Faculdade de Economia,
Administração e Contabilidade
de Ribeirão Preto
Universidade de São Paulo

Texto para Discussão

Série Economia

TD-E 05 / 2014

More of Less isn't Less of More: Assessing Environmental Impacts of Genetically Modified Seeds in Brazilian Agriculture

Renato Nunes de Lima Seixas

Av. Bandeirantes, 3900 - Monte Alegre - CEP: 14040-905 - Ribeirão Preto - SP
Fone (16) 3602-4331/Fax (16) 3602-3884 - e-mail: cebelima@usp.br site: www.fearp.usp.br

Universidade de São Paulo
Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto

CONSELHO EDITORIAL

Comissão de Pesquisa da FEA-RP/USP

Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto
Avenida dos Bandeirantes,3900
14040-905 Ribeirão Preto – SP

A série TEXTO PARA DISCUSSÃO tem como objetivo divulgar: i) resultados de trabalhos em desenvolvimento na FEA-RP/USP; ii) trabalhos de pesquisadores de outras instituições considerados de relevância dadas as linhas de pesquisa da instituição. Veja o site da Comissão de Pesquisa em **www.cpq.fearp.usp.br**. Informações: e-mail: cpq@fearp.usp.br

More of Less isn't Less of More: Assessing Environmental Impacts of Genetically Modified Seeds in Brazilian Agriculture

Job Market Paper

Renato Seixas♣

José Maria Silveira#

We investigate the environmental effects due to pesticides for two different genetically modified (GM) seeds: insect resistant (IR) cotton and herbicide tolerant (HT) soybeans. Using an agricultural production model of a profit maximizing competitive farm, we derive predictions that IR trait decreases the amount of insecticides used and HT trait increases the amount of less toxic herbicides. While the environmental impact of pesticides for IR seeds is lower, for the HT seeds the testable predictions are ambiguous: scale as substitution effects can lead to higher environmental impacts. We use a dataset on commercial farms use of pesticides and biotechnology in Brazil to document environmental effects of GM traits. We explore within-farm variation for farmers planting conventional and GM seeds to identify the effect of adoption on the environmental impact of pesticides measured as quantity of active ingredients of chemicals and the Environmental Impact Quotient index. The findings show that the IR trait reduces the environmental impact of insecticides and the HT trait increases environmental impact due to weak substitution among herbicides of different toxicity levels.

Keywords: Brazil, Agriculture, Environmental Impact, Genetically Modified Seeds, Herbicide Tolerant Soybeans, Insect Resistant Cotton, Pesticides

May, 2014

We thank Anderson Galvão from Celeres®, for kindly providing the dataset, and comments from David Zilberman, Sofia Villas Boas, Max Auffhammer, Christian Traeger, Jeff Perloff, Avery Cohn, Marieke Kleemans, Manuel Barron, Kyle Emerick, Sam Heft-Neal, participants in the ERE seminar and development lunch at UC Berkeley and at the 17th ICABR conference "Innovation and Policy for the Bioeconomy". Financial support from CAPES/Fulbright PhD fellowship (grant 2256-08-8) is greatly acknowledged. All remaining errors are ours.

♣ PhD candidate at ARE/UC Berkeley. Corresponding author: rnlseixas@berkeley.edu .

IE/UNICAMP

1 INTRODUCTION

The research agenda on food supply has received increased attention since the global food crisis of 2008. In this context, genetically modified (GM) seeds have been considered one of the major breakthroughs in technological innovation for agricultural systems and have been promoted as an effective tool for control of agricultural pests and food supply expansion. Their relevance can also be measured by the wide spam of controversial issues that have been raised in the related literature since their introduction. Those involve: intellectual property rights over organisms, productivity effects, economic returns, consumer safety, welfare and income distribution, and environmental effects (Qaim, 2009). Potential sources of related economic gains include reduced crop losses, reduced expenditure on pest control, farmworker safety and health conditions, and lower variability of output (Sexton & Zilberman, 2012).

In the environmental front, benefits from adoption of GM seeds have been argued based on findings about pesticide use and agricultural practices. Insect resistant (IR) cotton has been found to reduce the use of insecticides and therefore to produce environmental, health and safety gains (Qaim & Zilberman, 2003; Qaim & de Janvry, 2005; Huang, Hu, Rozelle, Qiao, & Pray, 2002). Herbicide tolerant (HT) soybeans have been found to change the mix of herbicides applied towards less toxic products and to allow the use of no-till cultivation techniques, leading researchers to conclude (tentatively) that they also produce environmental benefits (Fernandez-Cornejo, Klotz-Ingram, & Jans, 2002; Qaim & Traxler, 2005; Brookes & Barfoot, 2012).

This paper addresses the environmental impacts, associated with the use of pesticides, resulting from adoption of GM seeds in Brazil. First, we use a model of a profit maximizing competitive farm to show how the interaction of different GM traits (HT and IR) affects the optimal use of pesticides, more specifically herbicides and insecticides. We show that the IR trait works as substitute for insecticides and hence reduces the optimal use of these products. The resulting environmental effect is straightforward: less insecticide usage leads to lower environmental impact. The HT trait, on the other hand, works as a complement to herbicides, specifically to glyphosate[1], and induces an increase in the use of this product. The resulting environmental impact is ambiguous and we argue that it depends on the interplay of a substitution effect, between herbicides of different toxicity levels, and a scale effect, of increased use of glyphosate.

In the empirical analysis, we use a unique farm-level dataset that documents adoption of GM seeds and pesticide use between 2009 and 2011 for cotton, maize and soybeans cultivation by commercial farms in Brazil to present the first reduced form models estimates of environmental effects of two different biotechnology traits: IR cotton and HT soybeans. The dataset is disaggregated by fields, within a farm, cultivated with conventional or GM seeds. In other words, for each farm, we have potentially multiple observations related to fields cultivated with conventional or GM seeds. This setup allows us to use *within-farm* variation for farmers that plant both conventional and GM seeds to identify the effect of adoption on the environmental impact of pesticides.

We measure the environment impact as two outcome variables: quantity (kg/ha) of active ingredients of chemicals and the Environmental Impact Quotient (EIQ) index (Kovach, Petzoldt, Degnil, & Tette, 1992). This measure of environmental impact of pesticides was designed to capture risks associated with both toxicity levels and exposure to chemical pesticides on three components of agricultural systems: farmworker, consumer and ecological. Hence, the EIQ index gives a more complete picture than just the composition of the mix of pesticides used allowing for an adequate weighting of pesticides of different toxicity levels. This represents a big advancement over previous studies that only documents increased use of less toxic pesticides for HT soybeans and so cannot capture environmental effects due to substation and scale effects. Concretely, if the increase in the use of less toxic herbicides is not accompanied by a sufficient decrease in more toxic ones (substitution effect) or if the increase

---

[1] The United States Environmental Protection Agency (EPA) considers glyphosate as a pesticide of toxicity level III, in a scale from I (most toxic) to IV (practically nontoxic), requiring products that carry it as active ingredients to obey safety conditions for manipulation such as protective clothing and no re-entrance in treated fields for 4 hours (United States Environmental Protection Agency, 1993). In the classification of environmental impacts, glyphosate is in the 145° position out of 178 active ingredients classified (Kovach, Petzoldt, Degnil, & Tette, 1992).

in less toxic is much higher than the decrease in more toxic ones (scale effect), them the new mix of herbicides induced by HT seeds can be more harmful than the one induced by conventional seeds. The EIQ index calculated for field operations allows us to adequately weight pesticides of different toxicity levels and gets around the difficulties of looking only at the mix of pesticides used.

Our findings show that, as expected, adoption of cotton seeds with IR trait reduces the amount of insecticides used by 24.2% and, consequently, the environmental impact index by 23.4% when compared with fields cultivated with conventional seeds. For soybean seeds with HT traits, however, although farmers use more of less toxic herbicides, we estimate that the net environmental impact is higher than for conventional seeds. We find that adoption of these seeds cause an increase of 44.2% of herbicides use and a corresponding 35.6% increase in the EIQ index when compared with fields cultivated with conventional seeds. Moreover, we estimate that the increase in the use of herbicides of low toxicity levels is twelvefold the decrease in the use of herbicides of high toxicity levels. This result indicates that the main mechanism driving the findings on the EIQ index is the weak substitution among herbicides of different toxicity levels.

Those results are not inconsistent with the literature on environmental effects of GM seeds. For IR cotton, Qaim & Zilberman (2003), Qaim & de Janvry (2005) and Huan et al. (2005) find significant reductions in average use of insecticides in India, Argentina and China, respectively. For HT soybeans, Fernandez-Cornejo et al. (2002) and Qaim & Traxler (2005) find increases in the use of glyphosate and some reduction in the use of more toxic herbicides, which leads them to conclude for environmental benefits due to the adoption of this type of seed. Our results confirm the environmental gains from IR cotton but suggest that the findings on the environmental effects of HT soybeans have been misled by relying solely on the change in the mix of herbicides used.

The rest of the paper is organized as follows. Section 2 introduces a quick background on biotechnology and its regulation in Brazil. Section 3 describes the theoretical framework that informs the testable hypotheses. Section 4 describes the dataset and presents the empirical strategy. Section 5 shows the results obtained and section 6 concludes.

2. SOME BACKGROUND ON BIOTECHNOLOGY AND REGULATION

Since the mid 1990's, when first-generation GM seeds were commercially introduced, adoption by farmers has grown steadily in industrialized and developing countries as they provide an alternative and more convenient way of reducing pest damage[2] (Figure 1). By 2008, 13.3 million farmers dedicated 8% of total cropland (12.5 million ha) to the cultivation of GM seeds. The leading countries in terms of share of cultivated are in 2009 were the US (50%), Argentina (17%), Brazil (13%), India (6%), Canada (6%) and China (3%) (James, 2008).

The main traits that have been introduced in first generation GM seeds correspond to the herbicide tolerant (HT) and insect resistant (IR) technologies. The focus of this paper relies on HT soybeans and IR cotton.

Soybeans are an annual crop, which means the plant life cycle (seed-flower-seed) last one season only. Weeds are strong competitors with soybean plants for nutrients, water and sunlight. Field infestation can produce yield losses since soybeans are sensitive to moisture and light deficiency, especially in the emergency phase before the plant canopy closes and puts it in advantage against weeds. Weed control techniques have evolved from traditional mechanical methods to herbicides applications introduced in the 1960's (Carpenter & Gianessi, 1999). The first generation of herbicides were known as pre-emergence since they have to applied before planting as weed burn down. Following application, farmers still had to rely on mechanical control until soybean canopy closes and shades competing weeds. Starting in the 1980's, postemergence herbicides were introduced and allowed growers to use chemical control of weeds instead of mechanical tillage over the growing season. This change made possible to increase the planted acreage since herbicide-based weed control is more efficient than

---

[2] Second-generation GM seeds display quality improvements in nutritional contents and third generation are designed for pharmaceutical (vaccines and antibodies) and industrial (enzymes and biodegradable plastics) applications.

mechanical tillage. Postemergence herbicides also make possible to narrow the space between plant rows in the fields which increases yields as a result of a more efficient use of space.

