Table 8. Canadian canola: Permanent reduction in tractor fuel consumption and CO_2 emissions 1996–2009

	Annual reduction based on 1996 average 35.6 (l/ha)	Crop area (million ha)	Total fuel saving (million liters)	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	1.6	4.9	7.9	21.63
1998	1.6	5.4	8.8	24.11
1999	1.6	5.6	9.0	24.71
2000	1.6	4.9	7.8	21.58
2001	3.2	3.8	12.2	33.62
2002	4.8	3.3	15.8	43.46
2003	6.5	4.7	30.3	83.30
2004	8.1	4.9	39.9	109.68
2005	9.7	5.5	53.2	146.32
2006	11.3	5.2	59.2	162.85
2007	12.9	5.9	76.4	210.02
2008	14.5	6.5	95.1	261.41
2009	14.5	6.1	88.7	244.01
Total			**504.3**	**1,386.71**

Fuel usage NT = 11.4 liters/ha CT = 43.7 liters/ha.

Table 9. Canadian canola: Potential additional soil carbon sequestration (1996–2009)

	Annual increase in carbon sequestered based on 1996 average (kg carbon/ha)	Crop area (million ha)	Total carbon sequestered (million kg)	Carbon dioxide (million kg)
1996	0.0	3.5	0.0	0.00
1997	15.0	4.9	73.1	268.09
1998	15.0	5.4	81.4	298.86
1999	15.0	5.6	83.5	306.31
2000	15.0	4.9	72.9	267.50
2001	30.0	3.8	113.6	416.75
2002	45.0	3.3	146.8	538.67
2003	60.0	4.7	281.4	1,032.56
2004	75.0	4.9	370.4	1,359.46
2005	90.0	5.5	494.2	1,813.68
2006	105.0	5.2	550.0	2,018.57
2007	120.0	5.9	709.3	2,603.19
2008	135.0	6.5	882.9	3,240.24
2009	135.0	6.1	824.1	3,024.57
Total			**4,683.5**	**17,188.46**

NT/RT = +200 kg carbon/ha/yr CT = -100 kg carbon/ha/yr.

all spraying in these 2 countries is assumed to be undertaken by hand) increased from 0.86 million ha to 2.89 million ha in 2009. Based on a conservative estimate of four fewer insecticide sprays being required for the cultivation of GM IR cotton relative to conventional cotton, and applying this to the global area (excluding China and India) of GM IR cotton over the period 1996–2009, suggests that there has been a reduction of 132 million ha of cotton being sprayed. The cumulative saving in tractor fuel consumption has been 137.5 million liters. This represents a permanent reduction in carbon dioxide emissions of 378 million kg (**Table 10**).

Insect resistant maize. Limited analysis of the possible contribution to reduced level of carbon sequestration from the adoption of GM IR maize (via fewer insecticide spray runs) and the adoption of Corn Rootworm Resistance (CRW) maize is presented. This is because the impact of using these technologies on carbon sequestration is likely to have been small for the following reasons:

- in some countries (e.g., Argentina) insecticide use for the control of pests such as the corn borer has traditionally been negligible;

Table 10. Permanent reduction in global tractor fuel consumption and CO_2 emissions resulting from the cultivation of GM IR cotton 1996–2009

	Total cotton area in GM IR growing countries excluding India and China (million ha)	GM IR area (million ha) excluding India and China	Total spray runs saved (million ha)	Fuel saving (million liters)	CO_2 emissions saved (million kg)
1996	7.49	0.86	3.45	3.60	9.91
1997	7.09	0.92	3.67	3.84	10.56
1998	7.11	1.05	4.20	4.39	12.08
1999	7.15	2.11	8.44	8.82	24.25
2000	7.42	2.43	9.72	10.16	27.94
2001	7.07	2.55	10.18	10.64	29.27
2002	6.36	2.17	8.69	9.08	24.98
2003	5.34	2.17	8.70	9.09	24.99
2004	6.18	2.79	11.17	11.67	32.09
2005	6.28	3.21	12.84	13.41	36.89
2006	7.90	3.94	15.75	16.46	45.26
2007	6.07	3.25	12.99	13.58	37.34
2008	4.99	2.55	10.19	10.65	29.29
2009	5.32	2.89	11.58	12.10	33.27
Total			**131.57**	**137.49**	**378.10**

Assumptions: 4 tractor passes per ha, 1.045 liters/ha of fuel per insecticide application.

