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Regulatory System Impacts on Global GM Crop Adoption Patterns

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When GM crops were first commercialized, science-based risk assessments and regulations were applied to ensure food (human and animal) and environmental safety. Early adopting countries were Argentina, Canada, China, Europe and the United States. Over the intervening 20 years, commercial production spread to an additional 25 countries. With 20 years of adoption history, it is possible to assess if the diffusion of regulations away from a primarily science-based approach has impacted not only the adoption of GM crops, but also the diffusion of specific GM traits.

By assessing GM crop adoption patterns it is possible to gain insights into the relationship between regulatory systems and adoption. To do this an analysis of adoption patterns has been utilized. The objective of the analysis is to look for differences and trends in GM crop adoption across traits, countries and years of diffusion. Timelines of adoption are used to show the correlation between regulatory systems and adoption. This analysis provides insights into whether market saturation points are shortening or lengthening, whether familiarity with traits is reducing regulatory timelines and whether the diffusion curve plateaus or trails off over time. Determining the impact regulations have on GM crop adoption provides both regulators and industry development firms with valuable information on the efficiency of GM crop regulations over time.

Keywords: early adopters, innovation, science-based regulation, socio-economic considerations, technology diffusion

1. Introduction

Knowledge about iterative and transformative technologies, such as the recent technological changes in agriculture, accumulates incrementally over many years. Articles in the early to mid-1980s described the process of how one might genetically transform plants. These scientific publications have since provided more information and greater detail about how to insert or activate new traits in plants. By the mid to late 1990s, new articles began to appear that attempted to estimate the effects of this technology on consumers, producers and industry, both in developed and developing nations. This was matched by a flurry of work on consumer responses, intellectual property, regulatory frameworks, international trade impacts, biosafety assessments, adoption benefits and many other topics.

The application of biotechnology to agriculture has precipitated, if not the largest change in the history of agriculture, certainly the largest change since the move to mechanized agriculture. Responses to this innovation span a wide spectrum of applications and impacts. Much knowledge about the state of agri-food technology and its socio-economic impact on global agriculture, biotechnology and development has accumulated over the last quarter century of production history. Specific studies on the effects of agricultural biotechnology now provide a rich history and offer grounded thoughts on the future for the technology in this sector.

Twenty years of genetically modified (GM) crop production and event[2] approval have occurred and, as with any innovative product or process, one would expect that regulatory approval times would begin to decrease, given the increased level of information about not only the technology itself but also the processes used to develop the new plant varieties. The question of whether regulatory efficiencies are happening is important for several reasons. Given that the same two basic traits, herbicide resistance and insect tolerance, continue to dominate GM crops, is there an observable decline in regulatory approval times? If not, what is the reason for this? What impact might regulatory delays have on future investment in the technology? Is movement away from science-based[3] regulation adding inefficiencies? To what level has political interference impeded regulatory approval? Questions of this nature require investigation so that the agbiotech industry may be informed about whether, and to what degree, regulatory decision-making processes impact GM crop approval.

The article's objective is to examine global regulatory approval patterns to discern adoption trends for key GM crop commodities and traits. The structure is as follows. Section 2 provides the background to the article, with the methodology presented in section 3. Sections 4 and 5 provide the results and analysis, respectively. Concluding thoughts are offered in section 6.

2. Background

One lesson that can be gleaned from the Green Revolution[4] is that for transformations in agriculture to be successful, institutional management is essential. Ultimately, the right governance systems need to be in place to facilitate the uptake and use of an innovative technology (Ludlow, Smyth and Falck-Zepeda, 2014). During the Green Revolution, science was the dominant driver of the technology, but in the current global system for agriculture, innovation is an integrated blend of science and governance (Smyth, Kerr and Phillips, 2013). Within the present environment, science drives the advances in new crop varieties that are required to address the needs of global food security. Governance has a central role in the commercialization of technologies, particularly regarding aspects of regulation and trade (Phillips, 2007). Without the governance capacity for innovation, the science capacity for innovation will have an increased probability of not reaching its full potential.

The regulation of GM crops has been undertaken following one of two methods. Countries have examined GM crops and adjusted their regulatory frameworks to accommodate the new technologies, or they have created entirely new regulatory frameworks for GM crops. Canada and the United States are examples of the former, while the European Union (EU) is an example of the latter. In the late 1980s and early 1990s, Canada and the United States undertook extensive reviews of agbiotech and, in consultation with academic and industry experts, revised the existing regulatory approval process for new plant varieties to allow for the regulatory approval of GM varieties (Smyth and McHughen, 2008; McHughen and Smyth, 2008). Meanwhile, in Europe, the initial approvals of GM crops were at the member-state level, and several countries were early approvers and adopters of GM crops, with Germany, Portugal, Spain and the United Kingdom leading the way. However, following a series of adverse food safety issues,[5] the EU implemented a moratorium on the approval of GM crops, taking from 1999 to 2003 to entirely reconstitute its regulatory system for agricultural crops and food (Perdikis and Kerr, 1999; Kerr and Hobbs, 2005; Kerr, 2010).

While there has been significant study of the underlying regulatory regimes in the divergent countries (Isaac, 2002; Skogstad, 2008; Doern and Prince, 2012), this literature highlights that there are fundamental differences of approach and impact, which contribute to different review and approval processes. In 19 countries that had examined and approved at least one of the 144 events proposed for commercialization by 2011, the average country had undertaken reviews on only about 5 of the 16 species under investigation and completed environmental reviews on 12 percent of the possible cases and food safety audits on 27 percent (Phillips, 2011). No single country reviewed and recorded positive approvals for all of the 144 events as of 2011. The highest rates of positive review were in Canada and the United States, two of the largest producers and exporters of GM crops, and Japan, a key importer of foodstuffs with GM traits. The low level of successful review for environmental release reflects the politics of the adopting countries, while the somewhat higher percentage of completed food reviews reflects the reality that much of the international trade now includes GM elements.

One aspect to keep in mind is that companies make their own decisions about where and when to seek approval for commercialization. Soybeans and maize/corn have the highest penetration rates, averaging around 10 percent of the total number of countries producing those crops. Nevertheless, those countries adopting GM varieties account for an estimated 73 percent of global soybean area and 30 percent of global maize/corn area (Phillips, 2011). While one might interpret incomplete adoption as reflecting the unwillingness of countries to accept GM technologies, in many cases it is simply a decision based on business. For many nations, such a business decision may be rooted in the costs of approving and regulating GM technology, or in other cases a decision to protect the nation from future trade loses with other nations opposed to GM technologies.