Nevertheless, postemergence herbicides also have drawbacks that limit their application and effectiveness in highly infested areas. These include: potential for crop injury in the form of stunted growth or yellowing/burning leaves, development of herbicide resistant weeds and residual effects on soil that might be deleterious to rotation of crops (Carpenter & Gianessi, 1999).

Soybean seeds engineered with HT traits were introduced in 1996 under the commercial name Roundup Ready. They're the result of the transfer of part of the genetic code of a soil bacterium, *Agrobacterium tumefaciens*, which allow the plant to metabolize the herbicide glyphosate (Roundup). In 1998, soybean varieties tolerant to the herbicide glufosinate were introduced under the commercial name Liberty Link. Those herbicides target a large variety of broad-leaf and grass weeds species but cause severe damages to conventional crops when applied after germination (post-emergent weed control). The primary reason given for the rapid diffusion rated of those seeds, notably the Roundup Ready ones, is the simplicity of the glyphosate-based weed control, which allows farmers to concentrate on one herbicide to control a wide range of weeds. In addition, it also proved more convenient for farmers since the timing of application can be extended beyond soybean flowering and the maximum size of weeds that are effectively controlled is higher compared with other postemergence herbicides (Carpenter & Gianessi, 1999). Herbicide related cost savings have also been pointed as one of the reasons for adoption, since glyphosate patent expired in the year of 2000, allowing the entry of new suppliers and lowering the price of glyphosate-based herbicides (Qaim, 2009). Hence, from the point of view of farmers, HT soybeans have been shown to be both technically and economically advantageous, which explains the rapid diffusion that they have displayed.

IR seeds[3] are engineered to produce a natural toxin produced by the soil bacterium *Bacillus thuringiensis* (Bt), which is lethal to a number of bollworms pests but not to mammals. IR crops have also been deemed technically and economically efficient for producers. The most

---

[3] Also referred in the literature as Bt seeds.

straightforward reason is related to savings in insecticides applications (which spams from labor time to savings in machinery use, aerial spraying etc.) targeted to bollworm killing. Specifically, in regions with high insect infestation, typical less developed countries in tropical weather regions, and high rates of insecticide use, the potential for reduction is conversely high (Qaim & Zilberman, 2003). Positive yield effects have also been noted since the Bt toxin compound on the insecticide effect reducing losses due to insect attack (Qaim, 2009). In fact, it has been argued that yield and insecticide reduction effects are closely related: farmers facing high pest pressure and still using low rates of insecticides

Besides, it has also been considered a more efficient tool for managing the risk of pest attack than reactive application of insecticides (Crost & Shankar, 2008) which has been translated in reduced crop insurance premium (Brookes & Barfoot, 2012). Other benefits pointed relate to improve safety conditions for farm workers and shorter growing season (Brookes & Barfoot, 2012).

Crops that have been engineered with the above traits are: cotton, maize, rapeseed and soybean. More recently, some crops have also been engineered with both HT and IR traits and are commonly referred as stacked varieties. The most used technology is HT in soybeans, which corresponded to 53% of GM seeds planted area in 2008 and is grown mostly in US, Argentina and Brazil. The second-most used technology is HT and IR maize, which accounted for 30% of GM seeds planted area in 2008 (James, 2008).

Despite the production benefits, consumers have shown suspicious attitudes regarding the health and environmental safety of products originated from GM seeds and government regulation has ranged from cautionary permission to complete ban. The European Union, for instance, imposed a ban on GM seeds that was lifted in 2008. Also, GM seeds uses have been restricted to animal feed and fiber uses and producers are required to segregate GM crops output throughout the supply chain (Sexton & Zilberman, 2012). Other concerns relate to the undermining of traditional knowledge systems in developing countries and the possibility of monopolization of seed markets by large multinational companies and exploitation of small farmers (Sharma, 2004).

The regulation of GM seeds in Brazil originates in the first Biosafety Law from 1995, which ruled that commercialization of GM seeds is subject to approval by the National Technical Biosafety Commission (CTNBio). After a decision from CTNBio in favor of Monsanto's *Roundup Ready* seed (a type of HT soybean seed) that waved the company from releasing environmental impact studies was judicially contested in 1998, a period of ban of commercialization of GM seeds was imposed by the judiciary system, on the grounds that CTNBio's decision violated the principle of precaution espoused by the Brazilian constitution. The judiciary decision, nevertheless, wasn't fully implemented as competitive pressure by farmers from neighbor countries Argentina and Paraguay stimulated the smuggling and illegal adoption of soybean HT seeds by farmers in the southern states that bordered those countries. Also, the executive branch took a mostly favorable stance towards farmers and loosened repression of GM seeds adoption on the grounds that it would impose huge losses on southern producers, responsible for a significant share of soybean production in Brazil. After a series of temporary provisional measures designed to work around the legal ban, a new biosafety law was passed in 2005 that settled the issue in favor of the discretion of CTNBio's power to require environmental impact studies for commercial release of GM seeds (Pelaez, 2009).

In spite of the delay caused by the regulatory issues that took seven years to be resolved, adoption of GM seeds in Brazil spread rapidly and reached a level similar to neighbor country Argentina, which has a longer history of liberal policy towards adoption of GM seeds. Figure 2 illustrates the steady growth in the rates of adoption of GM seeds in cotton, maize and soybean crops. Adoption of HT soybeans increased from 45.2% in 2008 to 91.8 % of planted area. Cotton crops also observed growth in GE seeds adoption rates, ranging from 6.6% of the planted area in 2008 to 29.6% in 2011. It's worth noting the rapid adoption of GM Maize seeds, which were introduced in 2008 and reached an adoption rate of almost 80% of planted area by 2011 (Céleres, 2012). In terms of area, this equivalent to approximately 31.16 million ha of the total planted area with those crops in 2010.[4]

---

[4] Approximately equivalent to 73% of California.

3. THEORETICAL FRAMEWORK

We present a heuristic model that illustrates the effects of different GM traits on choices of pesticides inputs by a competitive profit maximizing farm. The model allows us to derive testable predictions that are going to guide us on in the empirical analysis. Building on previous work (Ameden, Qaim, & Zilberman, 2005) we show that the IR trait works as substitute for insecticides and hence reduce the optimal amount used whereas the HT trait works as complement for herbicides and induce more intense use of those products. The net environmental impact, which is the outcome we are ultimately interested in, will be different for each trait. For the IR trait, the result is unequivocal: less insecticide usage reduces environmental impact. For the HT trait, on the other hand, the environmental impact can't be determined a priori. HT trait makes the plant more resistant to glyphosate, which leads to a more intensive usage of this chemical. The net environmental effect will depend on how strong is the substitution between different types of herbicides.

The set-up of the model uses a damage control framework (Lichtenberg & Zilberman, 1986) that distinguishes between inputs that directly affect production, like labor, land and fertilizers and inputs that indirectly affect output by reducing the damage caused by pests like pesticides, biological control or GM seeds. Total output is given by the interaction between potential output, represented as a conventional production function of direct inputs, and a damage abatement function of indirect inputs that represents the share of output not lost by action of pests. We represent the total output function as:

$$Q = Q_i[1 - D(N_i)], i = 0, 1 \qquad \text{(eq. 1)}$$

where $Q_i$represents potential output, determined by direct inputs, $D(N_i)$ is a damage function that depends on the size of the pest infestation and the subscript i represents conventional or GM seeds respectively. We make the following regularity assumptions on the damage function:

(i) $0 < D(N_i) < 1$ and

(ii) $D' > 0$ and $D'' \geq 0$.

Pest infestation depends on the size of initial population and the fraction that survive the application of chemicals and biotechnology. It is represented by:

$$N_i = Nh(x)B_i \,, \qquad \text{(eq. 2)}$$

Where N is the initial population, $h(x)$ is the fraction of survival after application of pesticide quantity x and B_i is a parameter for the biotechnology effect. We also make the following regularity assumptions:

(i) $h' < 0$ and $h'' > 0$,

(ii) $B_0 = 1 \geq B_1$.

Letting p denote the market price for the crop and w the unit cost of application of pesticide, the choice of chemical input (x) for a competitive farm, for each trait i = 0, 1, is the result of the following program:

$$\max_x pQ_i[1 - D(Nh(x)B_i)] - wx. \qquad \text{(eq. 3)}$$

The first order condition for an interior solution is given by:

$$-pQ_iD'Nh'(x_i^*)B_i = w. \qquad \text{(eq. 4)}$$

Equation four represents the solution to the usual profit maximization problem where the left-hand side represents the value of marginal product of the pesticide and the right-hand side its unit cost. The interaction of the effects of different traits will determine the comparative statics of the optimal choice x_i^*.

The IR trait exerts a compound effect with the application of insecticide represented by: $B_0 = 1 > B_1$ and $Q_0 = Q_1$. The effect of adoption is them to reduce (shift down) the value of the marginal product of insecticide and, consequently, the amount of insecticide used. In this sense, the IR trait works as a *substitute* for insecticides. The left panel of figure 3 illustrates this effect.

The HT trait, on the other hand, allows tolerance to the non-selective herbicide glyphosate[5] which avoids damage to the plant. We interpret this property as an increase in potential output that can be obtained from regular inputs and is represented by: $B_0 = B_1$ and

---

[5] More recently, traits that allow resistance to other herbicides like ammonium-glufosinate have been introduced or are on the pipeline (Bidraban, et al., 2009).

$Q_1 > Q_0$[6]. This effect increases the value of marginal product of the specific herbicide that the plant becomes tolerant to and the amount of herbicide applied. The right panel of figure 3 depicts this effect graphically.

The environmental impact that follows biotechnology adoption can be differentiated by the type of trait. For the IR trait, the effect is unequivocal: since the amount of insecticides is reduced, environmental impact is reduced with adoption.

For the HT trait the net environmental impact depends on two factors. First, it depends on the degree of substitution between different types of herbicides. Glyphosate is considered a low toxicity chemical. Hence, substitution of more toxic herbicides that are designed for specific weeds for less toxic general purpose herbicides can reduce the environmental impact of chemicals. On the other hand, there is also a scale effect: if the increase in the amount of low toxicity herbicides is much larger than the decrease in high toxicity herbicides, the net effect can be a higher environmental impact due to the use of chemicals. In a nutshell, weak substitution and large scale effect renders the net effect on environmental impact ambiguous.