- even in countries where insecticide use for the control of corn boring pests has been practiced (e.g., the US), the share of the total crop treated has been fairly low (under 10% of the crop) and varies by region and year according to pest pressure. The main exception to this has been in Brazil (see below);
- nominal application savings have occurred in relation to the adoption of GM CRW maize where over 16.5 million ha were planted in 2009. The adoption of the GM CRW may become increasing important with wider adoption of no-till cultivation systems due to the potential increase in soil-borne pests.

In respect of the impact of using GM IR maize in Brazil (since 2008), in general, farmers using the technology have reduced the average number of insecticide spray runs by three (from five to two). This has resulted in a reduction of 19.35 million ha of maize being sprayed (for the two years 2008–2009), with a cumulative saving in tractor fuel of 20.22 million liters. This is equivalent to a permanent reduction in carbon dioxide emissions of 55.61 million kg.

Discussion and Conclusions

The analysis of pesticide use changes arising from the adoption of biotech crops shows that there have been important environmental benefits, amounting to 393 million kg less pesticide use by growers (an 8.7% reduction on the amount of active ingredient applied). As weight of active ingredient applied is a fairly crude measure of environmental impact, the analysis considered impacts using an alternative (more rounded) measure, known as the EIQ. Based on this, the environmental benefits have been more significant at a 17.1% reduction in the environmental impact associated with insecticide and herbicide use on the global crop area planted to biotech traits (1996–2009). The most significant environmental benefits derived have been associated with the adoption of GM IR cotton which has resulted in a substantial reduction in insecticide applications on cotton. There have also been important environmental gains associated with the adoption of GM HT technology which has seen a switch to the use of more environmentally benign active ingredients.

The analysis also shows that biotechnology trait adoption has made important contributions to reducing greenhouse gas emissions associated with cropping agriculture and a summary of the total carbon sequestration impact of GM crops is presented in **Table 11**. This shows that the permanent savings in carbon dioxide emissions (arising from reduced fuel use of 3,616 million liters of fuel) since 1996 have been about 9,947 million kg and the additional amount of soil carbon sequestered since 1996 has been equivalent to 115,178 million tonnes of carbon dioxide that has not been released into the global atmosphere (these estimates are based on fairly conservative assumptions and therefore the true values could be higher). Also, some of the additional soil carbon sequestration gains from RT/NT systems may be lost if subsequent ploughing of the land occurs. Estimating the possible losses that may arise from subsequent ploughing would be complex and difficult to undertake. This factor should be taken into account when using the estimates presented in this paper. The reader should, however, note that these soil carbon savings are based on saving arising from the rapid adoption of NT/RT farming systems in North and South America for which the availability of GM HT technology has been cited by many farmers as an important facilitator. GM HT technology has therefore probably been an important contributor to this increase in soil carbon sequestration but is not the only factor of influence. Other influences such as the availability of relatively cheap generic glyphosate (the real price of glyphosate fell threefold between 1995 and 2000 once patent protection for the product expired) have also been important, as illustrated by the rapid adoption of RT/NT production systems in the Brazilian soybean sector, largely in the

Table 11. Summary of carbon sequestration impact 1996–2009

Crop/trait/country	Permanent fuel saving (million liters)	Potential additional carbon dioxide saving from fuel saving (million kg)	Potential additional carbon dioxide saving from soil carbon sequestration (million kg)
US: GM HT soybeans	835	2,295	37,755
Argentina: GM HT soybeans	1,885	5,185	50,707
Other countries: GM HT soybeans	235	646	9,528
Canada: GM HT canola	504	1,387	17,188
Global GM IR cotton	137	378	0
Brazil; IR maize	20	56	0
Total	**3,616**	**9,947**	**115,178**

Other countries: GM HT soybeans Paraguay and Uruguay (applying US carbon sequestration assumptions). Brazil not included because of RT/NT adoption largely in the absence of GM HT technology.

Table 12. Context of carbon sequestration impact 2009: Car equivalents

Crop/trait/country	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Permanent fuel savings: as average family car equivalents removed from the road for a year ('000s)	Potential additional soil carbon sequestration savings (million kg of carbon dioxide)	Potential soil carbon sequestration: as average family car equivalents removed from the road for a year ('000s)
US: GM HT soybeans	291	130	4,711	2,094
Argentina: GM HT soybeans	695	309	7,018	3,119
Other countries: GM HT soybeans	102	45	1,507	670
Canada: GM HT canola	244	108	3,025	1,344
Global: GM IR cotton	33	15	0	0
Brazil: GM IR maize	43	19	0	0
Total	**1,408**	**626**	**16,261**	**7,227**

