GM Crops & Food, 8:216–228, 2017
ISSN: 2164-5698 print / 2164-5701 online
DOI: 10.1080/21645698.2017.1390637

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The contribution of glyphosate to agriculture and potential impact of restrictions on use at the global level

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ABSTRACT. This study assesses the potential economic and environmental impacts that would arise if restrictions on glyphosate use resulted in the world no longer planting genetically modified herbicide tolerant (GM HT) crops.

'First round' impacts are the loss of farm level and aggregate impacts associated with the widespread use of GM HT crops (tolerant to glyphosate). There would be an annual loss of global farm income gains of \$6.76 billion and lower levels of global soybean, corn and canola production equal to 18.6 million tonnes, 3.1 million tonnes and 1.44 million tonnes respectively. There would be an annual environmental loss associated with a net increase in the use of herbicides of 8.2 million kg of herbicide active ingredient (+1.7%), and a larger net negative environmental impact, as measured by the environmental impact quotient (EIQ[1]) indicator of a 12.4%. Also, there would be additional carbon emissions arising from increased fuel usage and decreased soil carbon sequestration, equal to the equivalent of adding 11.77 million cars to the roads.

Global welfare impacts based on these farm level impacts (identified through use of the Computable General Equilibrium (CGE) model GTAP-BIO) point to global production of soybeans and rapeseed falling by 3.7% and 0.7% respectively, partially offset by increases in other oilseeds (notably palm oil). World prices of all grains, oilseeds and sugar are expected to rise, especially soybeans (+5.4%) and rapeseed (+2%). The welfare impacts are mostly negative, with global welfare falling by \$7,408 million per year. Land use changes will arise, with an additional cropping area of 762,000 ha, of which 53% derives from new land brought into cropping agriculture, including 167,000 of deforestation. These land use changes are likely to induce the generation of an additional 234,000 million kg of carbon dioxide emissions.

KEYWORDS. Biotechnology, Economic impacts, Environmental impacts, GM Crops, Glyphosate ban, Herbicide tolerance

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Received July 24, 2017; Accepted October 5, 2017.
[1]Kovach J et al[1].

INTRODUCTION

The International Agency for Research on Cancer (IARC) re-evaluated the potential carcinogenic risk to humans of several pesticides, including glyphosate in 2015. IARC concluded that glyphosate belongs in a 2A category as probably carcinogenic to humans. As a result of the 're-classification', a number of governments' may/are considering establishing restrictions or limits on the use of glyphosate in agriculture.

Glyphosate is widely used in agriculture in many countries across a range of crops/uses and is a key part of the production system that uses GM HT crop technology. GM HT seed technology allows for the 'over the top' spraying of GM HT crops with the broad-spectrum herbicide glyphosate, that target both grass and broad-leaved weeds but does not harm the crop itself.

GM HT crops have been grown on a widespread commercial basis since 1996, and in 2015, the global cultivation reached 147.9 million hectares, a 200-fold increase from the 1996 level of 0.7 million hectares. The number of countries adopting biotech HT crop cultivation has also increased from three in 1996 to thirteen in 2015, with the United States leading the way in the use of this technology in crop production and accounting for 43% of total plantings in 2015.

Currently, the biotech-HT crop area is primarily found in soybeans, corn, cotton and canola, although GM HT sugar beet and alfalfa are also grown in the US and Canada[2] in the 2015. This technology has primarily been an agronomic, cost saving technology delivering herbicide tolerance (to glyphosate) in these crops and has provided farmers with productivity improvements through a combination of yield improvements and cost reductions. From an environmental perspective, GM HT technology adoption has resulted in important changes in the profile of herbicides used, largely in favour of more environmentally benign products. It has also played an important role in facilitating changes in farming systems, by enabling farmers to better capitalise on the availability of glyphosate (as a relatively low-cost, broad-spectrum herbicide) and move away from conventional plough-based to no tillage (NT) and reduced tillage (RT) production systems in North and South America. This change in production system has reduced levels of greenhouse gas emissions (GHG) emissions from reduced tractor fuel use and additional soil carbon sequestration. There has been, however, some over reliance on the use of glyphosate by farmers, in some regions, and this has contributed to the development of weed resistance.

This paper assesses the potential impact of a ban on the use of glyphosate that results in farmers who currently use GM HT (tolerant to glyphosate) crops, no longer using this technology and reverting to conventional (non-GM HT) seed technology. This may arise from bans on glyphosate use on countries where GM HT crop technology is currently permitted or where bans in significant importing countries or regions of the world result in farmers in GM HT growing countries switching away from these crops in order to avoid the risk of their crops not being rejected for importation and use in these main importing countries where bans have been introduced. Rejection of such imports could arise because of glyphosate residue levels breaching the extremely low maximum residue levels of 0.01 micrograms per kilogram of any product/crop for banned pesticides compared to the higher MRL levels permitted for authorised pesticides (e.g. 0.05 mg/kg).