Truncated adoption can be the result of two separate decisions. Many interpret the limited regulatory acceptance of GM crops as a judgment of regulators – some assume that stalled introduction is because companies have failed to satisfy the regulators of the safety of their products in relation to human and animal health and the environment. In fact, in many cases, proponents are simply waiting for regulators to make their judgments. To our knowledge, no GM product has been explicitly rejected for health or environmental safety reasons by any regulator anywhere. What appears to be happening is that many proponents have simply not applied for regulatory assessment in small markets. In many cases, this is simply a business decision based on the expectation that there would not be adequate revenues for the technology owners to justify the investments in acquiring regulatory approval and achieving compliance, as well as developing a local supply chain. A number of tentative estimates of the costs of regulatory compliance in developing countries suggest the upfront costs per country have ranged from US$500,000 to US$5 million for the first GM event in a species, and approvals have taken from two to seven years to complete, with the process for subsequent GM traits in the same crop being less expensive and somewhat more timely (Kalaitzandonakes, Alston and Bradford, 2007; Pray, Bengali and Ramaswami, 2005; Pray et al., 2006; Bayer, Norton and Falck-Zepeda, 2010). To provide a sense of the problem, assuming a biotechnology company could generate free cash flow of US$10 per acre planted (which would depend critically on the structure of local intellectual property laws and the structure of the local seed industry) and they got above average farmer adoption, there are at least 40 countries producing maize/corn where it is unlikely a biotechnology company would recoup even the lowest likely regulatory costs within ten years of starting the process (Smyth, McDonald and Falck-Zepeda, 2014). Given there would also be extra development costs to backcross their proprietary traits into cultivars appropriate for those markets, the number of unprofitable markets is probably higher. Few companies are willing to take such unreasonable commercial risks with their scarce capital.

While a scattering of GM crop approvals occurred prior to 1996, with very limited production acres, 1996 is widely recognized as the starting point for the widespread commercial production of GM crops. Initial countries commercializing GM crops were the United States, Canada, Australia, Argentina, Mexico and China (figure 1). For the subsequent 15 years, the number of countries adopting GM crops grew steadily; however, the number of GM crop producing countries has plateaued from 2010 onwards. Global acres of GM crop production have witnessed annual increases of 10 percent or greater, so the adopting countries are continually increasing the area under GM crop production year over year.

While figure 1 provides one conceptualization for the global diffusion of GM crops, two other key observations about diffusion also exist. The first of these diffusion framing efforts examines the challenge of the limited number of technology traits that have been commercialized to date. One study extends both upstream and downstream to encompass what many assert is the research pipeline, or what Graff, Zilberman and Bennett (2010) call the “research sieve”. They converged on this term as more descriptive of the triage process that takes place within the gestational stage. In their report, they identified 560 biotechnology traits at the “proof of concept” stage, which led to 383 early stage field trials but only 47 advanced trials, 14 regulatory applications, 5 market introductions and only 2 sustained products. These data highlight the challenge of generating new agbiotech technologies that successfully reach the market and suggest that while some technologies may have high regional appeal, they are not capable of sustaining a substantial enough return to justify further investment.

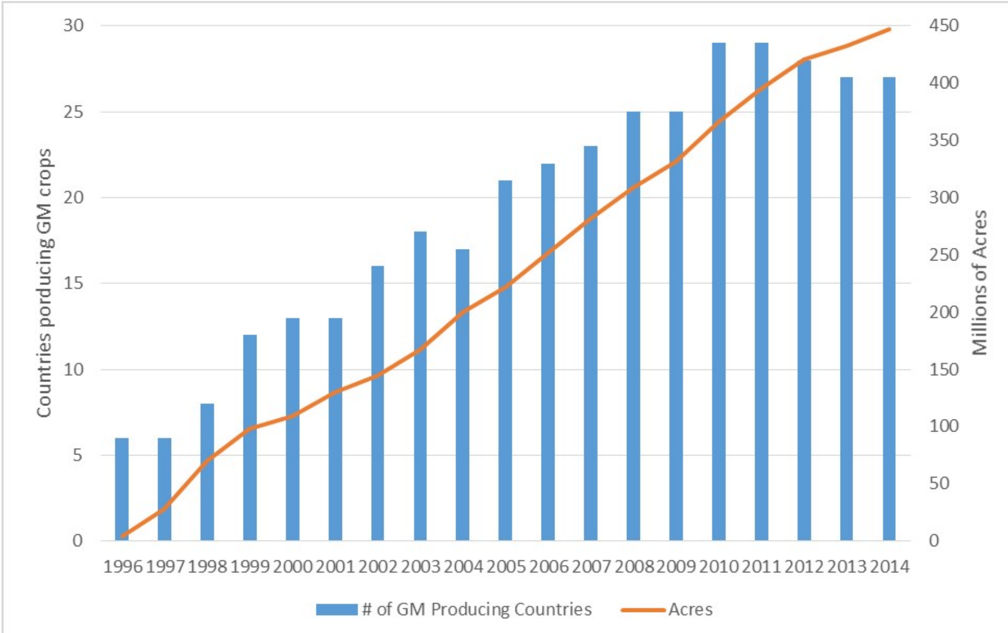

Figure 1 Approvals and acres of GM crops, 1996-2014.
Source: James, 2015

The second insight into diffusion is provided by Alston, Kalaitzandonakes and Kruse (2014), who report on the results of their effort to develop a partial equilibrium model to estimate the gross and net effects of the introduction of GM traits, both on adopters and targeted crops and on non-adopters and consumers. Their conclusion is that the gains from GM crops to date exceed US$40 billion per year, but that number varies depending on the overall market context. Tight markets drive out gains while loose markets amplify gains. Moreover, consumers ultimately gain virtually all of the net benefits, and farmers who are early adopters gain, but those gains diminish over time. In addition, crop sectors (e.g. wheat) that do not use the technology and individual farmers who do not use the technology unambiguously are worse off than if the technology had not been used.

3. Methodology

To examine the global patterns of GM regulatory approvals and adoptions, a database of approvals is necessary. For this article the International Service for the Acquisition of Agri-biotech Applications (ISAAA) GM approval database was utilized. ISAAA's database is a detailed compilation of a variety of GM crop event[6] approvals around the world. Regulatory approvals based on the form of cultivation are further analyzed statistically to seek out patterns and trends of GM adoption.