Economists that studied the issue have focused on the substitution between herbicides to conclude (somewhat tentatively) that there are environmental gains allowed by the use of HT traits (Fernandez-Cornejo, Klotz-Ingram, & Jans, 2002; Qaim & Traxler, 2005). Nevertheless, we argue that weak substitution effect and strong scale effect might undermine this conclusion as we show in the analysis that follows on the next sections.

4. DATASET AND EMPIRICAL STRATEGY

The dataset originates from a survey conducted by a private firm in Brazil among 1,143 farmers distributed in 10 states for harvest seasons 2008-2011. Information on pesticide use was collected for harvest seasons 2009-2011 and covers 839 farms. The data are disaggregated at the trait level. Hence, each observation correspond to a farm *i*, on year *t*, producing crop j, with trait *k*. This separation is possible since the Brazilian agricultural regulation requires segregation of

---

[6] We should point here that this is a comparative statics result, i.e., all other factors are held constant. More importantly we're holding constant the variety of the seed in which the GM trait is being inserted.

fields cultivated with conventional and GM seeds, as required by the Cartagena Protocol ratified by the Brazilian government in 2004 (Oliveira, Silveira, & Alvim, 2012). The crops covered are cotton maize (summer and winter crops) and soybean. The traits used are conventional (for all crops), HT (soybean) and IR (cotton and maize). For reasons of space, we show results for soybean and cotton crops since these corresponds to the different biotechnology traits analyzed in the theoretical model[7].

The dataset contains information on physical production and input expenditures separated by type of crop and traits for each farmer. The variables available are:

1. Production (kg) and planted area (ha) for each field cultivated with different seed trait (conventional and GM);
2. Monetary measures by trait of seed: total and net revenue, gross operating income, expenditures on fuel, pesticides, other chemicals, fertilizers and correctives, direct labor, seeds and planting materials, royalties and fees, outsourced services (planting, defensives application, harvesting and transport), storage and processing, other direct costs,
3. Demographic aspects of farmers[8] (sex, age, schooling, years of experience with the crop);
4. Property structure of the farm: whether it's managed by owner or manager,
5. Dose (kg/ha), number of applications and formulation (percentage of active ingredients) of pesticides used (acaricides, formicides, fungicides, insecticides and herbicides).

The environmental impact of pesticides is measured by an index designed by scientists from the Integrated Pest Management program from Cornell University (NY): the Environmental Impact Quotient (EIQ). The EIQ index (Kovach, Petzoldt, Degnil, & Tette, 1992) organizes information on toxicological and environmental impact generated as requirement for registration in the United States Environmental Protection Agency and assesses

---

[7] Results for IR maize are qualitatively very similar to the ones obtained for IR cotton and are available upon request.

[8] Collected only in 2010.

the environmental impact associated with pesticides by considering three different components of agricultural systems with equal weight: farmworker (picker and applicator), consumers and ecological (terrestrial and aquatic animals). The general principle that guides the index is that the environmental impact for each component is given by the product of the toxicity level of the chemical substance (*active ingredient*), rated in a scale of one to 5, and the risk of exposure (e.g. half-life of substance on ground and plant surface, leaching potential), ranked in a scale of 1 for low risk, 2 for medium and 3 for high risk of exposure. Figure 4 gives a schematic description of the different components of the index.

The researchers propose an index that weights all those components in a single measure of environmental impact for each *active ingredient* contained in pesticides[9]. Starting with this measure, a field EIQ for pesticide is obtained in two steps:

1. For each pesticide j, the *EIQ* is the interaction of the active ingredients' (EIQ_i) and the percentage content in the formulation (% of active ingredient per unit of weight): $EIQ_j = \sum_i \sigma_{ij} \times EIQ_i$, where i represents the active ingredient, j the pesticide and σ_{ij} is the percentage content of active ingredient *i* in the formulation of pesticide j. Inactive ingredients are assigned an *EIQ* value of zero.
2. For each field *f*, the *EIQ* is the interaction of the *EIQ* of each pesticide *j* (calculated in one) applied to field f (EIQ_{jf}) multiplied by the dose (kg/ha) of pesticide required to provide adequate pest control (δ_{jf}) and the number of applications (α_{jf}): $EIQ_f = \sum_j \alpha_{jf} \times \delta_{jf} \times EIQ_{jf}$.

The field *EIQ* index captures a non-monotonic effect due to scale (dose and number of applications) and substitution effect (mix of active ingredients used). In other words, a pest management strategy that uses less toxic pesticides but in very large amounts can have a higher *EIQ* than a pest management strategy that uses small amounts of a high toxic pesticide. This represents a clear advantage over comparing variations in quantities of pesticides of different toxicity levels without any proper weighting that takes into account the two aforementioned

---

[9] The updated list of pesticides (active ingredients) and their respective indexes can be found at: http://www.nysipm.cornell.edu/publications/eiq/equation.asp#table2 .

effects[10]. Since the survey collects information on dose, number of applications and formulation of pesticides used for each seed trait used, we can calculate field EIQ indexes for conventional and GM seeds.

Figures 5 and 6 map the cities where the cotton and soybeans farms where surveyed in the years 2009-2011. They are spread over 8 states which comprise a total area of 3,564.8 thousands Km^2, equivalent to 41.8% of the Brazilian territory. Tables one, two and three show the regional distribution of the surveyed farms and descriptive statistics for the surveyed farms that cultivated cotton and soybeans between 2009-2011[11]. We can see, for example, that those are on average large operations in terms of total planted area, which also includes other crops, and net revenue. For cotton growers, the average total planted area is 2.521 ha, ranging from 60ha to 28,374 ha. For Soybean growers, the average total planted area is 1,240 ha ranging from 8ha to 13,500 ha. In terms of experience, we notice that famers report an average of 22.4 and 29.4 years for cotton and soybeans respectively. This can be interpreted as a quite high level of accumulated human capital accumulated in the activity. The variable owner indicates whether the farm is managed[12] by the owner of by some other agent (e.g. a manager). This variable documents farms that belong to a business group (eg. some investor that decides to diversify her portfolio) or to an independent farmer[13]. We see that for cotton farms, only two percent are managed by owners, while for soybean we have 25%. In terms of geographical concentration, the region with most observation is the Central-West in both crops. This is not surprising since this is one of the largest geographical regions in terms of agricultural land in Brazil. Finally, in terms of education, we can see that the sample corresponds to farmers with quite high schooling level for cotton growers, 68% have at least a college degree, while for soybean growers 48% of them have at least a college degree.

---

[10] We should also recognize that the EIQ index is not free of criticism, notably about the simplicity of the linear functional form assumed and the ordinal nature of the toxicity and risk of exposure measures. Other indexes of environmental impact have been proposed in the scientific literature that are more comprehensive and more difficult to apply than the EIQ (Levitan, Merwin, & Kovach, 1995).

[11] The different number of observations corresponds to variables that weren't surveyed every year.

[12] By managed we mean, the person that has decision power on biotechnology use.

[13] It has been documented that soybean production, especially in the Central-West region has taken place predominately in large agricultural enterprises (Weihold, Killick, & Reis, 2013).

Another interesting statistic is the rates of biotechnology adoption for each crop. For cotton, we see that 43% of the farmers surveyed used some type of GM seed between 2009 and 2011, while 26% reported having used IR seeds. For soybeans, virtually all surveyed farmers used HT seeds in some year between 2009 and 2011. Hence, soybean growers can be divided in groups of partial adopters and complete adopters.

As participation in the survey is voluntary, attrition rates are very high; hence, use of panel data techniques cannot be applied to the data. Nevertheless we can use other sources of variation to identify the effect of adoption on the use of pesticides. The level of data disaggregation – fields with conventional and GM traits – allows us to explore within farm variation between fields cultivated with conventional and GM seeds to identify the effect of biotechnology traits on the use of pesticides and corresponding environmental impact. This empirical strategy holds constant all farm-level characteristics that might affect simultaneously the choices of pesticide use and biotechnology adoption such as: management skills, input/output prices, location, weather shocks, etc. Hence, for instance, if soybean farmers that adopt biotechnology have some intrinsic preference for pest management strategies that are more intensive in herbicides than mechanical control (like tillage) the effect of GM traits could be overestimated. Likewise, if cotton farmers that adopt IR traits are more efficient and also use less insecticide in their pest management strategies, the effect of IR trait will be underestimated. The use of within farm variation, i.e., comparing the pesticide use and corresponding environmental impact for farmers that cultivate fields with conventional and fields with GM seeds, gets around these sources of bias on the coefficient that measures the effect of the GM trait.

Two main caveats still need to be addressed. First, there may be systematic differences across fields within the farm that might affect adoption and use of pesticides. This can be particularly important in the case of soybean HT seeds if the presence of weeds is related to soil quality, for example, and if farmers tend to use GM seeds fields with more weed infestation, which would introduce an upward bias in the coefficient of the GM trait. Also, if farmers use no-till farming in fields that are cultivated with HT seeds, the coefficient on HT trait will be upward biased as well since the effect of no-till will be confounded with the effect of HT trait[14].

To address the issues related to differences in fields we rely on two findings. First, we compare levels of expenditure per hectare on inputs across fields with conventional and GM seeds to look for evidence of soil quality that might drive more intense use of inputs. Specifically we look at expenditures on fertilizers as evidence of systematic differences in soil quality. Tables 4 and 5 show that, for cotton and soybeans crops respectively, we don't observe statistically significant differences in the average expenditure on inputs for fields cultivated with conventional and GM seeds. The results for expenditures on fertilizers give us some confidence that systematic differences in soil quality are not introducing significant bias in our results[15]. With respect to the use of no-tillage farming, since the survey collects information on the planting system used for each field, we control for the use of conventional versus no-till in the equations for soybean, the crop associated with the use of herbicides. We also estimate the model considering only farmers that don't use different farming systems across fields.

The third possible systematic difference across fields refers to the level of weed infestation in the fields which farmers apply HT seeds. If use of HT seeds is positively correlated with the level of infestation, i.e., knowledge that a field has a high level of weed infestation leads the farmer to use HT seed, so that she can rely on chemical treatment instead of labor demanding mechanical weeding, we would have an upward bias in our coefficient, since part of the increase in herbicide use would be due to the higher weed infestation and not because of the HT trait.

Unfortunately, we don't have a direct measure of weed infestation in the fields cultivated with HT seeds. Nevertheless, we can address this source of bias by relying on two arguments. First, in order to prevent development of weed resistance to herbicides, farmers have to rotate the fields in which they plant conventional and GM soybeans, as well as soybeans and other

---

[14] In no-till cultivation systems, farmers substitute soil tillage for burndown chemical treatment of weeds before planting. Hence, in no-till systems, farmers tend to use more herbicides.