Assumption: an average family car produces 150 grams of carbon dioxide per km. A car does an average of 15,000 km/year and therefore produces 2,250 kg of carbon dioxide/year.

absence of the GM HT technology (the estimates of soil carbon sequestration savings presented do not include any for soybeans in Brazil because we have assumed that the increase in NT/RT area has not been primarily related to the availability of GM HT technology). Cumulatively the amount of carbon sequestered may be higher than these estimates due to year-on-year benefits to soil quality, however equally with only an estimated 15%–25% of the crop area in continuous no-till systems it is likely that the total cumulative soil sequestration gains have been lower. It is nevertheless, not possible to estimate cumulative soil sequestration gains that take into account reversions to conventional tillage because of the lack of detailed, disaggregated farm and field level tillage data. Consequently, the estimate provided above of 115,178 million tonnes of carbon dioxide not released into the atmosphere should be treated with caution and clearly represents a potential maximum rather than a realized level.

Further examining the context of the carbon sequestration benefits, **Table 12**, measures the carbon dioxide equivalent savings associated with planting of biotech crops for the latest year (2009), in terms of the number of car use equivalents. This shows that in 2009, the permanent carbon dioxide savings from reduced fuel use was the equivalent of removing nearly 0.626 million cars from the road for a year and the additional soil carbon sequestration gains were equivalent to removing nearly 7.23 million cars from the roads. In total, biotech crop-related carbon dioxide emission savings in 2009 were equal to the removal from the roads of nearly 7.85 million cars, equal to 27.6% of all registered private cars in the UK.

The impacts identified in this paper are, however, probably conservative reflecting the limited availability of relevant data and conservative assumptions used. In addition, the analysis examines only a limited number of environmental indicators. As such, subsequent research of the environmental impact might usefully include additional environmental indicators such as impact on soil erosion.

Materials and Methods

Methodology: Environmental impacts from insecticide and herbicide use changes. Assessment of the impact of biotech crops on insecticide and herbicide use requires comparisons of the respective weed and pest control measures used on biotech versus the 'conventional alternative' form of production. This presents a number of challenges relating to availability and representativeness. Comparison data ideally derives from farm level surveys which collect usage data on the different forms of production.

A search of literature on biotech crop impact on insecticide or herbicide use at the trait, local, regional or national level shows that the number of studies exploring these issues is limited[11-13] with even fewer,[14,15] providing data to the pesticide (active ingredient) level. Secondly, national level pesticide usage survey data is also extremely limited; in fact there are no published annual pesticide usage surveys conducted by national authorities in any of the countries currently growing biotech traits and, the only country in which pesticide usage data is collected (by private market research companies) on an annual basis and which allows a comparison between biotech and conventional crops to be made, is the US.

Unfortunately, even where national survey data is available on usage, the data on conventional crop usage may fail to be reasonably representative of what herbicides and insecticides might be expected to be used in the absence of biotechnology. When biotech traits dominate total production (e.g., for soybeans, corn, cotton and canola in the US since the early 2000s), the conventional cropping dataset used to identify pesticide use relates to a relatively small share of total crop area and therefore is likely to under estimate what usage would probably be in the absence of biotechnology. The reasons why this conventional cropping dataset is unrepresentative of the levels of pesticide use that might reasonably be expected to be used in the absence of biotechnology include:

- Whilst the levels of pest and weed problems/damage vary by year, region and within region, farmers who continue to farm conventionally are often those with relatively low levels of pest or weed problems, and hence see little, if any economic benefit from using the biotech traits targeted at these agronomic problems. Therefore their pesticide usage levels tend to be below the levels that would reasonably be expected to control weeds and pests on an average farm. A good example to illustrate this relates to the US cotton crop where, for example, in 2009, half of the conventional cotton crop was located in Texas. Here levels of bollworm pests (the main target of biotech insect resistant cotton) tend to be consistently low and cotton farming systems are traditionally of an extensive, low input nature (e.g., the average cotton yield in Texas was about 82% of the US average in 2009)
- Some of the farms continuing to use conventional (non biotech) seed traditionally use extensive, low intensive production methods (including organic) in which limited (below average) use of pesticides is a feature (see the Texas cotton example above). The usage pattern of this sub-set of growers is therefore likely to understate usage for the majority of farmers if all crops were conventional
- The widespread adoption of GM insect resistant technology has resulted in 'area-wide' suppression of target pests such as the European corn borer in maize crops. As a result, conventional farmers (e.g., of maize in the US) have benefited from this lower level of pest infestation and the associated reduced need to conduct insecticide treatments;[16]
- Many of the farmers using biotech traits have experienced improvements in pest and weed control from using this technology relative to the conventional control methods previously used. If these farmers were to now switch back to using conventional techniques, it is likely that most would wish to maintain the levels of pest/weed control delivered with use of the biotech traits and therefore would use higher levels of pesticide than they did in the pre biotech crop days.

