Bt and Ht corn versus conventional pesticide and herbicide use.

Do environmental impacts differ?

Eleonora Nillesen[a1], Sara Scatasta[b], and Justus Wesseler[a]

[a]Department of Social Sciences, Wageningen University, The Netherlands
[b]Department of Environmental and Resource Economics, Center for European Economic Research (ZEW), Germany

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[1] Corresponding: Hollandseweg 1, NL-6706 KN Wageningen, The Netherlands
Tel.: +31 317 483809; Fax: +31 317 484933
E-mail: Eleonora.Nillesen@wur.nl

1. Introduction

Growing transgenic crops can provide important social and private benefits including positive effects on yields, product quality, and production costs. However, one of the most important claimed benefits of transgenic crops include reduced health and environmental impacts due to reduced pesticide use. Empirical evidence to support this claim is scarce. In this paper we assess and compare the environmental impact of pesticide use of transgenic and non-transgenic crops, to investigate whetheter these type of benefits may indeed be gained by introducing transgenic crop production in the EU of 15 member states (EU-15). The outcomes are used to be included in an economic decision making framework to identify ex ante potential social welfare impacts of adoption of Bt and Ht corn in the EU-15 (Scatasta et al. 2005).

In this paper we use one of the composite environmental impact rating systems, defined as models that rate pesticides according to a number of environmental parameters, which are then combined into a single hazard index. We will use the Environmental Impact Quotient (EIQ) developed by Kovach et al., (1992), and apply this to our data for Bt, Ht and conventional corn managament practises.

The remaining of the paper is set out as follows: in section 2 we provide some background information on the transgenic corn varieties we use in our application. In section 3 we introduce the EIQ. Section 4 describes the data and presents the empirical results. Section 5 summarizes our findings and concludes.

2. Transgenic corn varieties

The environmental impact assessment of pesticide use is applied to non-transgenic and transgenic corn. The transgenic varieties include Bt and Ht corn, which are described below.

2.1. *Bt corn*

Bt corn has been genetically engineered to contain *Bacillus thuringiensis* (Bt), a species of soil-borne bacteria. When these spores are ingested by an insect, the protein crystal gets dissolved, thereby releasing protoxins, which are in turn activated by specific enzymes. When a susceptible insect tries to feed on a transgenic crop expressing the Bt protein, it stops feeding and will die of a result of the binding of the Bt toxin to its gut wall (Gianessi et al., 2002). In 1981, a Bt gene was cloned and sucessfully transferred to and expressed into another organism. Bt corn and potato plants were developed soon thereafter. The Bt technology in corn is particularly used to control the European Corn Borer (ECB) (*Ostrinia nubilalis*) moth larva, which is considered to be the most damaging pest to corn. Reported damages due to ECB attacks include: interference with nutrient flows in the host plant; entranced infection by stalk diseases and stalk breakage and ear drop, prior to harvest which may all result in considerable yield losses. Effective conventional crop control for ECB pests is complicated as a correct timing of insecticide applications is essential, but difficult to achieve. Inserting the Bt gene into the corn plant may improve a farmer's ability to manage ECB and other serious insect pests and in turn reduce harvest lossess due to ECB infestation. In addition, Bt corn is expected to have a beneficial impact on farmer's health and the environment through reduced insecticide use.

2.2. *Ht corn*

The negative influence of weed cover on yields is found to be one of the most important factors involved. To control weeds, conventionally a tank mix of soil active and leaf-active herbicides in pre- to early post-emergence of the crop is used. The post-emergence herbicides glyphosate and glufosinate-ammonium provide a broader spectrum of weed control than current herbicide programs, while at the same time reducing the number of active ingredients. Glyphosate was first introduced as a herbicide in 1971. The gene that confers tolerance to glyphosate was discovered in a naturally occurring soil bacterium. Glufosinate-ammonium was discovered in 1981. The gene that confers tolerance to glufosinate is also derived from a naturally occurring soil bacterium (Dewar, May, and Pidgean, 2000).