[15] Even if those expenditures don't correspond to pre-treatment observations, we believe that this is the best evidence we can provide on the degree the relative homogeneity of fields cultivated with conventional and GM seeds.

crops, most commonly maize. Hence, in a given year, rotation introduces a random component to weed infestation in the fields cultivated with HT soybeans that might alleviate the bias due to weed infestation. Second, as we're going to show in the results section, we observe small or even non-significant differences in the levels of utilization of herbicides of higher toxicity levels across fields cultivated with conventional or HT soybeans, which might be another indication that weed infestation is, on average, similar in both kinds of fields.

The second caveat relates to the sample of farmers chosen to perform the estimation, i.e., farmers that cultivate both conventional and GM seeds. This choice can potentially introduce a selection bias since it only considers adopters. In fact, tables 6 and 7 show that there are significant differences between farmers included and excluded from the regression samples. For cotton farms, the sample is more concentrated in the northeastern region and less in the Central-West. With respect to schooling, we see that farmers in the sample tend to have more of college (not statistically significant) and graduate degrees and less of basic and high school. For soybean farms, we see statistically significant differences for more variables. Specifically, they have larger operations (planted area), spend more on fertilizers, are younger and less experienced, although with in a still high level, more concentrated in the northeastern and southeastern regions and less in the southern region and are also more educated (less concentrated in basic school).

To alleviate this issue we rely on the observation that the farmers in the sample are more educated than the excluded ones. Hence, we can conjecture that the selection bias is in the downward direction. If more educated farmers are also more efficient, them the effect of adoption will be smaller for them than the effect for the whole population. In other words, the results are underestimating the true value of the effect of adopting GM seeds on the outcome variables of interest: pesticides quantities and environmental impact. Another characteristic of the soybean farms is that virtually all farmers are adopters of HT seeds: there's exactly one observation corresponding to a farmer that uses only conventional soybeans. Hence, in the case of soybeans, the distinction between farms included and excluded from the sample refers to complete adopters, excluded, and partial adopters. Hence, the selection problem is also alleviated as unobservable characteristics between these two groups might not be as different as if the excluded farms were comprised of adopters and non-adopters.[16]

The models are estimated for cotton and soybean crops separately. The dependent variables are quantity (kg/ha) of pesticides used (insecticides for cotton and herbicides for soybean) and EIQ index for each field. The traits considered are the most common ones for each crop: IR for cotton and HT for soybean. The estimated equations have the following form:

$$y_{itf} = \alpha + \beta trait_f + \gamma_i + \theta_t + \varepsilon_{itf} \ . \qquad \text{(eq. 4)}$$

Subscripts i, t and f indicate farmer, year and field (each field cultivated with conventional or GM seed). We include farmers (γ_i) and time dummies (θ_t) that capture farm-specific and year specific effects. Although these variables are orthogonal to the field level effects that we are interested, they provide efficiency gains in the estimation that prove worth keeping them.

5. RESULTS

To recap and as derived by the model outlined in section three, for cotton crops (IR trait) we expect a negative coefficient for trait in the equation for quantity of insecticides and for the EIQ index. For the soybean model (HT trait) we expect to find a positive coefficient for trait in the equation for quantity of herbicides but in the EIQ equation, the trait coefficient can go either way. To give a better picture of the intensity of substitution between different types of herbicides, for soybean crop, we estimate separate equations for each type of toxicity class of herbicides. We expect to find positive coefficients for quantities of low toxicity (classes III and IV) and negative (or non-significant) coefficient for quantities of high toxicity (classes I and II) herbicides. The magnitudes of those coefficients might shed light to the process of substitution of herbicides that is induced by the HT trait is soybean crops.

The regression results that we obtained are consistent with the predictions of the model. For IR cotton, we observe a reduction in the quantity of insecticides and environmental impact. For HT soybean, on the other hand, we observe increased quantities (kg/ha) of low toxicity

---

[16] A second conjecture might be that, by using only farmers that adopt GM seeds, we are approximating the treatment effect on the treated, that is on farmers that have intrinsic characteristics that make them more likely to adopt GM seeds.

herbicides and no corresponding reduction for high toxicity ones. The net result is an increase in EIQ index of herbicides applied.

Insect Resistant Cotton

Table 8 shows estimates of the effect of adoption of IR trait in cotton crops for quantities (Kg/ha) of active ingredients of insecticides and total pesticides applied, considering all farms in the survey and the restricted sample respectively. The point estimates in the restricted sample are lower (in absolute terms) than the ones in the full sample, which indicates that bias due to uncontrolled unobserved variables is an issue. The coefficient of the IR trait indicates that it allows a reduction of 0.956Kg/ha of active ingredients of insecticides. Table 9 shows the results estimated with farm and year fixed effects, which shows efficiency gains reflected in lower standard errors obtained, and a log-linear specification that estimates the proportional effect of adoption on the dependent variable. The result shows a decrease of 24% in the amount of insecticides[17] used and 9.2% in total quantity of active ingredients.

Table 10 is the counterpart of table 9 for the EIQ index. Consistent with the reduction in quantity of insecticides, the coefficient indicates a reduction of 34.225 EIQ points. To gain some perspective on this magnitude, in comparison with the general classification of active ingredients for insecticides, this is higher than the median EIQ index of 32.07. Also, the Mean EIQ for insecticides is 145.8 and for all pesticides 304.4. The log-linear specification shows a proportional reduction of 23.4% in the EIQ index for insecticides. Hence, it can be considered a significant reduction in terms of environmental index.

As a robustness check for our results, we perform a falsification test that consists on regressing quantities (Kg/ha) of pesticides that should not be affected by the introduction of IR trait: acaricides, fungicides and herbicides. Table 11 shows the results using all cotton farms and the restricted sample and it can be seen that none of the coefficients are statistically significant.

The results so far are all consistent with the current state of the literature on environmental effects of IR seeds. Studying IR cotton seeds in India, Qaim & Zilberman (2003)

---

[17] We also estimate similar models per toxicity class (I-IV in decreasing level of toxicity) which indicate reductions in all classes, the most prominent effect being for class III (medium-low level of toxicity) with a proportional decrease of 40%. Those results are available upon request.

found reduction of 1 kg/ha on average use of insecticides (70% compared with the baseline conventional field) while Qaim & de Janvry(2005) found reductions between 1.2kg/ha and 2.6Kg/ha of active ingredients used in Argentina, which represents about 50% reduction in comparison with conventional plots. For China, Huan et al. (2005) found even bigger reductions of about 49kg/ha of average insecticide use (80.5% compared to the average of 60.7 Kg/ha in conventional fields).

Herbicide Tolerant Soybeans

For soybeans, the regression estimates on table 12 show that adoption of HT trait increases the quantities (Kg/ha) of active ingredients of herbicides used. The point estimate for the coefficient of the HT trait effect on the use of herbicides in the restricted sample is bigger than the one in the full sample and indicates that it causes an increase of 0.996Kg/ha of active ingredients of herbicides Table 13 shows the results including year and farmer fixed effects, which provide efficiency gains in the estimation and a log-linear specification that shows a proportionate increase of 44.2% in the quantity of active ingredients of herbicides and 26.2% in total.

Table 14 breaks the effects on herbicides by categories of toxicity level (1 to 4 in decreasing order). Categories 3 and 4 show significant increases of 0.64 and 0.44 kg/ha of active ingredients respectively while categories 1 and 2 show reductions of 0.084 and 0.005 (not statistically significant) respectively. Hence, the increases in less toxic herbicides is twelve fold the reduction in more toxic herbicides. This result reflects two points on the pattern of herbicide use. First, the substitution effect among different toxicity classes is very low, which indicates that this channel of environmental benefits is very limited. Second, the scale effect is not so big as compared to the effect found in other countries. Nevertheless, these results show that farmers are increasing the use less toxic herbicides on top of the more toxic ones, which suggests more environmental impact as a result of adoption of HT seeds.

The environmental effect is shown in Table 15 that reports the results for HT trait coefficient on the EIQ index equation. The weakness of the substitution among herbicides of different toxicity categories is reflected in higher environmental impact as shown by the coefficient that indicates an increase of 13.847 EIQ points. In comparison with the general EIQ classification for herbicides, this is lower than the median value for EIQ index of 19.5. The EIQ for glyphosate is also larger than this result: 15.33. In the sample, the mean EIQ for herbicides is 37.8 and for all pesticides 91.3. The proportional effect on the EIQ index is shows an increase of 35.6% in the EIQ index for herbicides and 16.2% in total. Hence, we can conclude for a relatively modest increase in environmental impact caused by HT soybeans.

We conduct two robustness checks for our results on HT soybeans. First, as with the case of IR cotton, we run a falsification test that consists on regressing quantities (Kg/ha) of pesticides that should not be affected by the introduction of HT trait: fungicides and insecticides. Table 16 shows the results using all soybean farms and the restricted sample and it can be seen that none of the coefficients are statistically significant. Additionally, we estimate the models for quantities and environmental impact controlling for the use of no-tillage cultivation in each field. This cultivation method requires more herbicides since it doesn't use tillage to clean the soil from weed infestation before the planting. Since this variable varies between fields, it might capture an important characteristic that should be controlled for. Tables 17 and 18 show the results for quantity of active ingredients and environmental impact, respectively, that are qualitatively and quantitatively very similar to the ones obtained before.

The results suggest that previous findings on the environmental effects of HT soybeans might have been biased by the qualitative nature of the mix of herbicides. Fernandez-Cornejo et al. (2002) found evidence of reduction in the use of acetamide herbicides and increase in the use of glyphosate in USA. Qaim and Traxler (2005) studying HT seeds in Argentina found a total increase of 107% in the use of herbicides, which are divided in a decreases of 87% and 100% in toxicity classes two and three, respectively, and an increase of 248% in toxicity class four. The authors suggest that this change is basically due to the use of no-till farming by adopters of HT soybeans.

Our results are not incompatible with those previous findings. In fact, we also observe a change in the composition of the mix of herbicides used towards less toxic products. This movement is predicted by the theoretical analysis that shows how the HT trait increases the value of marginal product of herbicide (glyphosate) and, therefore, the optimal amount used. On the other hand, we also find very weak substitution among herbicides of different toxicity classes, which suggests that the environmental impact of herbicides in being magnified. The analysis with the EIQ index confirms that this is not only a possibility: even inducing more use of a less toxic herbicide, HT seeds cause higher environmental impact, even when controlling for the use of no-till farming.