ISAAA's GM approval database as of the spring of 2015 reported events for 29 GM plants and 40 approving nations (ISAAA, 2015). So far there have been 375 events reported. Event information is typically sourced directly from the Cartagena Protocol on Biosafety's Biotechnology Clearing House after an approval from a national regulatory agency. Information collected regarding the event includes the event and trade name, developer, GM traits, commercial traits and the gene(s) introduced to the plant. Additionally, ISAAA provides a list of regulatory approvals by country, year and approval type, as well as any further documentation or links to the event.

For the purposes of this research, data have been collected on the four most prevalent GM crops – canola, cotton, maize/corn and soybeans – as, cumulatively, they represent 216 of the 375 events approved. However, for practical purposes, corn will be the only crop presented within this article, as it has the greatest number of events, 138, and was one of the earlier crops approved.

Of the three types of regulatory approval – food, feed and cultivation – only cultivation will be examined in detail. More often food and feed are approved before cultivation, yet it is the approval of GM events for cultivation which signifies a willingness to adopt GM crop technologies. Therefore, the analysis of GM approvals will be made with regard to the approvals of events for cultivation. As well, events until the end of 2014 are reviewed, and the most recent event approvals of 2015 are not included.

4. Results

The approval to produce/cultivate a GM crop is ***equally*** important to, if not more important than, food and feed approvals, yet it is the least often achieved. This is especially the case as cultivation approvals require a more detailed regulatory process than is the case for food/feed approvals. Table 1 shows that in total, food and feed event approvals are 93 percent and 87 percent respectfully, while only 73 percent of events received cultivation approval (ISAAA, 2015). This section statistically evaluates the approval of GM corn cultivation events by approvals and diffusion, commercial traits and country approvals. The intent is to determine whether clear approval trends or patterns have occurred, and to further assist in the analysis of GM crop regulations and approvals in the various approving nations. Over time, food and feed approvals began to occur at a greater rate than cultivation approvals, as shown in Appendix A, figure A1.

Table 1 Approval of GM Events

Crop	Number of events approved	Events approved for		
		Food	Feed	Cultivation
Canola	32	32	30	22
Cotton	54	44	42	45
Corn	138	133	123	90
Soybean	30	28	26	28
Total	254	237	221	185

Source: ISAAA 2015

Figure 2 illustrates the three approval options for GM corn, highlighting three distinct phases of approval. The first phase occurred between 1995 and 1999, when the early adopters of GM crops were approving the initial varieties, and approvals were consistent with all three options. The second adoption phase, 1999 to 2005, shows that corn cultivation approvals were beginning to be exceeded by feed and food approvals. Finally, the third phase, post-2005, witnessed the highest approval levels, which reached their highs in 2010 and are currently in decline. Of the total of 138 corn events approved by the end of 2014, 697 food approvals had been granted, 500 approvals for feed use and 258 for cultivation. All three approval options follow a similar trend of distribution; cultivation approvals are a suppression of the other forms. Yet in 2014 it appears that cultivation approvals increased minimally while the others declined. This could be an indication of a trend toward increases in future years.

As figure 2 identifies, cultivation approvals began to decline after 2010. This deflection could be a sign that cultivation approvals have peaked. However, an upturn in approvals in 2014 could suggest the start of another wave of regulatory approvals. To determine which way approvals are trending, a Rogers' diffusion of innovation curve is calculated for the approval of corn cultivation (figure 3). The diffusion of innovation approach divides approvals by standard deviation into five categories that differentiate the varying rates of adoption of innovations (Rogers, 1983). The five categories are innovators, early adopters, early majority, late majority and laggards.

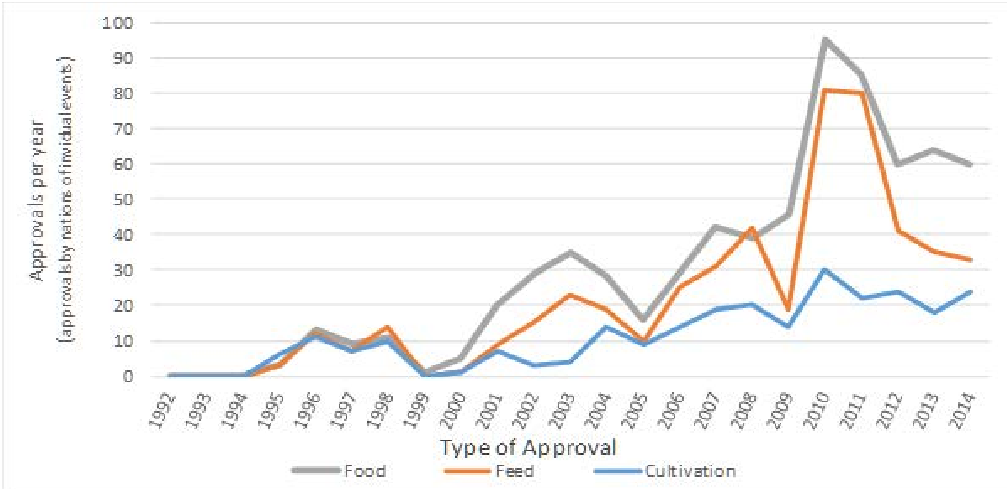

Figure 2 Yearly approvals for all corn events.
Source: ISAAA, 2015

Looking strictly at the occurrence and diffusion of the first approval of each event, distributed over the diffusion curve (figure 3), not a single event is found to be in the innovator category. Instead, the earliest approvals of corn are in the early adopter category. These early adopters likely have a strong interaction with the scientific research and development of GM technologies and the presence of strong, science-based regulatory agencies. There are fewer first approvals in the early majority category, but significantly more approvals in the late majority category. It is possible that this could indicate longer regulatory processes, or later-developed GM events entering into the regulatory process. Late 2013 represents the laggard adopter category, those that are the last to adopt. However, these laggards may not be significant, as this curve is not looking at one specific technology; yet if GM corn does not further advance, the diffusion of the innovation suggests that GM corn would be nearing its saturation point.