To overcome these problems in the analysis of pesticide use changes arising from the adoption of biotech crops (i.e., where biotech traits account for the majority of total plantings), presented in this paper, recorded usage levels for the biotech crops are used (based on survey data), with the conventional alternative (counterfactual situation) identified based on opinion from extension advisors and industry specialists as to what farmers might reasonably be expected to use in terms of crop protection practices and usage levels of pesticide. This methodology has been used by others.[17] Details of how this methodology has been applied to the 2009 calculations, sources used for each trait/country combination examined and examples of typical conventional versus biotech pesticide applications are provided in **Appendices 1 and 2**.

The most common way in which changes in pesticide use with biotech crops has been presented in the literature has been in terms of the volume (quantity) of pesticide applied. Whilst comparisons of total pesticide volume used in biotech and conventional crop production systems are a useful indicator of associated environmental impacts, amount of active ingredient used is an imperfect measure because it does not account for differences in the specific pest control programs used in biotech and conventional cropping systems. For example, different specific products used in biotech versus conventional crop systems, differences in the rate of pesticides used for efficacy and differences in the environmental characteristics (mobility, persistence, etc.,) are masked in general comparisons of total pesticide volumes used.

In this paper, the pesticide related environmental impact changes associated with biotech crop adoption are examined in terms of changes in the volume (amount) of active ingredient applied but supplemented by the use of an alternative indicator, developed at Cornell University in the 1990s, the environmental impact quotient (EIQ). The EIQ indicator, developed by Kovach et al. and updated annually, effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare'. The EIQ value is multiplied by the amount of pesticide active ingredient (ai) used per hectare to produce a field EIQ value. For example, the EIQ rating for glyphosate is 15.33. By using this rating multiplied by the amount of glyphosate used per hectare (e.g., a hypothetical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.86/ha.

The EIQ indicator used is therefore a comparison of the field EIQ/ha for conventional versus biotech crop production systems, with the total environmental impact or load of each system, a direct function of respective field EIQ/ha values and the area planted to each type of production (biotech versus conventional). The use of environmental indicators is commonly used by researchers and the EIQ indicator has been, for example, cited by Brimner et al. in a study comparing the environmental impacts of biotech and conventional canola and by Kleiter.

Appendix 1. Details of methodology as applied to 2009 calculations of environmental impact associated with pesticide use changes; GM IR corn (targeting corn boring pests) 2009

Country	Area of trait ('000 ha)	Maximum area treated for corn boring pests: pre GM IR ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US	20,292	3,220	0.23	0.83	12.8	32.8	-1,932.6	-64.42
Canada	1,107	61.5	0.04	0.64	4.8	24.8	-36.9	-1.23
Argentina	2,399	0	0	0	0	0	0	0
Philippines	392	Very low—assumed zero	0	0	0	0	0	0
South Africa	2,400	1,768	0	0.094	0	3.42	-165.3	-6.02
Spain	76.1	34.1	0.36	1.32	0.9	26.9	-32.8	-0.88
Uruguay	90	Assumed to be zero: as Argentina	0	0	0	0	0	0
Brazil	5,000	6,234	0 targeted at corn boring pests	0.356 targeted at corn boring pests	0 targeting corn boring pests	21.47	-1,780	-107.36

As South American countries do not disaggregate data between no and reduced tillage areas, the more conservative carbon saving associated with reduced tillage is used. Due to the likely small scale impact and lack of tillage-specific data relating to GM HT cotton crops (and the US GM HT canola crop), analysis of possible GHG emission reductions in these crops have not been included. Also, no analysis is presented for no tillage used with GM HT maize because of the scope for 'double counting' impacts where the crop is grown in rotation with GM HT soybeans. The no/reduced tillage areas to which these soil carbon reductions were applied were limited to the increase in the area planted to no/reduced tillage in each country since GM HT technology has been commercially available. In this way, the authors have tried to avoid attributing no/reduced tillage soil carbon sequestration gains to GM HT technology on cropping areas that were using no/reduced tillage cultivation techniques before GM HT technology became available. Also the development of the no tillage soybean crops in Brazil have not been attributed to the plantings of GM HT crops due to the rapid development of this production system before GM HT soybean technology was permitted in 2003. (1) Other countries: Honduras and EU countries: areas planted to GM IR corn under 10,000 ha in each country: not examined. (2) Baseline amount of insecticide active ingredient shown in Canada refers only to insecticides used primarily to control corn boring pests.