6. CONCLUSION

In this paper we analyze the environmental effects related to the use of pesticides arising from adoption of GM seeds in cotton and soybean crops. Cotton crops are genetically engineered to display IR traits that make the plant produce a natural toxin that helps fight certain types of harmful bollworms. Soybeans are modified to display HT trait that make the plant resistant to glyphosate, a general purpose low toxicity herbicide. We use a model of profit maximizing competitive farm to show how the introduction of these traits affects the optimal choices of pesticides. We show that the IR trait works as a substitute for insecticides and reduces the quantity used whereas the HT trait works as a complement for the herbicide glyphosate and so induces more usage of this product.

The environmental effects are also different for each type of trait. The IR trait has unequivocal benefits since it’s basically a chemical saving technology. The HT trait, on the other hand, has ambiguous effects: it induces more usage of a less toxic herbicide but we argue that the total effect depends on the substitution among herbicides of different toxicity classes and on the scale of additional usage of glyphosate. Increased environmental impact can arise from a combination of low substitution and high scale effect.

Using within-farm variation across fields treated with conventional and GM seeds, we find that the IR trait reduces the amount of insecticides applied to cotton crops, measured by kg/ha of active ingredients applied to the fields. HT trait, on the other hand, leads to more usage of herbicides. Specifically, we see increased usage of herbicides from lower toxicity classes (3 and 4) and very small reductions in herbicides from higher toxicity classes (1 and 2). This finding evidences a very weak substitution among herbicides which raises the possibility of higher environmental impact.

To assess the environmental effect of GM traits due to the use of pesticides, we use a measure developed by integrated pest management scientists that takes into account levels of toxicity of active ingredients, risk of exposure and application in the field (dose and number of applications): the EIQ index. Within-farm analysis shows that IR trait reduces the environmental impact by about 23% in the treated fields compared to fields cultivated with conventional seeds. This is consistent with the previous result on kg/ha of insecticides and confirms the environmental impact saving nature of the IR technology.

The resulting environmental impact for HT trait, on the other hand, is found to be positive. The estimates imply an increase of 35.6% on the impact of herbicides compared to fields cultivated with conventional seeds. This finding confirms that the weak substitution among herbicides makes adoption of HT seeds to increase the environmental impact from pesticide use.

We believe this to be an important result for three reasons. First, it contributes to uncover environmental effects that have been hidden by the qualitative nature of the mix of herbicides induced by HT trait. Second, environmental policy makers designing policies for biotechnology adoption might consider this new evidence to differentiate among GM traits that produce positive or negative externalities. Finally, as the composition of the EIQ index suggests, the environmental impact of pesticides can have multiple dimensions that might involve farmworker health and safety, consumer safety and ecological impacts. Hence, the results on HT soybeans points to additional avenues of work that should be taken to evaluate each of these possible channels since they can also affect other important outcomes such as human capital accumulation.

REFERENCES

Ameden, H., Qaim, M., & Zilberman, D. (2005). Adoption of Biotechnology in Developing Countries. In J. Cooper, L. Lipper, & D. Zilberman, *Agricultural*

Biodiversity and Biotechnology in Economic Development (pp. 329-357). New York: Springer.

Bidraban, P., Franke, A., Ferraro, D., Ghersa, C., Lotz, L., Nepomuceno, A., . . . van de Wiel, C. (2009). *GM-related sustainability: agro-ecological impacts, risks and opportunities of soy production in Argentina and Brazil.* Wageningen: Plant Research International B.V.

Brookes, G., & Barfoot, P. (2012). *GM Crops: Global Socioeconomic and Environmental Inpacts 1996 - 2010.* Dorchester: P.G. Economics.

Carpenter, J., & Gianessi, L. (1999). Herbicide Tolerant Soybeans: Why Growers are Adopting Roundup Ready Varieties. *AgBioforum, 2*(2), 65-72.

Céleres. (2012). *The Economic Benefits from Crop Biotechnology in Brazil: 1996 - 2011.* Report prepared for the Brazilian Association of Seeds Producers (ABRASEM), Uberlândia (MG). Retrieved June 2012, from http://www.cib.org.br/estudos/Rel_BiotechBenefits_2009_Economico_Eng.pdf

Crost, B., & Shankar, B. (2008). Bt-Cotton and Production Risk: Panel Data Estimates. *International Journal of Biotechnology, 10*, 122-131.

Fernandez-Cornejo, J., Klotz-Ingram, C., & Jans, S. (2002). Farm-level effects of adopting herbicide-tolerant soybeans in the U.S.A. *Journal of Agricultural and Applied Economics*, 149-163.

Huang, J., Hu, R., Rozelle, S., Qiao, F., & Pray, C. (2002). Transgenic Varieties and Productivity of Small-Holder Cotton Farmers in China. *The Australian Journal of Agricultural and Resource Economics, 46*, 367 - 387.

James, C. (2008). *Global Status of commercialized Biothech/GM Crops: 2008.* Int. Serv. Acquis. Agri-Biothech Appl., ISAAA, Ithaca, NY.

Kovach, J., Petzoldt, C., Degnil, J., & Tette, J. (1992). *A method to measure the environmental impact of pesticides.* Ithaca, NY: New York State Agricultural Experiment Station, a division of the New York State College of Agriculture and Life Sciences, Cornell University.

Levitan, J., Merwin, I., & Kovach, J. (1995). Assessing the Relative Environmental Impacts of Agricultural Pesticides: the Quest for a Holistic Method. *Agriculture, Ecosystems and Environment, 55*, 153-168.

Lichtenberg, E., & Zilberman, D. (1986). The Econometrics of Damage Control: Why Specification Matters. *American Journal of Agricultural Economics, 68*(3), 261 - 273.

Oliveira, A., Silveira, J., & Alvim, A. (2012, March). Cartagena Protocol, Biosafety and Grain Segregation: The Effects on the Soybean Logistics in Brazil. *Jounal of Agricultural Research and Developmento, 2*(1), 17-30.

Pelaez, V. (2009). State of Exception in the Regulation of Genetically Modified Organisms in Brazil. *Science and Public Policy, 36*(1), 61 - 71.

Qaim, M. (2009). The Economics of Genetically Modified Crops. *Annual Review of Resource Economics, 1*, 665 - 694. Retrieved from http://www.annualreviews.org/doi/abs/10.1146/annurev.resource.050708.144203

Qaim, M., & de Janvry, A. (2005). Bt Cotton and Pesticide use in Argentina: Economic and Environmental Effects. *Environment and Development Economics, 10*, 179 - 200.

Qaim, M., & Traxler, G. (2005). Roundup Ready soybeans in Argentina: farm level and aggregate welfare effects. *Agricultural Economics*, 73-86.

Qaim, M., & Zilberman, D. (2003). Yield Effects of Genetically Modified Crops in Developing Countries. *Science, 299*(5608), 900 - 902.

Sexton, S., & Zilberman, D. (2012). Land for Food and Fuel Production: The Role of Agricultural Biotechnology. In J. Zivin , & J. Perloff, *The Intended and Unintended Effects of U.S. Agricultural and Biotechnology Policies* (pp. 269 - 288). Chicago: University of Chicago Press.

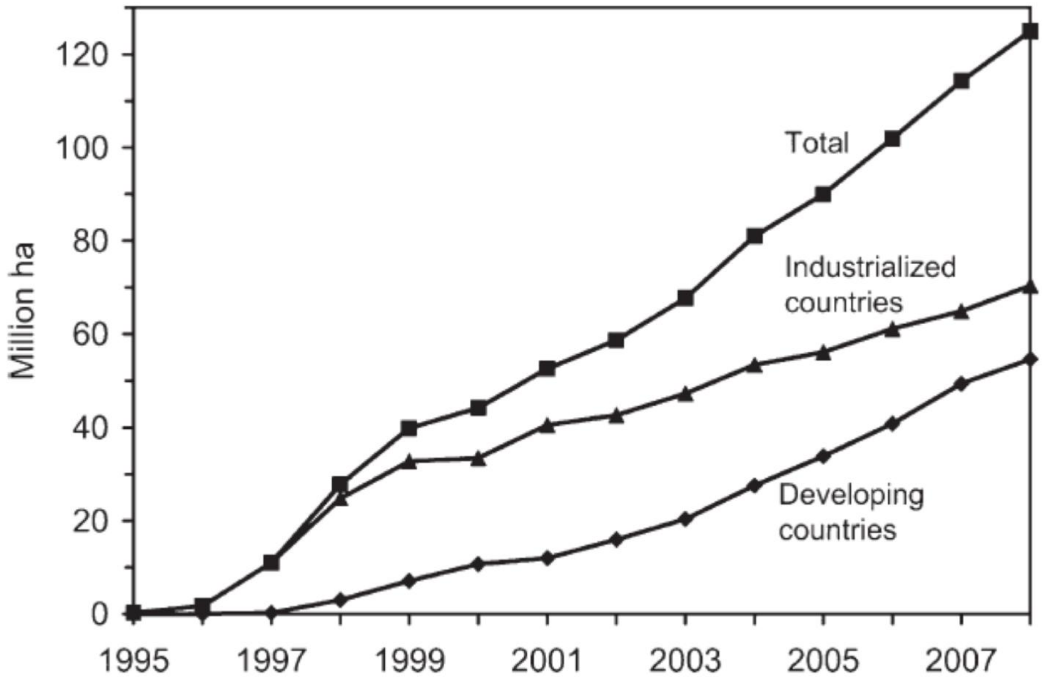
Sharma, D. (2004). Food and Hunger: a View from the South. *Forum on Biotechnology and Food Security.* New Delhi.

United States Environmental Protection Agency. (1993). *Registration Decision Fact Sheet for Glyphosate (EPA-738-F-93-011).* Retrieved 11 02, 2013, from http://www.epa.gov/oppsrrd1/REDs/factsheets/0178fact.pdf

Weihold, D., Killick, E., & Reis, E. (2013). Soybeans, Poverty and Inequality in the Brazilian Amazon. *World Development, 52*, 132-143.