By inserting these herbicide tolerance (HT) genes into a plant's genome, two commercial transgenic HT systems resulted: the Roundup Ready® system, providing tolerance to glyphosate and the Liberty Link® system, tolerant to glufosinateammonium. Because of genetic transformations these herbicides can be sprayed on transgenic crops without damage, while nearby weeds are being killed. The herbicides are toxic to untransformed conventional crop cultivars. These combinations of transgenic seed combined with a post-emergence herbicide offer farmers broad-spectrum weed control, flexibility in the timing of applications and reduce the need for complex compositions of spray solutions. At the same time, a net reduction in pesticide use on HT corn will have a positive impact on farmers' health and on biodiversity (e.g. Antle and Pingali 1994; Waibel and Fleischer 1998). If the introduced transgenic crop results in a lower pesticide application, it provides additional benefits. Both glyphosate and glufosinate-ammonium have a low toxicity and are metabolised fast, without leaving soil residues, and therefore have better environmental and toxicological profiles than most of the herbicides they replace. In our application we focus on crops that are glufosinate-tolerant.

3. The Environmental Impact Quotient (EIQ)

The EIQ was intially designed by IPM specialists to help farmers in their choice for pest-control options. The underlying premise of the EIQ is that environmental and health impacts result from the interaction of toxicity and exposure. The EIQ incorporates the impacts of active ingredients of formulated products on farm workers, (application and harvest worker) consumers, and ecology (non-target organisms: fish, birds, honeybees, and other beneficial insects) (Kovach et al., 1992). Separate impacts are calculated based on inherent properties of certain pesticides, for example toxicity towards certain organisms and exposure of these organisms to these pesticides. The inherent properties are assigned ratings that range from 1-3, or 1-5 where 1 denotes the lowest toxicity or harmfulness, and 3 or 5 the highest, based on predefined boundary values (Kleter and Kuiper, 2005). Summing the separate impacts results in a single number, the EIQ for one specific active ingredient. Annex 1 provides the mathematical presentation of the EIQ. For those pesticides that contain multiple active ingredients, the individual EIQ's are summed. However, the EIQ alone does not provide any information about the dosage and application rate yet. Therefore the EIQ is multiplied by the active ingredient, the rate per hectare used and the number of applications, resulting in the field rate EIQ.

4. Data analysis

The EU-15 produces about 3% of the world's corn. The corn production is concentrated in France (40%), immediately followed by Italy (30%). The EU-15 also is a net importer of corn for human consumption, 6.4% of its consumption is imported (mainly from Argentina - 4%, and Hungary - 2%), while only 0.4% of domestic production is exported outside the EU-15 (FAOSTAT). Corn is grown in the EU-15 mainly for animal feed (80%). Corn for human consumption (20%) is used to produce corn oil, starch and sweeteners which are common ingredients in many processed foods such as breakfast cereals and dairy goods, and only a small amount is used for direct consumption (see Essential Biosafety; EUROSTAT).

4.1. *Data*

Both primary and secondary data have been used. For Bt and conventional corn we used field trial data (2004) from Narbonne, France as presented in figure 1.

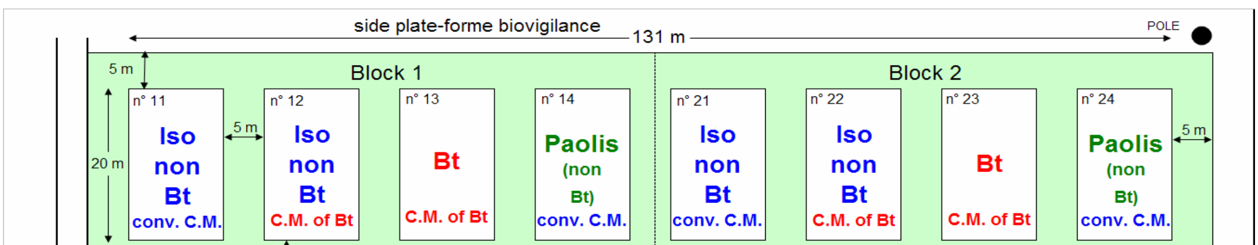

Fig. 1. ECOGEN Field trials in Narbons 2004

For Ht-corn field trials we have no data available yet. We therefore use a combination of primary and secondary data here. Ht corn management data we obtained from an earlier study done by Gianessi, Sankula and Reigner (2003) who estimated the environmental and economic impact of glufosinate corn for several countries in Europe. We use two data sources for conventional herbicide use. First, data on herbicide use from our Bt field trials, and second from a commonly applied conventional herbicide program used in the EU, as reported by Gianessi, Sankula and Reigner (2003). Data on EIQ values has been generated and made available for a large number of pesticide active ingredients by the New York State Integrated Pest Management Program (NYSIPM).

4.2. *Results*

The field rate EIQ's of Bt corn and conventional corn are presented in Table 1.