GM IR corn (targeting corn rootworm) 2009

Country	Area of trait ('000 ha)	Maximum area treated for corn boring pests: pre GM IR ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US	16,524	9,740	0.234	0.45	12.8	20.43	-2,106	-74.32

(1) There are no Canadian-specific data available: analysis has therefore not been included for the Canadian crop of 432,000 ha planted to seed containing GM IR traits targeted at corn rootworm pests.

GM IR cotton 2009

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US	2,317	0.92	1.06	29.1	38.0	-32.2	-20.56
China	3,570	1.84	2.80	83.22	127.96	-3,177	-151.0
Australia	159.5	2.2	11.0	39	220	-1,403.8	-28.87
Mexico	30.3	3.6	5.22	120.4	177.0	-49.2	-1.76
Argentina	244.5	0.64	1.15	21.0	53.0	-124.7	-7.82
India	8,824	1.06	1.86	34.43	70.07	-7,042	-314.5
Brazil	116	0.64	1.15	21.0	53.0	-59.2	-3.71

(1) Due to the widespread and regular nature of bollworm and budworm pest problems in cotton crops, GM IR areas planted are assumed to be equal to the area traditionally receiving some form of conventional insecticide treatment. (2) South Africa (8,300 ha), Burkino Faso (115,000 ha) and Columbia (17,400 ha) not included in analysis due to lack of data. (3) Brazil: due to a lack of data, usage patterns from Argentina have been assumed.

GM HT soybeans 2009

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/ha GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US	28,744	1.65	1.66	26.69	42.68	-403.7	-449.9
Canada	940	1.32	1.43	20.88	34.20	-103.4	-12.52
Argentina	18,414	2.68	2.53	41.38	43.64	+2,762	-41.6
Brazil	16,200	1.92	1.51	31.04	25.60	+6,642	+91.5
Paraguay	2,475	1.16	0.99	18.8	20.05	+430.7	-3.09
South Africa	202	1.89	1.556	28.97	32.08	+67.6	-0.63
Uruguay	891	2.68	2.53	41.38	43.64	+133.6	-2.03
Bolivia	663	1.16	0.99	18.8	20.05	+112.7	-0.83

Due to lack of country-specific data, usage patterns in Paraguay assumed for Bolivia and usage patterns in Argentina assumed for Uruguay. Mexico not included (7,300 ha) due to lack of data.

GM HT corn 2009

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/HA GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US glyphosate tolerant	20.764	2.55	3.78	48.94	78.81	-25,442	-620.2
US glufosinate tolerant	1,139	2.04	3.48	44.76	77.15	-1,645.0	-36.9
Canada glyphosate tolerant	799	1.83	2.71	37.01	61.10	-702.1	-19.17
Canada glufosinate tolerant	123	1.64	2.71	36.01	61.01	-131.4	-3.08
Argentina	1,248	2.55	2.93	47.58	62.06	-511.7	-17.5
South Africa	727	2.754	3.103	46.17	65.87	-253.8	-14.3

(1) Philippines: not included due to lack of data on weed control methods and herbicide product use.

GM HT cotton 2009

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/HA GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US	2,531.88	3.12	3.59	55.40	64.59	-1,192.0	-23.26
S Africa	7.0	1.80	1.81	27.59	31.86	-0.07	-0.03
Australia	176.8	3.93	4.4	64.67	69.2	-83.1	-8.00
Argentina	244.5	1.80	3.48	27.60	68.04	-411.7	-9.9

(1) Mexico and Colombia: not included due to lack of data on herbicide product use.

The EIQ indicator provides an improved assessment of the impact of biotech crops on the environment when compared to only examining changes in volume of active ingredient applied, because it draws on some of the key toxicity and environmental exposure data related to individual products, as applicable to impacts on farm workers, consumers and ecology. Readers should, however, note that the EIQ is an indicator only and does not take into account all environmental issues and impacts. It is therefore not a comprehensive indicator. Detailed examples of the relevant amounts of active ingredient used and their associated field EIQ values for biotech versus conventional crops for the year 2009 are presented in **Appendix 2**.