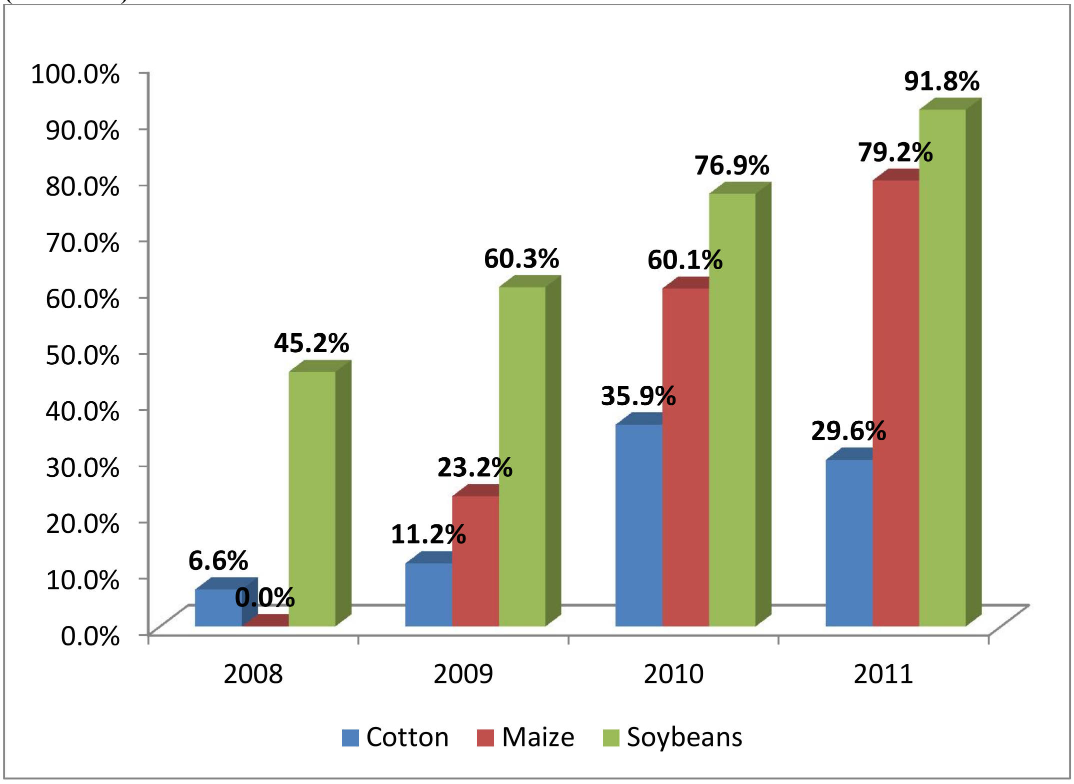
Tables and Figures

Figure 1: Steady Increase in Global Planted Area Using GM Crops



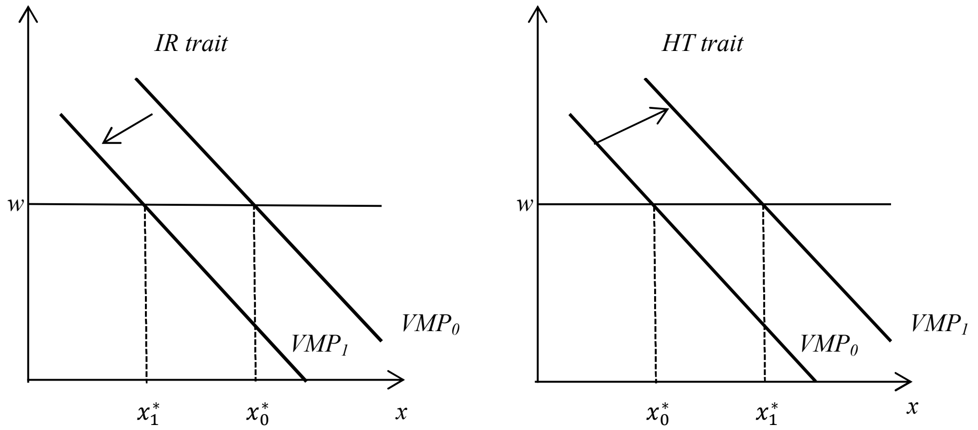
Source: Qaim (2009).

Figure 2: Share of Planted Area with Genetically Modified Seeds for Cotton, Maize and Soybeans (2008-2011)



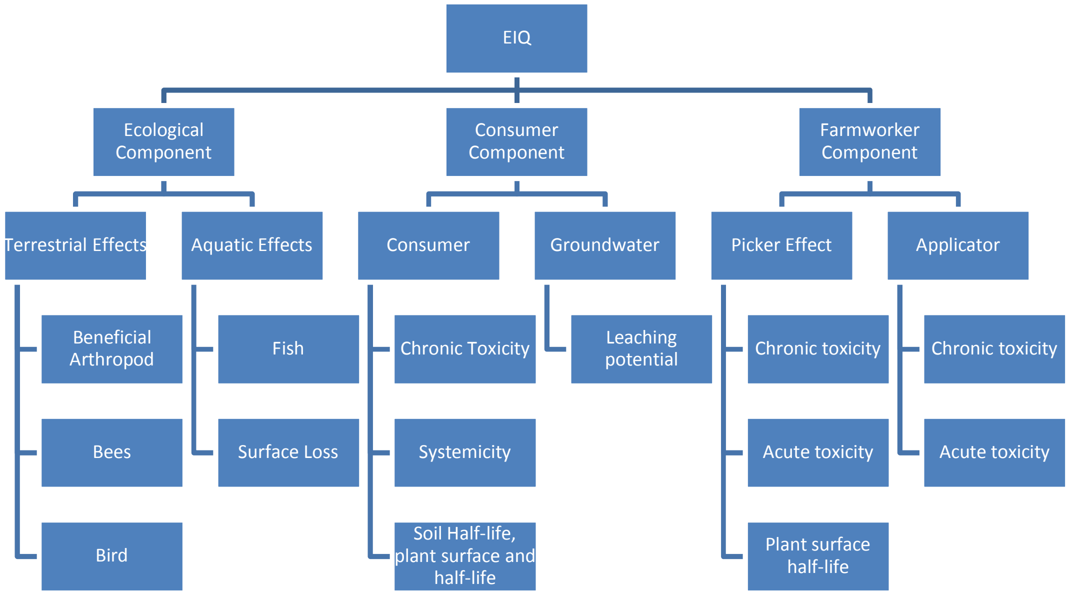
Source: own elaboration based on Celeres (2012)

Figure 3: Effect of GM Traits on Pesticide Use



Left panel: IR trait reduces the value of marginal product of insecticides (from VMP_0 to VMP_1) due to compound effect over insects and so reduces the optimal quantity of insecticides (from x_0^* to x_1^*). Right panel: HT trait increases the value of marginal product of herbicide (from VMP_0 to VMP_1) due to reduction of harmful side-effects and so increases the optimal quantity of herbicide (from x_0^* to x_1^*).

Figure 4: EIQ Components



EIQ for active ingredient: average of ecological, consumer and farmworker components:

- $Ecological = (F \times R) + \left(D \times \frac{S+P}{2} \times 3\right) + (Z \times P \times 3) + (B \times P \times 5)$, F = fish toxicity, R = surface runoff potential, D = bird toxicity, S = soil half-life, P = plant surface half-life, D = bird toxicity, Z = bee toxicity and B = beneficial arthropod toxicity;
- $Consumer = C \times \left[\frac{S+P}{2}\right] \times SY + L$, C = chronical toxicity, SY = systemicity (potential of absorption, by plant) L = leaching potential, S = soil half-life and P = plant surface half-life
- $Farmworker = C \times [(DT \times 5) + (DT \times P)]$, C = chronical toxicity, P = plant surface half-life and DT = dermal toxicity.

Figure 5: Cities with Cotton Farms Surveyed

Figure 6: Cities with Soybean Farms Surveyed

Table 1: Distribution of Cotton and Soybean Farms by Region

	Cotton		Soybean	
Region	N	pct.	N	pct.
Central-West	145	67.44	124	48.06
Northeast	62	28.84	25	9.69
South	-	-	95	36.82
Southeast	8	3.72	14	5.43
Total	215	100.00	258	100.00

Note: farms are spread over 8 states (figs. 5 and 6) which comprise a total area of 3,564.8 thousands Km^2, equivalent to 41.8% of Brazilian territory.

Table 2: Farm-Level Descriptive Statistics for Cotton Growers

	mean	sd	min	max	count
Planted Area (ha)	2,521.0	3,538.5	60.0	28,374.0	255
Net Rev. (US$/ha)	3,344.1	1,364.9	791.6	7,171.2	255
Gross Margin (US$/ha)	1,495.5	1,112.4	-6.2	4.988.8	255
Costs (US$/ha)	1,848.6	412.0	604.6	2,586.7	255
Pesticides (US$/ha)	588.2	194.9	99.9	1,144.9	255
Fertilizers (US$/ha)	1,007.2	270.7	304.5	1,927.5	255
Central-West	0.67	0.47	0.0	1.0	215
Northeast	0.29	0.45	0.0	1.0	215
South	0.00	0.00	0.0	0.0	215
Southeast	0.04	0.19	0.0	1.0	215
Basic School	0.07	0.26	0.0	1.0	83
High School	0.29	0.46	0.0	1.0	83
College	0.53	0.50	0.0	1.0	83
Graduate Degree	0.11	0.31	0.0	1.0	83
Age	38.08	9.14	23.0	57.0	75
Experience	25.80	14.60	2.0	58.0	75
Owner	0.02	0.15	0.0	1.0	215
Biotech User	0.43	0.50	0.0	1.0	215
IR user	0.26	0.44	0.0	1.0	255

Sample: 2009 – 2011.

Area, revenue, expenditures and IR trait use statistics consider each farm/year as a separate observation since they can change over the years for farms that are surveyed more than once.

Other statistics consider each farm as a separate observation and are not influenced by farms that appear in more than one survey. Age and experience correspond to the maximum value of that variable observed. “Biotech User” shows whether the farmer adopted any type of GM seed over the surveyed years. The value is different than “IR user” since there are other types of GM seeds for cotton.

Table 3 Farm-Level Descriptive Statistics for Soybean Growers

	mean	sd	min	max	count
Planted Area (ha)	1,240.3	1,771.8	8.0	13,500.0	291
Net Rev. (US$/ha)	1,164.8	484.9	334.3	3,711.6	291
Gross Margin (US$/ha)	499.3	352.7	-140.4	2,115.5	291
Costs (US$/ha)	665.6	248.2	283.6	1998.2	291
Pesticides (US$/ha)	135.5	86.8	17.0	630.1	291
Fertilizers (US$/ha)	478.3	190.2	0.0	1,383.4	291
Central-West	0.48	0.50	0.0	1.0	258
Northeast	0.10	0.30	0.0	1.0	258
South	0.37	0.48	0.0	1.0	258
Southeast	0.05	0.23	0.0	1.0	258
Basic School	0.28	0.45	0.0	1.0	120
High School	0.27	0.44	0.0	1.0	120
College	0.38	0.49	0.0	1.0	120
Graduate Degree	0.08	0.28	0.0	1.0	120
Age	43.97	12.41	24.0	74.0	118
Experience	32.46	17.10	5.0	75.0	118
Owner	0.22	0.42	0.0	1.0	258
HT User	1.00	0.06	0.0	1.0	258

Sample: 2009 – 2011.