Although not shown in this section (see figure A2 in Appendix A), diffusion can also be illustrated based on total event approvals. When over-all approvals are illustrated, diffusion shifts to the start of the early adopter category, or mid-1996. This means that the first approvals for 11 events are now classified as being in the innovator category. Innovator approvals suggest that the countries to first approve these events are well connected financially and scientifically to be the first to evaluate the risks of the new crops' technology and determine that commercialization is safe. The remainder of the diffusion is similar to that of figure 3, where the late majority and laggards represent the saturation point.

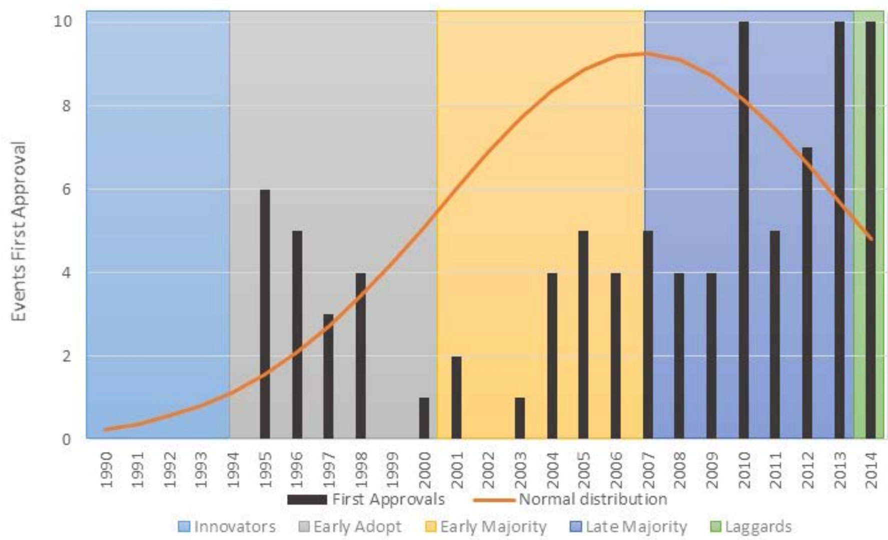

Figure 3 First approvals and distribution of corn.
Source: ISAAA 2015

The diffusion of approvals suggests that approvals of corn cultivation events should be reaching the point of saturation; however, the high number of first event approvals in recent years suggests otherwise. To determine if the saturation of GM corn approvals is approaching or if a new wave of approvals is beginning to emerge, all event approvals are reviewed, illustrating the adoption timeline from one approval to the next. All event approvals (figure 4) are organized by the year of an event's first approval. Each bubble signifies the number of event approvals in a given year, and the colour varies with each year of approval. There is a mixture of approvals ratings per event. In total 37 events receive only single approval, with 22 of these occurring between 2012 and 2014. These new single approvals may not be a sign of fewer approvals, but rather an indication of a new approval surge which is occurring after the first adoption.

Of the remaining 53 events, approvals range from 2 to 14 countries. The diffusion of event approvals over time clearly shows that there are innovators, early adopters, majority adopters and laggards for most events. The earlier an event is approved, the greater the number of total approvals it has received. Early event approvals begin with few approving nations, increasing over time and then declining with the late adopters. Events with first approval post-2003 have fewer high approvals, yet when they do achieve higher approvals they begin with a larger number of early adopters, thereafter declining over time. The events first approved in 2012 and subsequently do not match this trend of multiple early adopters; therefore, it cannot be conclusively determined if the recent approvals will remain as single approvals or whether they are the innovators of the next phase of GM approvals.

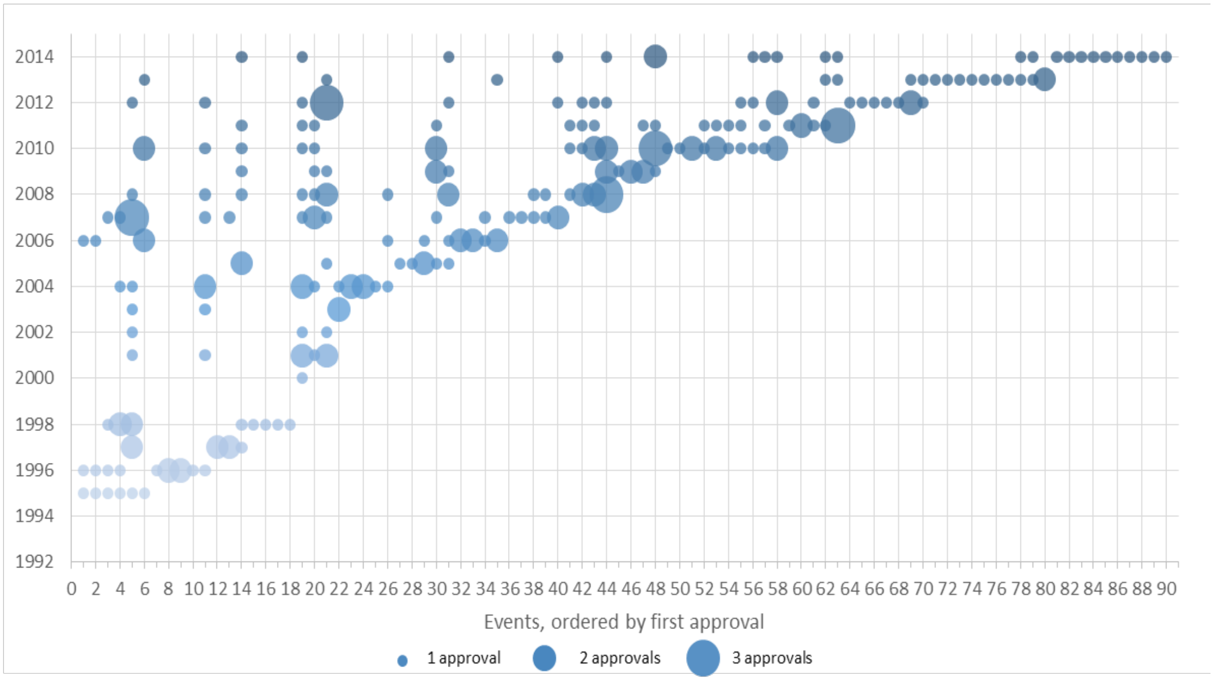

Figure 4 Corn event approvals by year.
Note: 48 non-approved events have been excluded.
Source: ISAAA 2015

Figures 2 and 4 highlight evidence of approval phases, which are directly linked to specific GM event traits and countries approving these particular event traits. Commercial traits are analyzed in Figures 5, 6 and A3 (in Appendix A). GM corn currently has five marketed commercial traits: herbicide tolerance (HT); insect resistance (IR); abiotic stress tolerance; modified product quality; and pollination control system. Initially, single trait varieties were introduced for approval, eventually evolving to stacked traits, where two or more traits are added to a plant. Figure 5 shows how single traits have always been present; however, post-2004, stacked trait approvals have become the prominent approved corn varieties.