Methodology: Impact of greenhouse gas emissions. The methodology used to assess impact on greenhouse gas emissions combines reviews of literature relating to changes in fuel and tillage systems and carbon emissions coupled with evidence from the development of relevant biotech crops and their impact on both fuel use and tillage systems. Reductions in the level of GHG emissions associated with the adoption of biotech crops are acknowledged in a wide body of literature.[23-31] First, biotech crops

GM HT canola 2009

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/HA GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units (millions)
US glyphosate tolerant	190.9	0.649	1.12	9.95	25.71	-21.0	-1.95
US glufosinate tolerant	122.05	0.383	1.12	7.78	25.71	-87.9	-2.15
Canada glyphosate tolerant	3,174.0	0.7	0.56	10.68	11.52	+434.9	-2.66
Canada glufosinate tolerant	2,503.0	0.35	0.56	7.07	11.52	-531.2	-11.13
Australia glyphosate tolerant	41.2	0.988	1.62	15.7	29.33	-0.03	-0.56

GM herbicide tolerant sugar beet 2009

Country	Area of trait ('000 ha)	Average ai use GM crop (kg/ha)	Average ai use if conventional (kg/ha)	Average field EIQ/HA GM crop	Average field EIQ/ha if conventional	Aggregate change in ai use ('000 kg)	Aggregate change in field EIQ/ha units
US	438	1.91	1.40	29.13	30.89	+220	-0.58

contribute to a reduction in fuel use due to less frequent herbicide or insecticide applications and a reduction in the energy use in soil cultivation. For example, Lazarus and Selley estimated that one pesticide spray application uses 1.045 liters of fuel which is equivalent to 2.87 kg/ha of carbon dioxide emissions. In this analysis, we used the conservative assumption that only GM IR crops reduced spray applications with the number of spray applications of herbicides remaining the same as for conventional production systems.

In addition, there has been a shift from conventional tillage to reduced/no till. This has had a marked impact on tractor fuel consumption due to energy intensive cultivation methods being replaced with no/reduced tillage and herbicide-based weed control systems. The GM HT crop where this is most evident is GM HT soybeans. Here adoption of the technology has made an important contribution to facilitating the adoption of reduced or no tillage farming. Before the introduction of GM HT soybean cultivars, no tillage (NT) systems were practiced by some farmers with varying degrees of success using a number of herbicides. The opportunity for growers to control weeds with a non residual foliar herbicide as a "burndown" pre-seeding treatment followed by a post-emergent treatment when the soybean crop became established has made the NT systems more reliable, technically viable and commercially attractive. These technical and cost advantages have contributed to the rapid adoption of GM HT cultivars and the near doubling of the NT soybean area in the US (also more than a five fold increase in Argentina). In both countries, GM HT soybeans are estimated to account for over 95% of the NT soybean crop area since 2007/8.

Substantial growth in NT production systems have also occurred in Canada, where the NT canola area increased from 0.8 million ha to 2.6 million ha (equal to about half of the total canola area) between 1996 and 2005 (95% of the NT canola area is planted with GM HT cultivars). Similarly the area planted to NT in the US cotton crop increased from 0.2 million ha to 1 million ha over the same period (of which 86% is planted to GM HT cultivars) and has remained at this share of the total crop since 2007.

The fuel savings resulting from changes in tillage systems used in this paper are drawn from Jasa,[25] CTIC[23] and University of Illinois.[32] The adoption of no tillage (NT) farming systems is estimated to reduce cultivation fuel usage by 32.3 liters/ha compared with traditional conventional tillage (CT: average usage 43.7 liters/ha) and by 19.33 liters/ha compared with (the average of) reduced tillage (RT) cultivation methods (average usage 30.73 liters/ha). In turn, this results in reductions of carbon dioxide emissions of 88.81 kg/ha for NT relative to CT and 35.66 kg/ha for RT relative to CT.

Secondly, the use of 'no-till' and 'reduced-till' farming systems that utilize less ploughing increase the amount of organic carbon in the form of crop residue that is stored or sequestered in the soil. This carbon sequestration reduces carbon dioxide emissions to the environment. A number of researchers have examined the relationship between carbon sequestration and different tillage systems.[28,29,31,33-39] This literature shows that the amount of carbon sequestered varies by soil type, cropping system, eco-region and tillage depth. It also shows that tillage systems can impact on levels of other GHG emissions such as methane and nitrous oxide and on crop yield. Overall, the literature highlights the difficulty in estimating the contribution NT/RT systems can make to soil carbon sequestration, especially because of the dynamic nature of soils, climate, cropping types and patterns. If a specific crop area is in continuous NT crop rotation, the full soil carbon sequestration benefits described in the literature can be realized. However, if the NT crop area is returned to a conventional tillage system, a proportion of the soil organic carbon gain will be lost. The temporary nature of this form of carbon storage will only become