Table 1
Field Rate EIQ for Bt and conventional corn production

Iso non Bt - conventional crop management-variety A	**Treatment**	**Active Ingredient (g/l)**	**Dosage (l/ha)**	**Field Rate EIQ**

Lambda-cyhalothrine	Insecticide against ECB	100	0.15	0.65
Deltaméthrine	Insecticide against ECB	15	1.33	0.51
Total environmental impact conventional program				**1.16**
Total environmental impact Bt				**0.00**

Source: Calculated by the authors

The results in Table 1 show that the Bt management program has a lower environmental impact than conventional management of ECB. This is an obvious result as Bt corn does not require any additional spraying to control for ECB.

The Field Rate EIQ's for Ht and conventional corn management programs are presented in Table 2. In addition to the herbicides that were used for the field trial program, we used information with respect to Ht corn fromGianessi, Sankula and Reigner (2003), and compared some well-known conventional herbicide programs for the EU, Germany, France, and Italy respectively.

Table 2
Field Rate EIQs for Ht and conventional maize management

Conventional Crop management Field trials Narbons 2004	**Treatment**	**Active Ingredient (g/l)**	**Dosage (l/ha)**	**Field Rate EIQ**
Acétochlore	Herbicide	400	4	36.77
Dichlormid	Herbicide	66	4	.
Isoxaflutole	Herbicide	75	0.5	0.85
Aclonifen	Herbicide	500	0.5	5.75

Total environmental impact conventional program		**43.37**
HT Crop management (Gianessi et al., 2003)		
Glufosinate 0.45KgAI/ha	Herbicide	25.43
Total environmental impact Ht		**25.43**
Conventional Crop Management (Gianessi et al., 2003)		
Flufenacet 0.6 kg/ha	Herbicide	6.80
Therbuthylazine 0.8 kg/ha	Herbicide	18.38
Nicrosulfuron 0.04 kg/ha	Herbicide	0.76
Sulcotrione 0.3 kg/ha	Herbicide	5.40
Total environmental impact EU program		**31.34**

Source: Calculated by the authors

Comparing the results for Ht corn and conventional herbicide programs we see a that in both cases the conventional programs do worse than the Ht variety, and here growing Ht would thus be the preferable choice.

4.3. *Limitations of the EIQ*

As with any other method, the EIQ had several shortcomings that should be kept in mind. We will mainly replicate concerns reported earlier by Dushoff et al., (1994) and Levitan et al., (1997) which are discussed below. An important limitation is that there are only three scores that can be assigned, either, 1, 3 or 5, which limits the range of scores. For example, a pesticide that is 1000 times more toxic than another will receive a toxicity rating that is at most only five times as high. Related to this problem is the rating score of 1 instead of 0 for neutral effects, thereby decreasing the ‘distance’ between relatively benign substances and extremely hazardous ones. In addition, the relative importance of factors depends largely on what other factors they are multiplied by. For example, in the farmworker component, the value for chronic toxicity is always multiplied by the value of dermal toxicity. Thus, a substance with known long-term health effects on humans, but which showed no acute dermal effects (i.e, dermal toxicity is 0) would not be considered a risk to farmworkers. Another problem is the weighing of persistence versus toxicity. The EIQ measures toxicity by exposure with the possible result that a non-toxic but persistent pesticide, may receive a higher EIQ than a more toxic but less persistent pesticide. Furthermore, a single number ignores the fact that the environmental effect of a pesticide depends on the conditions on which it is used (including soil type, hydrology, local ecology and type of crop) which are not taken into account when using the EIQ. By combining various components with different weights implicit value judgements are made that would require a more explicit examination. Also, the effect of pesticides may accumulate over time, but dynamic effects are not taken into account. Lastly, the use of a single number hides information gaps and gives an illusion of firm knowledge.

All in all, there are some weakness that should be kept in mind when using the EIQ. However, other methods only consider toxicity but not exposure or make no difference at all among active ingredients. Hence, provided that results are indeed treated with some caution we believe the EIQ can be very useful.

5. Conclusion

In this paper we calculated the environmental impact of pesticide use for conventional and transgenic corn varieties to investigate whether growing Bt and Ht corn provides social benefits. Preliminary results suggest that indeed benefits may be gained by growing Bt corn through reduced insecticide use. However, some caution is warranted, with respect to the interpretation of these results. Perceived environmental gains may be overstated if the area has not been sprayed in the past. Moreover, if insecticides are not only sprayed to control ECB but also other target pests the reduction in pesticide use may be much smaller than assumed. Results for Ht corn show that the environmental impact of the Ht variety is less than that of the conventional programs.