Since 2004, stacked GM traits have become increasingly commonplace, as they offer a broader range of agronomic benefits to producers. Figure 6 presents stacked trait event approvals, finding that the combination of herbicide tolerance and insect resistance traits dominates 153 approvals of 167 stacked approvals. By the late 2000s, a small number of approvals for the three other stacked traits events with HT and IR begin to be approved.

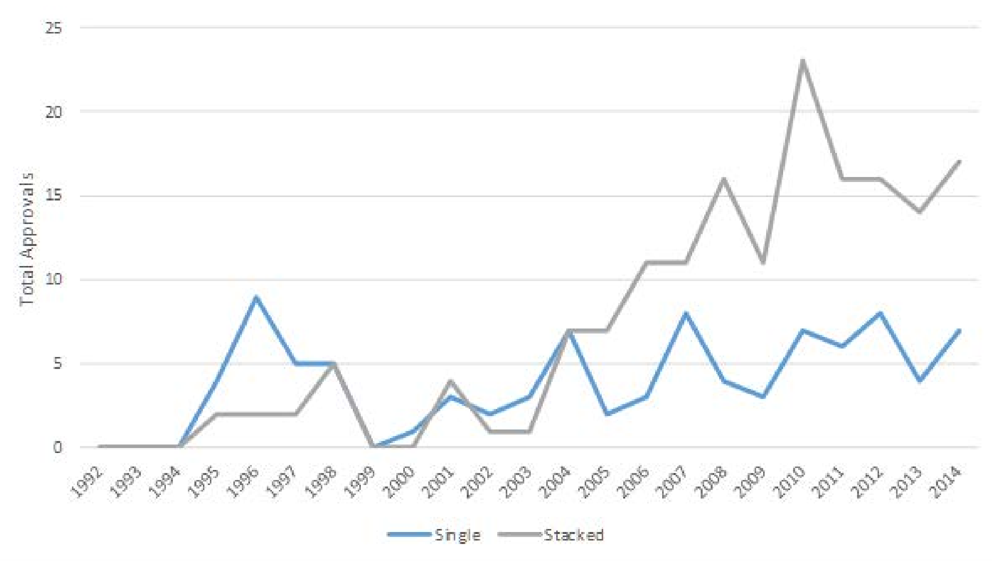

Figure 5 Single and stacked GM corn trait approvals.
Source: ISAAA 2015

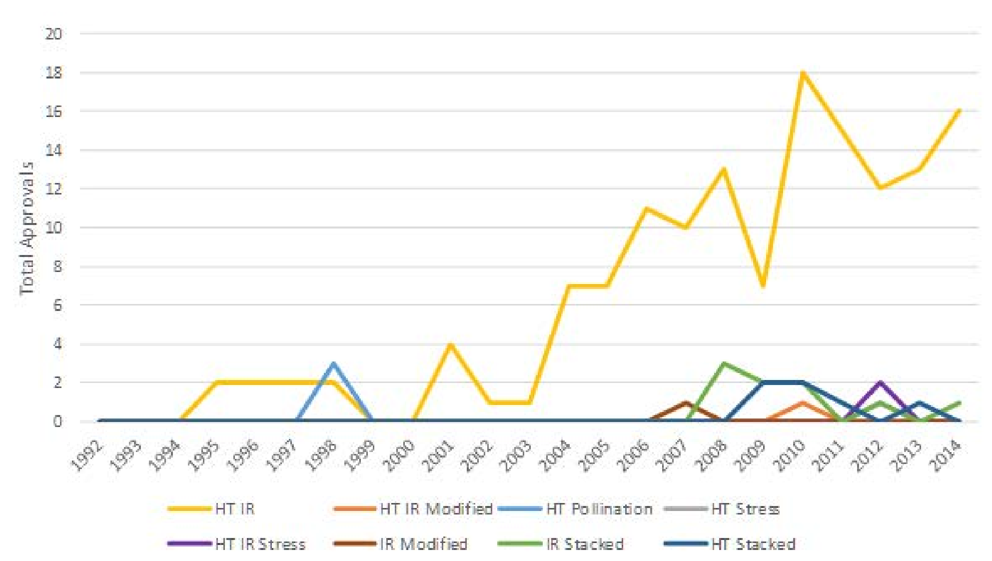

Figure 6 Stacked GM corn trait approvals.
Source: ISAAA 2015

Single trait approvals represent only 26 of 90 approved events, yet on average receive a higher number of approvals than stacked events. The approvals of single trait events appear to be for the first generation of a GM trait, which is then later utilized with others in stacked events. As a result, single events are approved each year, and a high concentration of these have been either HT or IR. Recently, single trait approvals for modified quality, stress tolerance and pollination have occurred, supporting the hypothesis that this could be the beginning of a future surge of corn approvals (figure A3 in Appendix A).

The first 5 GM corn event approvals occurred in the United States in 1995 (figure 7). The United States led the approvals for 19 different corn events. Canada's approvals began in 1996, and Canada has subsequently led the approvals for 22 events. Ten additional events have received first approval in both countries; however, it is unknown which country approved each of these events first. Initially, the United States and Canada were the only countries approving events, followed by approvals from South Africa in 1997 and from Argentina and the EU in 1998. Japan first gave approval in 2004, approving 8 events that first year. Since then Japan has approved 54 events.

In the first decade (1995-2004) of approvals, Canada and the United States led approvals for 24 events, with seven other nations following. In the second decade (2005-2014) of approvals, nine more countries granted approvals for GM corn events, with 64 events being approved for production (figure 8).

Together, Canada, Japan and the United States have led regulatory approvals, approving 78 of the 90 events approved (figure 9). Trends are less clear in the remaining approving countries. Although Argentina was an early adopter of several events, approvals ceased for a time and have only recently resumed. Of Argentina's approvals, 19 are also approved by the bordering country Brazil. Argentina most often approved the event before Brazil, and the two countries approved events within two years of one another in 15 of these instances. This would appear to suggest that these two countries have regulatory systems dependent on one another.