Appendix 2. Examples of eiq calculations; Estimated typical herbicide regimes for conventional reduced/no till soybean production systems that will provide an equal level of weed control to the GM HT system in Argentina 2009

option 1	Active ingredient (kg/ha)	Field eiq/ha value
Glyphosate	0.864	13.25
Metsulfuron	0.03	0.50
2 4 d amine	0.3	6.21
Imazethapyr	0.08	1.57
Diflufenican	0.05	0.88
Clethodim	0.144	2.45
Total	**1.468**	**24.85**
option 2		
Glyphosate	1.35	20.70
Dicamba	0.0576	1.46
Acetochlor	1.08	21.49
haloxifop*	0.096	2.13
Sulfentrazone	0.0875	1.02
Total	**2.67**	**46.80**
option 3		
Glyphosate	1.62	24.83
Atrazine	0.384	8.79
Bentazon	0.6	11.22
2 4 db ester	0.04	0.61
Imazaquin	0.024	0.37
Total	**2.67**	**45.83**
option 4		
Glyphosate	1.8	27.59
2 4 d amine	0.384	7.95
Flumetulam	0.06	0.94
Fomesafen	0.25	6.13
Chlorimuron	0.015	0.29
Fluazifop	0.12	3.44
Total	**2.63**	**46.34**
option 5		
Glyphosate	1.8	27.59
Metsulfuron	0.05	0.84
2 4 d amine	0.75	15.53
Imazethapyr	0.1	1.96
haloxifop	0.096	2.13
Total	**2.80**	**48.05**
option 6		
Glyphosate	1.8	27.59
Metsulfuron	0.05	0.84
2 4 d amine	0.75	15.53
Imazethapyr	0.1	1.96
Clethodim	0.24	4.08
Total	**2.94**	**49.99**
Average all conventional options	**2.53**	**43.64**

Sources: AAPRESID and Monsanto Argentina (personal communication 2006, 2007 & 2009).

Appendix 2. Examples of eiq calculations; Estimated typical herbicide regimes for conventional reduced/no till soybean production systems that will provide an equal level of weed control to the GM HT system in Argentina 2009

Sources: AAPRESID and Monsanto Argentina (personal communication 2006, 2007 & 2009).

GM HT soybeans Argentina 2009

	Active ingredient (kg/ha)	Field eiq/ha value
Derived from AMIS Global farm survey market research data	2.68	41.38

GM HT versus conventional corn Argentina 2009

	Active ingredient (kg/ha)	Field eiq/ha value
Conventional		
Option 1		
Acetechlor	1.68	33.43
Atrazine	1.0	22.90
Misotrione	0.14	2.52
Total	**2.82**	**58.85**
Option 2		
Acetechlor	1.68	33.43
Atrazine	1.0	22.90
Foramsulam	0.03	0.46
Total	**2.71**	**56.79**
Average conventional	**2.77**	**57.82**
GM HT corn		
Acetochlor	0.84	16.72
Atrazine	0.5	11.45
Glyphosate	1.02	15.64
Total	**2.36**	**43.80**

Sources: AMIS Global and Monsanto Argentina.

permanent when farmers adopt a continuous NT system which itself tends to be highly dependent upon effective herbicide-based weed control systems.

In sum, drawing on the various discussed literature, the analysis presented below uses the following conservative assumptions:

- *North America:* soil carbon sequestered by tillage system for corn and soybeans in continuous rotation; NT systems store 300 kg of carbon/ha/year, RT systems store 100 kg carbon/ha/year; and CT systems release 100 kg carbon/ha/year.
- *South America:* soil carbon retained is 100 kg of carbon/ha/yr for NT/RT (soybean) cropping systems but CT systems release 100 kg carbon/ha/year.
- One kg of carbon sequestered is equivalent to 3.67 kg of carbon dioxide.

Typical herbicide regimes for GM HT soybeans in South Africa 2009

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional soybeans		
Option one		
Alochlor	1.536	27.49
Chlorimuron	0.01	0.19
Total	**1.546**	**27.69**
Option two		
S Metalochlor	1.536	33.79
Imazethapyr	0.07	0.78
Total	**1.576**	**34.58**
Option 3		
S Metalochlor	1.536	33.79
Chlorimuron	0.01	0.78
Total	**1.546**	**34.58**
Average	**1.556**	**32.08**
GM HT soybeans		
Glyphosate	1.89	28.97

Source: Monsanto South Africa.