Area and expenditure statistics consider each farm/year as a separate observation since they can change over the years for farms that are surveyed more than once. Other statistics consider each farm as a separate observation and are not influenced by farms that appear in more than one survey. Age and experience correspond to the maximum value of that variable observed. "HT User" shows whether the farmer adopted HT seeds over the surveyed years. Since HT is the only GM seed for soybean, this table doesn't display a variable "Biotech User".

Table 4: Within-Farm Descriptive Statistics: Fields Cultivated with Conventional vs. Fields Cultivated with Insect Resistant Cotton

	CO	IR	Total	Diff.
Area (ha)	1,741.9	1,087.2	1,414.6	654.7
	[2,442.4]	[1,948.8]	[2,224.5]	[1.62]
Yield (Kg/ha)	3,871.8	3,560.2	3,716.0	311.6
	[521.9]	[1,120.3]	[884.2]	[1.95]
Net Rev. (US$/ha)	5,980.2	6,077.3	6,027.5	-97.08
	[2,253.7]	[2,273.0]	[2,253.9]	[-0.23]
Direct Costs (US$/ha)	3,563.3	3,533.3	3,548.7	30.03
	[433.0]	[480.6]	[455.1]	[0.36]
Costs-Seed (US$/ha)	3,461.8	3,349.3	3,407.0	112.5
	[440.1]	[474.8]	[458.8]	[1.33]
Gross Margin (US$/ha)	2,416.9	2,544.0	2,478.8	-127.1
	[2156.2]	[2178.2]	[2158.5]	[-0.32]
Fertilizers (US$/ha)	992.1	981.4	986.9	10.63
	[214.9]	[219.7]	[216.4]	[0.26]
Observations	60	60	120	60

Standard errors (columns CO and IR) and t statistics (column Diff.) in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Cost-Seed: excludes expenditures with seeds and royalties.

Table 5: Within-Farm Descriptive Statistics: Fields Cultivated with Conventional vs. Fields Cultivated with Herbicide Tolerant Soybean

	CO	HT	Total	Diff.
Area (ha)	692.6	706.6	699.6	-14.01
	[992.0]	[773.2]	[886.7]	[-0.10]
Yield (Kg/ha)	3,148.1	3,146.8	3,147.5	1.240
	[512.9]	[603.6]	[558.4]	[0.01]
Net Rev. (US$/ha)	1,865.3	1,850.9	1,858.0	14.42
	[390.8]	[419.2]	[404.2]	[0.23]
Direct Costs (US$/ha)	1,180.3	1,193.3	1,186.8	-12.92
	[241.4]	[247.4]	[243.8]	[-0.34]
Costs-Seed (US$/ha)	1,085.4	1,066.8	1,076.1	18.62
	[243.3]	[249.6]	[245.9]	[0.49]
Gross Margin (US$/ha)	685.0	657.6	671.2	27.34
	[439.7]	[442.3]	[439.9]	[0.40]
Fertilizers (US$/ha)	489.0	488.0	488.5	0.936
	[180.3]	[179.1]	[179.2]	[0.03]
	85	85	170	85

Standard errors (columns CO and HT) and t statistics (column Diff.) in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Cost-Seed: excludes expenditures with seeds and royalties.

Table 6: Differences Between Cotton Farms Included (Sample) and not Included (Non-Sample) in Regression Analysis

	Non-Sample	Sample	Total	Diff.
Total Area (ha)	2,371.5	3,006.6	2,521.0	-635.1
	[3,273.7]	[4,284.0]	[3,538.5]	[-1.06]
Net Rev. (US$/ha)	3,403.3	3,151.7	3,344.1	251.6
	[1,323.3]	[1,487.7]	[1,364.9]	[1.17]
Gross Margin (US$/ha)	1,547.6	1,326.2	1,495.5	221.4
	[1051.1]	[1,286.9]	[1,112.4]	[1.21]
Costs (US$/ha)	1,855.7	1,825.5	1,848.6	30.25
	[429.7]	[350.7]	[412.0]	[0.55]
Pesticides (US$/ha)	592.1	575.5	588.2	16.55
	[205.5]	[156.0]	[194.9]	[0.66]
Fertilizers (US$/ha)	1,001.8	1,024.7	1,007.2	-22.91
	[279.9]	[239.9]	[270.7]	[-0.62]
Age	38.24	34.76	37.28	3.478
	[9.165]	[10.44]	[9.611]	[1.58]
Experience	23.70	19.03	22.41	4.663
	[15.93]	[10.93]	[14.82]	[1.71]
Owner	0.0103	0.0667	0.0235	-0.0564
	[0.101]	[0.252]	[0.152]	[-1.70]
Central-West	**0.749**	**0.317**	**0.647**	**0.432*****
	[0.435]	**[0.469]**	**[0.479]**	**[6.34]**
Northeast	**0.241**	**0.567**	**0.318**	**-0.326*****
	[0.429]	[0.500]	[0.466]	[-4.56]
Southeast	**0.0103**	**0.117**	**0.0353**	**-0.106***
	[0.101]	**[0.324]**	**[0.185]**	**[-2.51]**
Basic School	0.0595	0.0313	0.0517	0.0283
	[0.238]	[0.177]	[0.222]	[0.70]
High School	**0.321**	**0.125**	**0.267**	**0.196***
	[0.470]	**[0.336]**	**[0.444]**	**[2.50]**
College	0.571	0.594	0.578	-0.0223
	[0.498]	[0.499]	[0.496]	[-0.22]
Graduate Degree	**0.0476**	**0.250**	**0.103**	**-0.202***
	[0.214]	**[0.440]**	**[0.306]**	**[-2.49]**

Sample: farms that use both conventional and IR seeds and so are included in regression analysis.

Non-Sample: farms that use only one type of seed (conventional or IR) and are not included in regression analysis.

Total: all farms.

Standard errors (columns Non-Sample, Sample and Total) and *t* statistics (column Diff.) in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Differences Between Soybean Farms Included (Sample) and not Included (Non-Sample) in Regression Analysis

	Non-Sample	Sample	Total	Diff.
Total Area (ha)	**868.2**	**2,142.3**	**1,240.3**	**-1,274.1*****
	[1,201.7]	**[2,480.1]**	**[1,771.8]**	**[-4.52]**
Net Rev. (US$/ha)	1,160.5	1,175.5	1,164.8	-14.99
	[415.2]	[625.2]	[484.9]	[-0.20]
Gross Margin (US$/ha)	**530.1**	**424.5**	**499.3**	**105.6***
	[344.6]	**[362.8]**	**[352.7]**	**[2.29]**
Costs (US$/ha)	**630.4**	**750.9**	**665.6**	**-120.6****
	[192.3]	**[334.8]**	**[248.2]**	**[-3.12]**
Pesticides (US$/ha)	**122.9**	**166.2**	**135.5**	**-43.38****
	[64.33]	**[120.6]**	**[86.76]**	**[-3.14]**
Fertilizers (US$/ha)	**443.8**	**561.9**	**478.3**	**-118.1*****
	[159.7]	**[229.5]**	**[190.2]**	**[-4.33]**
Age	**46.55**	**38.94**	**43.98**	**7.613*****
	[11.06]	**[12.65]**	**[12.13]**	**[3.57]**
Experience	**34.20**	**20.08**	**29.43**	**14.12*****
	[15.53]	**[13.80]**	**[16.35]**	**[5.58]**
Owner	0.248	0.271	0.254	-0.0230
	[0.433]	[0.447]	[0.436]	[-0.40]
Central-West	0.466	0.518	0.481	-0.0516
	[0.500]	[0.503]	[0.501]	[-0.80]
Northeast	**0.0291**	**0.235**	**0.0893**	**-0.206*****
	[0.169]	**[0.427]**	**[0.286]**	**[-4.32]**
South	**0.490**	**0.118**	**0.381**	**0.373*****
	[0.501]	**[0.324]**	**[0.487]**	**[7.52]**
Southeast	**0.0146**	**0.129**	**0.0481**	**-0.115****
	[0.120]	**[0.338]**	**[0.214]**	**[-3.06]**
Basic School	**0.367**	**0.0612**	**0.265**	**0.306*****
	[0.485]	**[0.242]**	**[0.443]**	**[5.11]**
High School	0.235	0.306	0.259	-0.0714
	[0.426]	[0.466]	[0.439]	[-0.90]
College	0.337	0.469	0.381	-0.133
	[0.475]	[0.504]	[0.487]	[-1.53]
Graduate Degree	0.0612	0.163	0.0952	-0.102
	[0.241]	[0.373]	[0.295]	[-1.74]

Sample: farms that use both conventional and HT seeds and so are included in regression analysis.

Non-Sample: farms that use only one type of seed (conventional or HT) and are not included in regression analysis.

Total: all farms.

Standard errors (columns Non-Sample, Sample and Total) and *t* statistics (column Diff.) in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8 OLS Estimates of Effects of IR Trait on Quantity of Insecticides and Total Pesticides
Dependent Variable: Active Ingredients (Kg/ha)

	(1) Insecticides$^+$	(2) Total$^+$	(3) Insecticides	(4) Total
IR trait	-1.279***	-1.790***	-0.956**	-0.980
	[0.264]	[0.485]	[0.362]	[0.568]
Constant	4.914***	12.352***	4.630***	11.551***
	[0.163]	[0.314]	[0.256]	[0.413]
N	312	312	120	120
r2	0.046	0.025	0.056	0.025
F	11.141	145.516	12.215	8.340
Mean of Dep. Var.	4.639	11.967	4.152	11.061

Models (1) and (2) include all cotton farms, models (3) and (4) only farms that use both conventional and IR seeds (within farm variation as source of identification). Models are in linear specification.

+ Robust standard errors in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

IR trait affects the quantity (Kg/ha) of insecticides. Total represents the sum of all pesticides used (acaricides, fungicides, herbicides and insecticides). Coefficients are smaller in magnitude in the restricted sample, but not statistically different than the ones in the model with all farms.

Table 9 OLS Estimates of Effects of IR Trait on Quantity of Insecticides and Total Pesticides (Restricted Sample)
Dependent Variable: Active Ingredients (Kg/ha)

	(1) Insecticides$^+$	(2) Total$^+$	(3) Insecticides	(4) Total
IR trait	-0.956***	-0.980***	-0.242***	-0.092***
	[0.155]	[0.252]	[0.037]	[0.024]
Constant	8.721***	19.018***	2.346***	3.025***
	[0.874]	[0.644]	[0.207]	[0.134]
N	120	120	120	120
r2	0.905	0.896	0.913	0.878
F	11.141	145.516	12.215	8.340
Mean of Dep. Var.	4.152	11.061	-	-

Models (1) and (2) are linear specifications, models (3) and (4) are log-linear specifications. All models include farm and year fixed-effects.