5. Analysis

With 20 years of GM crop approval history, we have used GM corn approvals to study diffusion patterns, given that GM corn is the most widely adopted of the main GM crops being produced. What has become evident based on the above is that there is a clear distinction between GM corn approvals for import use (food and feed) compared with approvals for cultivation. Given that the vast majority of GM corn being produced is not intended for human consumption, but destined for animal feed markets, import approvals are predominantly being given for use in the animal feed sector in the approving countries. The diffusion of the technology of GM corn for animal feed use appears to be quite diverse, including countries that have an announced aversion to GM crop production, such as the EU.

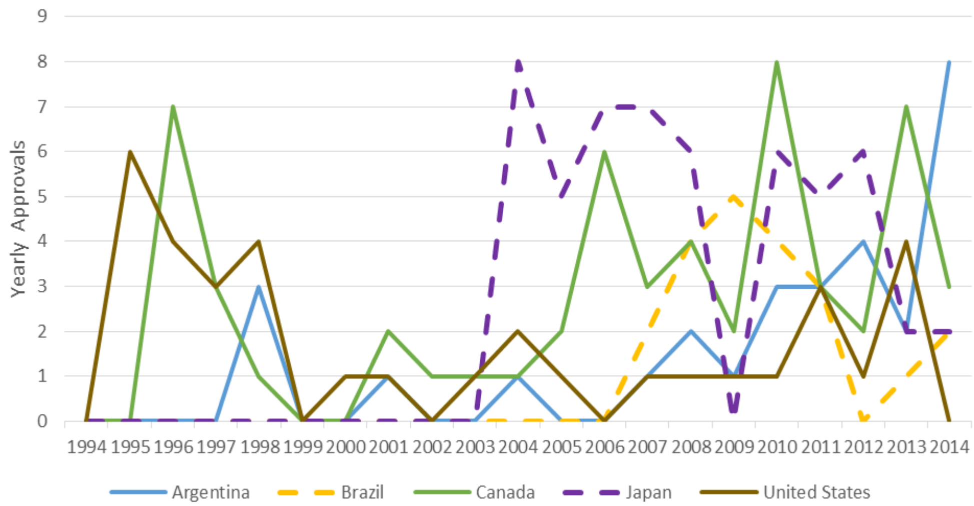

Figure 7 Country approvals by year, top five.
Source: ISAAA 2015

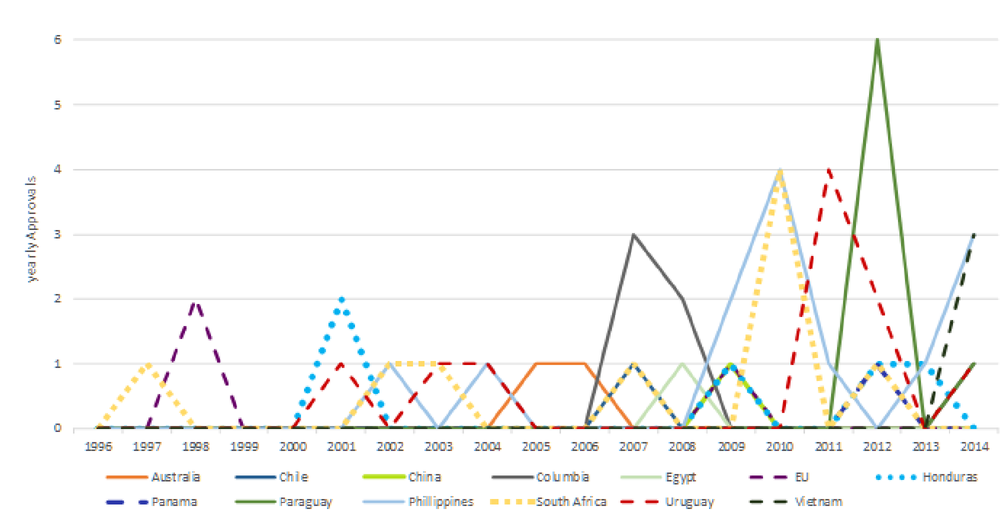

Figure 8 Country approvals by year, without top five.
Source: ISAAA 2015

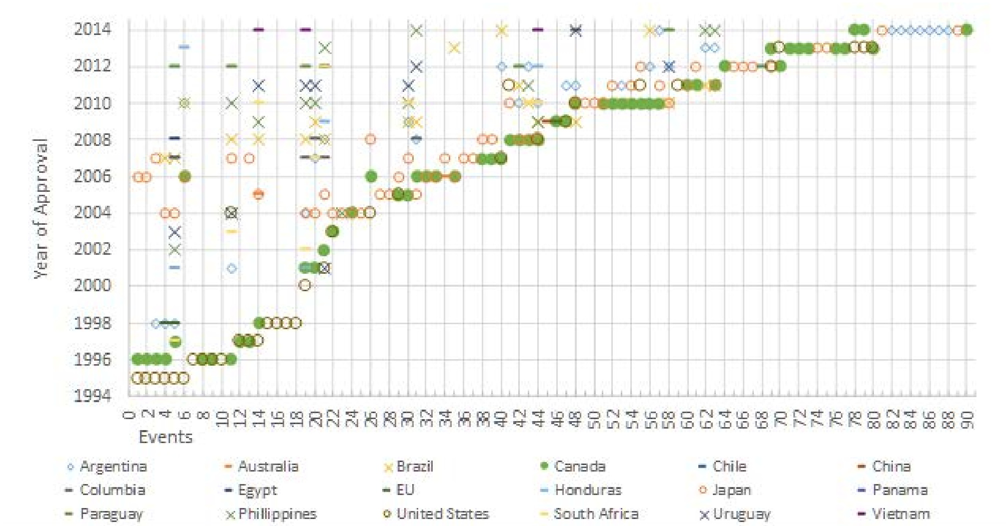

Figure 9 Country approvals by event.