Typical herbicide regimes for GM HT maize in Canada

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional maize		
Metalochlor	1.3566	29.84
Atrazine	1.1912	27.28
Primsulfuron	0.0244	0.41
Dicamba	0.14	3.54
Total	**2.7122**	**61.07**
GM glyphosate tolerant maize		
Metalochlor	0.678	14.92
Atrazine	0.594	13.60
Glyphosate	0.56	8.58
Total	**1.832**	**37.10**
GM glufosinate tolerant maize		
Metalochlor	0.678	14.92
Atrazine	0.594	13.60
Glufosinate	0.37	7.49
Total	**1.642**	**36.01**

Sources: Weed Control Guide Ontario—annually updated, industry personal communications (various).

Typical insecticide regimes for cotton in India 2009

Active ingredient	Amount (kg/ha of crop)	Field EIQ/ha
Conventional cotton		
Option 1		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Triazophos	0.5	17.80
Profenfos	0.625	37.19
Acephate	0.6	14.94
Spinosad	0.384	5.53
Metaflumizone	0.025	0.82
Flubendiamide	0.048	0.93
Total	**2.42**	**84.15**
Option 2		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Profenfos	0.625	37.19
Chloripyrifos	0.4	10.76
Metaflumizone	0.025	0.82
Emamectin	0.011	0.29
Total	**1.30**	**56.00**
Average conventional	**1.86**	**70.07**
GM IR cotton		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Triazophos	0.5	17.80
Profenfos	0.625	37.19
Total	**1.36**	**61.92**
Option 2		
Imidacloprid	0.0356	1.31
Thiomethoxam	0.05	1.67
Acetamiprid	0.05	1.44
Diafenthiuron	0.1	2.53
Total	**0.24**	**6.94**
Average GM IR cotton	**1.06**	**34.43**

Source: Monsanto India.

- Where the use of biotech crops has resulted in a reduction in the number of spray passes or the use of less intensive cultivation practices (i.e., less ploughing) this has provided (and continues to provide) a permanent reduction in carbon dioxide emissions.

These assumptions were applied to the reduced insecticide spray applications data on GM IR crops, derived from separate analysis and reviews of impact literature by the authors,[1,40] and the GM HT crop areas using no/reduced tillage (limited to the GM HT soybean crops in North and South America and GM HT canola crop in Canada) herbicide regimes for conventional reduced/no till soybean production systems that.

Data sources (for pesticide usage data)

	Sources of data for assumptions
US	Gianessi and Carpenter (1999)[30] Sankala and Blumenthal (2003 and 2006)[19,20] Johnson S and Strom S (2008)[17] Own analysis (2010) All of the above mainly for conventional regimes (based on surveys of extension advisors across the US) GFK Kynetec—private market research data on pesticide usage. Is the most comprehensive dataset on crop pesticide usage at the farm level and allows for disaggregation to cover biotech versus conventional crops. This source primarily used for usage on biotech traits
Argentina	AMIS Global and Kleffmann—private market research data on pesticide use. Is the most detailed dataset on crop pesticide use AAPRESID (farmer producers association)—personal communications 2007 Monsanto Argentina (personal communications 2005, 2007, 2009 and 2010) Qaim M and De Janvry A (2005)[11] Qaim M and Traxler G (2002)[12]
Brazil	AMIS Global and Kleffmann—private market research data on crop pesticide use. Is the most detailed dataset on crop pesticide use Monsanto Brazil (2008)[42] Galveo A (2009), plus personal communications[43] Monsanto Brazil (personal communications 2007 and 2009)
Uruguay	As Argentina: no country-specific data identified
Paraguay	As Argentina for conventional soybeans (over the top usage), AMIS Global for GM HT soybeans
Bolivia	As Paraguay: no country-specific data identified
Canada	George Morris Center (2004)[44] Canola Council (2001)[45] Gusta M (2008)[46] Weed Control Guide Ontario (updated annually)
S Africa	Monsanto S Africa (personal communications 2005, 2007, 2009 and 2010) Ismael Y et al. (2002)[47]
Romania	Brookes (2005)[15]
Australia	Doyle et al. (2003)[48,49] CSIRO (2005)[50] Monsanto Australia (personal communications 2005, 2007, 2009 and 2010) Fisher J and Tozer P (2009)[51]
Spain	Brookes (2003 and 2008)[14,52]
China	Pray et al. (2002)[13] Monsanto China personal communication (2007, 2009 and 2010)
Mexico	Monsanto Mexico (2005, 2007, 2008 and 2010)[53-56] Traxler G et al. (2001)[57]
India	APCOAB (2006)[58] IMRB (2007)[59,60] Monsanto India (2007–2009 and 2010)—personal communications

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