Our empirical findings support the argument of lower environmental and health impacts with respect to pesticide use when growing Bt and Ht corn. These outcomes will be used in an economic framework to assess potential welfare implications.

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Annex 1 Mathematical presentation of the EIQ

The EIQ consists of three components, the farm worker, the consumer and the ecology component, with an equal weight for each component.

Farm worker component:

$$C(DT*5)+(DT*P) \tag{1}$$

Consumer component:

$$(C*(S+P)/2*SY)+(L) \tag{2}$$

Ecology (fish, birds, honeybees, other beneficial insects) component:

$$(F*R)+(D*S+P)/2*3)+(Z*P*3)+(B*P*5) \tag{3}$$

Total (Farm worker + Consumer + Ecology)/3)

$$\begin{aligned} EIQ = \{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+ \\ [(F*R)]+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3 \end{aligned} \tag{4}$$

Where DT= dermal toxicity, C= chronic toxicity, SY= systemicity, F= fish toxicity, L = leaching potential, R= surface loss potential, D=bird toxicity, S= soil half-life, Z=bee toxicity, B= beneficial arthropod toxicity, and P= plant surface half-life.

The ***field rate*** EIQ is then calculated as:

Field rate EIQ = EIQ* % a.i.* rate used

Annex 2 Poster Layout

The detailed lay-out for the poster I present below in two pages.

- The first page represents the background, the title and the **first column** of the poster including the problem statement, and the methodology that has been used.
- The second page represents the **second column** of the poster including the objective, the data sources, the conclusions and the results
- Please note that the original poster will also contain the authors, and their affiliations. This information will be placed immediately under the title.

All regular text will be in 'Arial', 10 pnts, normal style.
All headings will be in 'Arial' 12 pnts, normal style
The title will be in 'Arial' 18 pnts, normal style
The author's names and affiliations will be in 'Arial' 10 pnts, normal style

Bt and Ht corn versus conventional pesticide and herbicide use. Do environmental impacts differ?

Problem Statement

Reduction in pesticide and herbicide use is claimed to be a major **environmental** benefit of GM-crops. However, reduction in amounts do not necessarily lead to a lesser impact on the environment.

Methodology

The EIQ consists of three components, the farm worker, the consumer and the ecology component, with an equal weight for each component.

Farm worker component:

$$C(DT*5)+(DT*P) \quad (1)$$

Consumer component:

$$(C*(S+P)/2*SY)+(L) \quad (2)$$

Ecology (fish, birds, honeybees, other beneficial insects) component:

$$(F*R)+(D*S+P)/2*3)+(Z*P*3)+(B*P*5) \quad (3)$$

Total (Farm worker + Consumer + Ecology)/3)

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+ [(F*R)]+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3 \quad (4)$$

Where DT= dermal toxicity, C= chronic toxicity, SY= systemicity, F= fish toxicity, L = leaching potential, R= surface loss potential, D=bird toxicity, S= soil half-life, Z=bee toxicity, B= beneficial arthropod toxicity, and P= plant surface half-life.

The ***field rate*** EIQ is calculated as:

Field rate EIQ = EIQ* % active ingredient* rate used

Objective

Empirical environmental assessment of the impact of pesticide use for Bt, Ht (Glufosinate) and conventional maize in Europe to quantify expected trade-offs between GM and non-GM maize and its implications for the European Agricultural Policy

Data

•Field trials in Narbons (France) 2004 of Bt and conventional maize
•Secondary literature for Ht (glufosinate) maize (Gianessi, Sankula and Reigner (2003)

Conclusions and policy implications

Field trial analysis confirms that the environmental impact of transgenic crops with respect to pesticide and herbicide use is less for both Bt and Ht maize when compared to conventional crop management.
The outcomes have been used to estimate the incremental reversible and irreversible social benefits of planting Bt and Ht maize in the EU to provide information as to whether or not transgenic maize should be introduced from a socio-economic perspective.

Iso non Bt - conventional crop management-variety A	Treatment	Active Ingredient (g/l)	Dosage (l/ha)	Field Rate EIQ
Lambda-cyhalothrine	Insecticide against ECB	100	0.15	0.65
Deltaméthrine	Insecticide against ECB	15	1.33	0.51
Total environmental impact conventional				**1.16**
Total environmental impact Bt				**0.00**

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Total environmental impact				***43.37***
HT Crop management (Gianessi et al. 2003)				
Glufosinate 0.45KgAI/ha	Herbicide	.	.	25.43
Total environmental impact HT				***25.43***