The above diffusion evidence highlights the lack of regulatory efficiencies regarding cultivation of GM corn. With 20 years of GM corn production in Canada and the United States and 18 years of production history in South Africa, it would appear that there have been no regulatory efficiencies gained based on the increasing volume of adoption benefits. Studies that quantify the benefits of GM corn include those that identify spillover benefits (Hutchinson et al., 2010); yield increases (Carpenter, 2010; Finger et al., 2011; Areal, Riesgo and Rodriguez-Cerezo, 2013; Klümper and Qaim, 2014); reductions in hand weeding (Gouse, 2013); and producer profitability (Trigo, 2011). While the technology has exhibited successful diffusion, this is clearly not the case for the diffusion of the quantified, science-based risk assessment information that has been generated by the technology development firms or the national regulatory agencies that have thus far approved GM corn, and most evidently not for the ex-post benefits validation.

If technical scientific knowledge about GM crops was being shared between regulatory agencies, one should be witnessing a reduction in the regulatory span between approvals. However, as highlighted in figure 10, regulation periods continue to be as long (if not longer) for new varieties as they were for the initial GM corn varieties. The initial, single trait varieties have now predominantly given way to stacked trait varieties, which explains why there are no recent approvals for LibertyLink™ corn after 2007. Stacking insect resistance with herbicide tolerance resulted in YieldGard™ varieties that continue to receive new regulatory approvals right up to the present.

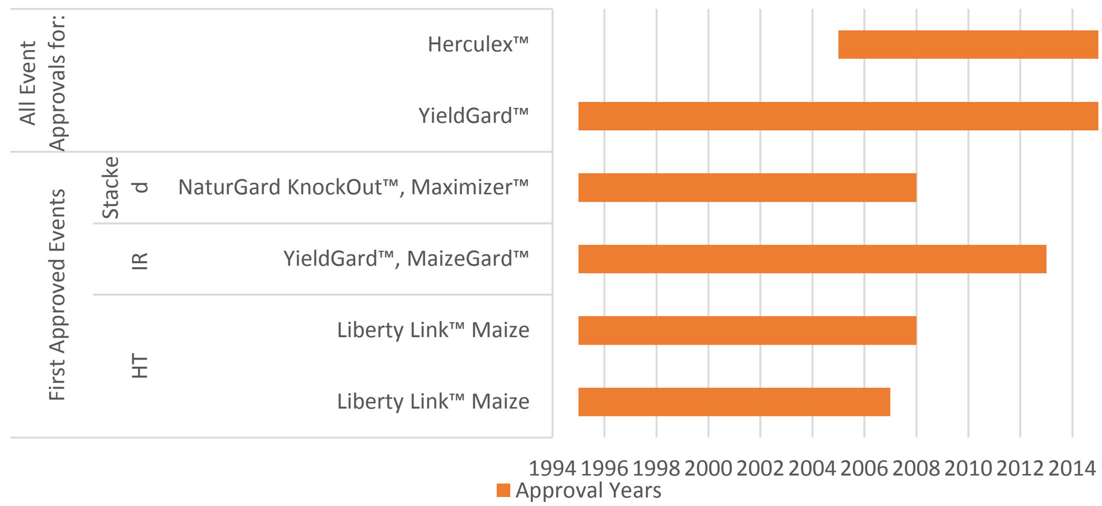

Figure 10 Diffusion of regulatory knowledge for GM corn varieties.
Source: ISAAA 2015

It may well be that national sovereignty issues are constraining the diffusion and uptake of regulatory knowledge regarding GM crops. Each approving country must justify that its regulatory system is superior to that of other countries, that the risks of allowing the GM crop variety to be approved for cultivation have been thoroughly and adequately assessed, and that the product is indeed safe, making it difficult to accept a regulatory decision in another country as the basis for approval. Increased regulatory efficiencies would be evident if the regulation of new GM events existed for 5-6 years and then event approvals were globally accepted by any nation wishing to adopt the event. The fact that stacked corn events, such as those presented in the second row of figure 10, are still receiving first approvals in some countries 18 years after receiving their first approvals elsewhere abundantly verifies that diffusion of knowledge is not occurring in parallel with the actual diffusion of the technology.

The results show cultivation approvals face higher scrutiny and regulatory oversight or require larger and longer funded research phases to receive approval in comparison to the approval processes for food and feed. The small number of cultivation approvals, when examined by diffusion models, indicates that corn is reaching a point of saturation. However, it could be that single trait event GM technologies have reached the saturation point, and new diffusion patterns are beginning to emerge for stacked trait events. Single trait approvals of HT and IR led to the approval of those same traits being stacked, and these stacked trait events represent the majority of recent corn event approvals. Recent single approvals of other GM traits are also being stacked with HT and IR traits and are beginning to enter the market. These new stacked varieties appear to be the next wave of GM corn approvals.

6. Conclusions

This assessment on the diffusion of GM corn has highlighted that diffusion of biotechnology is occurring more deeply within GM crop–adopting countries rather than more widely across countries and that the diffusion is limited to the technology itself and does not include the accompanying knowledge.

As identified above, the number of GM crop–adopting countries appears to have plateaued in the upper 20s. While the acreage of GM crop adoption has continued to increase year over year, the number of adopting countries has shown a slight decline over the past five years. Over this same five-year period, the production of GM crops has increased by approximately 100 million acres. Clearly, countries that have adopted GM crops are planting them on increasingly larger acreages year after year as opposed to broader diffusion of the technology to previously non-adopting countries.

One troubling observation is that diffusion of the knowledge about risk assessment, production benefits and regulatory efficiencies pertaining to GM crops is not occurring. Regulatory timeframes are as long as they have ever been for GM events; there is no evidence to indicate that efficiencies are present in the regulation of GM events. This is most troubling when put in the context of market solutions that can have a meaningful impact on improving global food security. Klümper and Qaim’s (2014) meta analysis of GM crops quantified a 22 percent yield increase for GM adopters,[7] so further delaying a technology that can improve the production of food by as much as one-quarter should be a priority for regulatory agencies in developing countries. If knowledge diffusion to do with biotechnologies does not begin to rapidly progress, such delays may further exacerbate food insecurity as the next generations of GM crops advance further into staple food crops for the developing world and improved nutrition.

