists (Monbiot 2002, Worthy et al. 2005). Subsequent studies first failed to confirm the transgene contamination (Ortiz-García et al. 2005) and then succeeded (Piñeyro-Nelson et al. 2009). Effects of transgene introgression on local ecology and farming practices are uncertain but troubling for Mexico (Fitting 2011, Gepts 2005, Soleri et al. 2006, Soleri & Cleveland 2006) as they are elsewhere in Latin America (Soleri et al. 2008). GM maize in Mexico has also been seen against the backdrop of trade liberalization (Fitting 2006).

South Africa, the only African country to approve GM crops, has been the scene of important collisions of interests (Freidberg & Horowitz 2004). GM maize and cotton have been grown there since 1996 on large farms, but there has been enormous interest in plantings of Bt cotton by Zulu smallholders in Makhathini Flats, KwaZulu-Natal. This case became a staple in the literature on GM crops after early reports of yield increases and rapid adoption seemed to exemplify benefits of GM crops for SSTW farmers (ISAAA 2002). However, it is not clear whether adoption of the technology indicates its benefit or lack of choice (Witt et al. 2006). Investigators later determined that the benefits were tied to the vertical integration in the local cotton industry and to extra services provided to Bt planters (Gouse et al. 2003, Smale et al. 2006), and economists judged this case a "technological triumph but institutional failure" (Gouse et al. 2005).

India, with its strong biology infrastructure, enormous population of farmers, and energetic civil society, has had a particularly heated debate on GM crops in which Indian writer Vandana Shiva has emerged as a leading opponent (Shiva 2000, 2005; Shiva et al. 1999; Shiva & Jafri 1998). India has seen a bitter dispute on the role of Bt cotton in farmer suicide. Biotechnology opponents linked GM seeds with farmer suicide even before the seeds had been adopted (Christian Aid 2000, Shiva & Jafri 1998), but biotechnology supporters also use farmer suicide to bolster their position (Stone 2002a). A growing body of research (Kantor 2008, Mohanty & Shroff 2004, Sridhar 2006, Vakulabharanam 2005) has not settled the matter; an IFPRI study (Gruère et al. 2008) shows that both the adoption timeline and the cost/benefit patterns exonerate Bt cotton, but activists (Shiva 2008) and British princes (Lean 2008) still blame GM seeds.

Anthropological research in a high-suicide area in Andhra Pradesh, India, found a more complex relationship between Bt cotton and farmer desperation. Just as Tripp (2001a,b) had warned of informational issues with the spread of GM seeds, studies in Andhra Pradesh found unrecognizability and frenetic change in the cotton seed market to have wrecked the "agricultural skilling" process (Stone 2005a, 2007a). GM seeds were hardly the cause of the suicides, but they did exacerbate the root causes. In Gujarat, Shah (2008) saw the spread of Bt cotton as conforming to a technological culture shaped by the green revolution; Bt cotton reinforced the hegemony of global and local elites (2005). But Gujarat also saw the unauthorized release of "stealth seeds" (Herring 2007), with stolen Bt technology bred into locally adapted cotton. This triggered a burst of farmer breeding and prosperity in Gujarat's cotton sector, contrasting the skilling problems that bedeviled farmers in Andhra Pradesh (Stone 2007b).

China is a unique case because of its early release of GM seeds and because GM crops are developed there largely by the state (Pray 1999). Bt cotton, available since 1997, is now planted widely (**Table 1**). As in Argentina, the cost of seeds in China is low owing to weak IP protection (Smale et al. 2006). Studies by economists of field-level impacts showed years of increased yields and reduced pesticide applications (Huang et al. 2009, Smale et al. 2006), followed by surging populations of pests not targeted by Bt, eroding the earlier benefits (Ho et al. 2009). Broader impacts of Bt cotton in China have been little studied, although some recent work focuses on livelihoods (Wang et al. 2009) and farmers' knowledge about the new seeds and trust in institutions (Ho et al. 2009). It is interesting that the successes of Bt cotton in China were facilitated by the breaking of the rules: The Bt trait has been bred in many locally adapted varieties of cotton, without authorization and without complying with biosafety regulations (Huang et al. 2009). Taken with the findings in Gujarat and Argentina, this case raises questions not only about whether GM crop technologies can be regulated, but also of whether they tend to work best in developing-world agriculture when they circumvent regulation.

Although the focus here is on sociocultural impacts in SSTW farming, there may have been significant impacts on industrial farmers in North America. For instance, biotechnology firms send detectives into farmers' fields and promote farmers turning each other in for noncompliance, which is punished by attempts at public shaming and lawsuits (Weiss 1999). The possibility of a "culture of surveillance" (Mehta 2005b) remains to be studied by rural sociology or anthropology.

ANTHROPOLOGY AND GM CROPS

The advent of GM crops obviously raises a range of questions of major interest in anthropology, and I have surveyed key issues and findings under the rubrics of political economy, responses and resistance, and impacts in developing countries. Although anthropology has shed important light in each of these areas, the overall contribution has not maintained the level of engagement that was signaled by pioneering work on biotechnology (Rabinow 1996). In particular there is need for research on more synthetic, indirect, and social aspects of the technology (Stone 2011). Many key questions about GM crops have been recognized but remain largely unresearched, including gendered effects (Bryant & Pini 2006, Morse & Bennett 2008), impacts on social cohesion (Mehta 2005b), and how biotechnology research changes in institutional cultures in developing countries (Richards 1994, Richards & Ruivenkamp 1996). Meanwhile, the demand for anthropologically informed analysis is frequently being filled by others. Thus when domestication of maize was compared with GM maize, the analysis was performed by a microbiologist (Fedoroff 2003), and it was a rheumatologist (Kwiecinski 2009) who questioned whether anthropological approaches help to explain people's irrational reactions to GM crops and food. Social aspects of biotechnology are often handled in major academic forums with coarse generalizations (e.g., Da Silva 1992).

GM crops are not going away, and they will continue to have highly consequential impacts on research agendas and institutional relationships, on IP rights, on civil society, on rural environments, and on farmers. An expanded role for anthropology, especially involving primary fieldwork, is definitely needed, whether it is to "take sides" or to concentrate on "how the sides came to be the way they are" (Murcott 2001).

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