Restricted saple: farms that use both conventional and IR seeds (within farm variation as source of identification).

+ Robust standard errors in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Farmer and year fixed-effects don't affect coefficients since they are orthogonal to within-farm variables. Log-linear specifications show a reduction of 24% in the quantity of insecticides and 9.2% in total pesticides.

Table 10 OLS Estimates of Environmental Impact of IR Trait (Restricted Sample)
Dependent Variable: EIQ

	(1) Insecticides^{+}	(2) Total^{+}	(3) Insecticides^{+}	(4) Total^{+}
IR trait	-34.225***	-36.856***	-0.234***	-0.120***
	[5.525]	[7.482]	[0.035]	[0.026]
Constant	316.085***	557.297***	6.041***	6.455***
	[23.144]	[42.071]	[0.198]	[0.082]
N	120	120	120	120
r2	0.906	0.905	0.918	0.886
F	48.981	11.134	12.972	75.140
Mean of Dep. Var.	145.807	304.489	-	-

Models (1) and (2) are linear specifications, models (3) and (4) are log-linear specifications. All models include farm and year fixed-effects.

Restricted saple: farms that use both conventional and IR seeds (within farm variation as source of identification).

+ Robust standard errors in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Consistent with the reduction in quantity of insecticides, the coefficient indicates a reduction of 34.225 EIQ points. In comparison with the general classification of active ingredients for insecticides, this is higher than the median EIQ index of 32.07. The log-linear specification shows a proportional reduction of 23.4% in the EIQ index.

Table 11 Robustness Check: OLS Estimates of Effect of IR Trait on Other Pesticides. Dependent Variable: Active Ingredients (Kg/ha).

	(1) Acaricides	(2) Fungicides	(3) Herbicides	(4) Acaricides	(5) Fungicides	(6) Herbicides
IR trait	0.003	-0.063	-0.346	-0.011	0.007	-0.056
	[0.049]	[0.091]	[0.366]	[0.027]	[0.032]	[0.191]
Constant	0.428***	0.956***	4.933***	0.544***	1.283***	7.723***
	[0.023]	[0.042]	[0.170]	[0.152]	[0.181]	[1.075]
N	312	312	312	120	120	120
r2	0.000	0.002	0.003	0.906	0.950	0.840
F	0.003	0.481	0.894	11.185	22.264	6.123
Mean of Dep. Var.	0.429	0.942	4.858	0.455	0.869	4.608

Models (1)-(3) include all farms and models (4)-(6) only restricted sample (farms that use conventional and IR seeds) with farm and year fixed-effects. All models are linear specifications.

+ Robust standard errors in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Falsification test shows that other pesticides are not affected by IR trait.

Table 12 OLS Estimates of Effects of HT Trait on Quantity of Herbicides and Total Pesticides
Dependent Variable: Active Ingredients (Kg/ha)

	(1) Herbicides^{+}	(2) Total^{+}	(3) Herbicides^{+}	(4) Total^{+}
HT Trait	0.762***	0.546***	0.996***	0.995***
	[0.099]	[0.150]	[0.138]	[0.202]
Constant	1.741***	3.284***	1.769***	3.315***
	[0.075]	[0.121]	[0.074]	[0.122]
N	376	376	170	170
r2	0.091	0.025	0.236	0.126
F	59.114	13.192	51.766	24.194
Mean of Dep. Var.	2.326	3.703	2.267	3.813

Models (1) and (2) include all soybean farms, models (3) and (4) only farms that use both conventional and HT seeds (within farm variation as source of identification). Models are in linear specification.
+ Robust standard errors in brackets.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
HT trait affects the quantity (Kg/ha) of herbicides. Total represents the sum of all pesticides used (fungicides and insecticides).

Table 13 OLS Estimates of Effects of HT Trait on Quantity of Herbicides and Total Pesticides (Restricted Sample)
Dependent Variable: Active Ingredients (Kg/ha)

	(1) Herbicides^{+}	(2) Total^{+}	(3) Herbicides	(4) Total
HT Trait	0.996***	0.995***	0.442***	0.262***
	[0.089]	[0.096]	[0.056]	[0.027]
Constant	4.518***	5.930***	2.206***	1.848***
	[0.880]	[0.814]	[0.486]	[0.214]
N	170	170	170	170
r2	0.836	0.899	0.755	0.888
F	90.919	249.438	3.278	144.793
Mean of Dep. Var.	2.267	3.813	-	-

Models (1) and (2) are linear specifications, models (3) and (4) are log-linear specifications. All models include farm and year fixed-effects.
Restricted saple: farms that use both conventional and HT seeds (within farm variation as source of identification).
+ Robust standard errors in brackets.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Farmer and year fixed-effects don't affect coefficients since they are orthogonal to within-farm variables. Log-linear specifications show as increase of 44.2% in the quantity of herbicides and 26.3% in total pesticides.

Table 14 OLS Estimates of Effects of HT Trait on Quantity of Herbicides per Toxicity Level (Restricted Sample)

Dependent Variable: Active Ingredients (Kg/ha)

	(1) Herbicides 1	(2) Herbicides 2	(3) Herbicides 3	(4) Herbicides 4
HT Trait	-0.084***	-0.005	0.635***	0.438***
	[0.021]	[0.054]	[0.098]	[0.090]
Constant	0.444***	0.053	2.103***	-0.499
	[0.046]	[0.344]	[0.466]	[0.523]
N	168	168	168	168
r2	0.887	0.777	0.855	0.845
F	508.764	404.682	20.309	12.929
Mean of Dep. Var.	0.200	0.219	1.124	0.706

Restricted sample: farms that use both conventional and HT seeds (within farm variation as source of identification).

Robust standard errors in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Toxicity levels 1 - 4 in decreasing order (from more to less toxic). Herbicides based on Glyphosate are considered of lower toxicity level. Increases in less toxic herbicides (levels 3 and 4) are twelvefold the decreases in more toxic ones (levels 1 and 2).

Table 15 OLS Estimates of Environmental Impact of HT Trait (Restricted Sample)

Dependent Variable: EIQ

	(1) Herbicides	(2) Total	(3) Herbicides	(4) Total
HT Trait	13.847***	14.329***	0.356***	0.162***
	[1.639]	[2.054]	[0.049]	[0.023]
Constant	75.205***	140.924***	4.987***	4.925***
	[13.188]	[12.379]	[0.472]	[0.136]
N	170	170	170	170
r2	0.836	0.936	0.790	0.933
F	634.267	1378.593	142.869	556.876
Mean of Dep. Var.	37.875	91.337	-	-

Models (1) and (2) are linear specifications, models (3) and (4) are log-linear specifications. All models include farm and year fixed-effects.

Restricted sample: farms that use both conventional and HT seeds (within farm variation as source of identification).

Robust standard errors in brackets.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Weakness of the substitution among herbicides of different toxicity categories is reflected in higher environmental impact as shown by the coefficient that indicates an increase of 13.847 EIQ points. Log-linear specifications show an increase of 35.6% in the EIQ index for herbicides and 16.2% in total. In comparison with the general EIQ classification for herbicides, this is lower than the median value for EIQ index of 19.5. The EIQ for glyphosate is also larger than this result: 15.33. Result can be interpreted as reflecting the weakness of substitution between high and low toxicity herbicides shown in table 14.

Table 16 Robustness Check: OLS Estimates of Effect of HT Trait on Other Pesticides
Dependent Variable: Active Ingredients (Kg/ha)

	(1) Fungicides	(2) Insecticides	(3) Fungicides	(4) Insecticides
HT Trait	-0.047	-0.131*	0.021*	-0.007
	[0.047]	[0.066]	[0.009]	[0.020]
Constant	0.445***	0.841***	0.913***	-0.017
	[0.042]	[0.058]	[0.045]	[0.178]
N	376	376	170	170
r2	0.003	0.011	0.989	0.970
F	0.975	3.955	1228.421	20622.927
Mean of Dep. Var.	0.409	0.740	0.454	0.840

Models (1)-(2) include all farms and models (3)-(4) only restricted sample (farms that use conventional and HT seeds) with farm and year fixed-effects. All models are linear specifications.
Robust standard errors in brackets.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Falsification test shows that other pesticides are not affected by HT trait.

Table 17 Robustness Check: OLS Estimates of Effects of HT Trait on Quantity of Herbicides and Total Pesticides and Controlling for No-Tillage Cultivation (Restricted Sample)
Dependent Variable: Active Ingredients (Kg/ha)

	(1) Herbicides	(2) Total	(3) Herbicides	(4) Total
HT Trait	0.983***	0.983***	0.892***	0.876***
	[0.089]	[0.096]	[0.089]	[0.095]
No Tillage	0.180	2.443***		
	[0.469]	[0.469]		
Constant	2.272***	3.095***	1.038***	4.069***
	[0.328]	[0.392]	[0.096]	[0.091]
N	168	168	154	154
r2	0.833	0.899	0.829	0.887
F	248.083	363.742	864.663	4047.737
Mean of Dep. Var.	2.248	3.8	2.180	3.626

Restricted Sample: farms that use conventional and HT soybeans (within-farm variation as source of identification). All models use linear specifications and farm and year fixed-effects.
Robust standard errors in brackets.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Models (1) and (2) control for the use of no-tillage techniques that require more herbicides than conventional planting. Models (3) and (4) consider only farmers that use conventional planting.

Table 18 Robustness Check: OLS Estimates of Environmental Impact of HT Trait Controlling for No-Tillage Cultivation (Restricted Sample)
Dependent Variable: EIQ

	(1) Herbicides	(2) Total	(3) Herbicides	(4) Total
HT Trait	13.457***	13.944***	12.151***	11.951***
	[1.613]	[2.043]	[1.667]	[2.047]
No Tillage	3.160	69.325***		
	[6.713]	[6.513]		
Constant	36.751***	68.413***	16.518***	112.068***
	[5.635]	[9.850]	[0.999]	[1.119]
N	168	168	154	154
r2	0.828	0.937	0.814	0.928
F	355.885	1213.411	308.650	1698.950
Mean of Dep. Var.	37.280	90.935	36.006	85.974

Restricted Sample: farms that use conventional and HT soybeans (within-farm variation as source of identification). All models use linear specifications and farm and year fixed-effects.
Robust standard errors in brackets.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Models (1) and (2) control for the use of no-tillage techniques that require more herbicides than conventional planting. Models (3) and (4) consider only farmers that use conventional planting.