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Appendix A

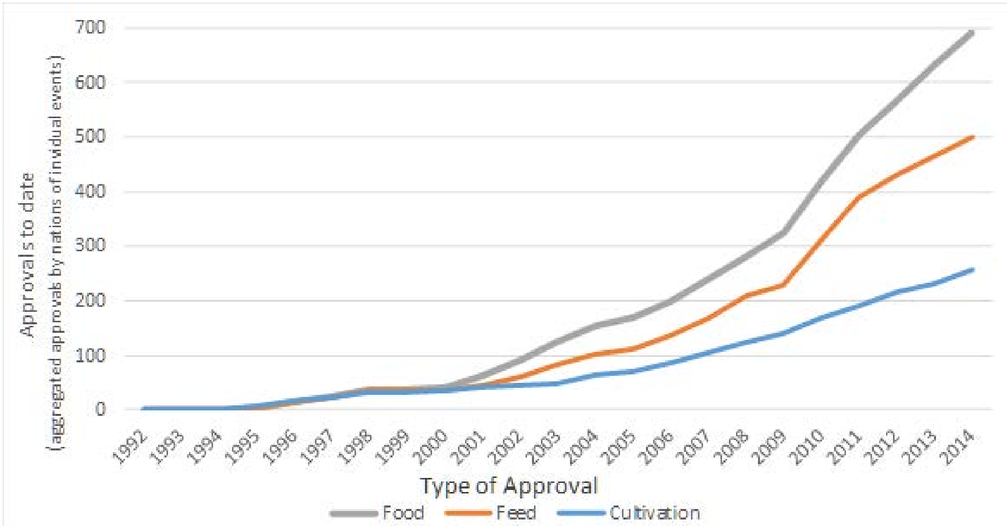

Figure A1 Aggregated GM corn approvals, year and type.
Source: ISAAA 2015

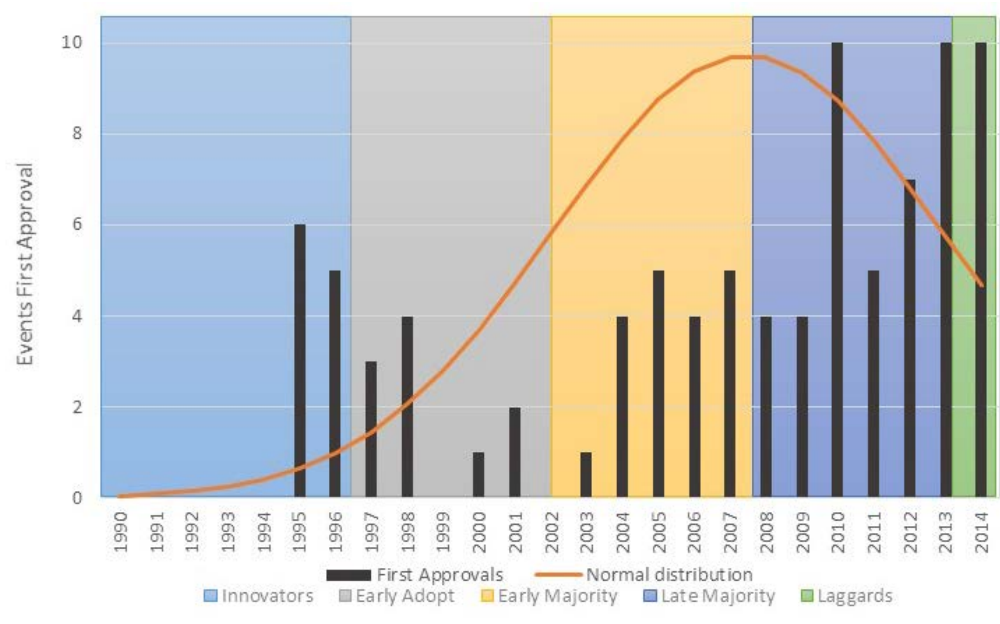

Figure A2 Diffusion of corn first approvals, with total events approval distribution and standard deviation.
Source: ISAAA 2015

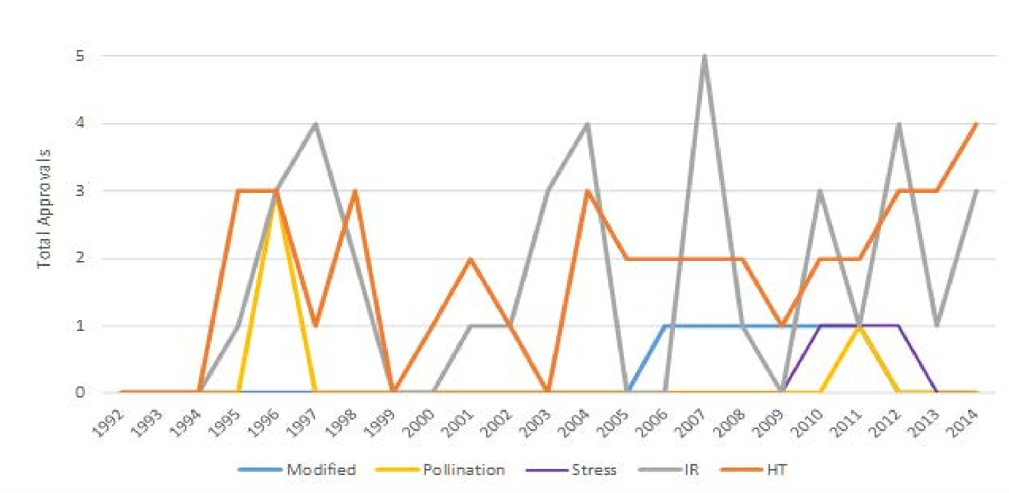

Figure A3 Single GM trait approvals.
Source: ISAAA 2015

Endnotes

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[2] A GM crop event is the occurrence of an individual firm, or public developer, seeking approval for the production, trade and/or consumption of their specific GM trait or event, such as the trait for herbicide tolerance. Each crop to receive approval is given an event ID, which has both a name and a code for future referencing.

[3] Science-based regulation is motivated by scientific research and calculated risk, unlike regulation based on socio-economics, which considers unsubstantiated hazards and "perceived" risks.

[4] In the 1960s and 1970s technological advancements were made in agriculture which led to substantial crop production gains, known as the Green Revolution (Borlaug, 1970). The research behind these technological advancements was organized and funded through the International Maize and Wheat Improvement Center (CIMMYT), which is part of the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an international group of 15 various research centres located throughout the world. CIMMYT was essential to engaging with national agricultural research institutes to get the new wheat varieties distributed to developing-country farmers.

[5] None of which had anything to do with biotechnology or GM crops.

[6] An event refers to a new plant variety that has been submitted for approval.

[7] Klümper and Qaim's finding also quantified a reduction in chemical pesticide use of 37 percent and an increase in farmer profits of 68 percent.