RESULTS

'First Round' farm Level Impacts

The 'first round' impact of a glyphosate ban on the usage of GM HT crops would, in effect, 'undo' the farm level benefits arising from the use of this technology. A summary of these is presented below, and derives from Brookes G and Barfoot P.[2,3]

[2]GM HT alfalfa is grown only in the US, with both countries growing GM HT sugar beet.

Impacts on Farm Income and Crop Production and Their Potential Loss

At the farm level, GM HT (tolerant to glyphosate) technology has mostly been providing farmers who have used this technology with a more cost effective (less expensive) and easier weed control system. Some users of the technology have also derived higher yields from better weed control (relative to weed control obtained from conventional technology) and in some countries (notably in South America), the technology, by facilitating the adoption of NT systems and shortening the overall cropping time (of soybeans), has allowing the additional cropping of ('second crop') soybeans after wheat in the same season. The combination of these impacts resulted in farmers using this technology, increasing their incomes by $69.27 billion over the period 1996–2015, of which the value of this income gain in 2015 was $6.76 billion.

The 'first round' impact of a glyphosate ban would therefore be a significant annual loss of farm income gains ($6.76 billion: Table 1), in which 63% are accounted for by soybeans and 25% by corn. Canola would account for 10% of this annual loss, with the small balance in cotton and sugar beet.

Examining this in more detail, Fig. 1 provides a breakdown of the potential economic losses by country. This highlights the concentration of the losses in North and South America, where HT crops are mostly grown. The US would be the largest loser, accounting for half of the total losses, equal to about $3.385 billion. Just under two-thirds of this loss would be associated with soybeans and a third from the corn sector. Argentina and Brazil would be the next most significant losers accounting for 21.2% and 12.1% respectively of the total losses. In both countries, the losses would derive mostly from soybeans (just under three-quarters of the losses) and corn (a quarter of the losses), with the small balance accounted for by cotton. The other significant loser country would be Canada (11.6% of the total), where the main source of these losses would be associated with the canola sector (78% of the total losses).

TABLE 1. Farm income gains derived from GM HT (tolerant to glyphosate) crops in 2015 that would be lost if glyphosate was no longer allowed to be used (1000 USD).

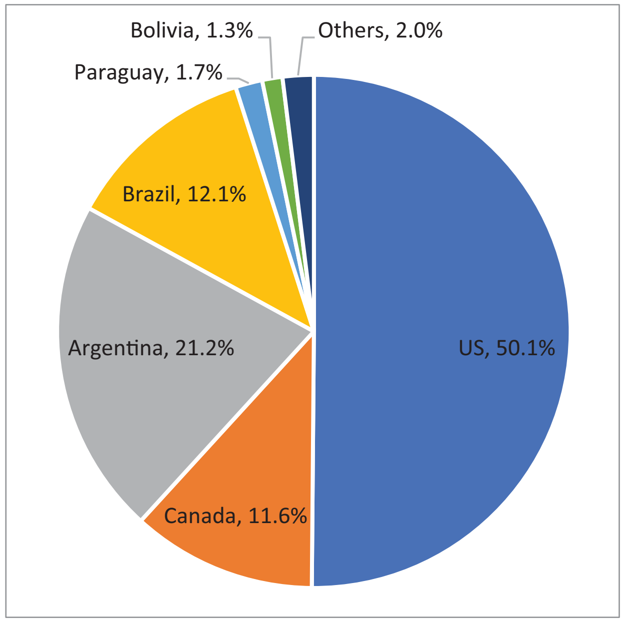
Crop	2015
HT soybeans	4,243.6
HT corn	1,687.4
HT cotton	116.7
HT canola	655.0
HT sugar beet	54.0
Total	6,756.7

Source: Derived from Brookes G and Barfoot P[2].

As indicated above, through a combination of improved weed control in some crops/countries and the way in which the HT technology helped farmers grow an additional soybean crop after wheat in the same season in Argentina and Paraguay, the GM HT (tolerant to glyphosate) technology has contributed to additional global production of soybeans, corn and canola equal to 18.6 million tonnes, 3.1 million tonnes and 1.44 million tonnes respectively in 2015. A 'first round' consequence of no longer growing HT crops tolerant to glyphosate would therefore be a decrease in these annual volumes of the four main crops.

At the country level, these production losses would be felt most in Argentina (55% of the total production losses), where the main impact is likely to be a significant reduction in the 'second' soybean crop. This source of decreased soybean production is likely to account for over 85% of the total soybean production in Argentina as farmers would be expected, in the long run to switch away from reduced/no tillage production systems to conventional tillage (due to greater difficulties in obtaining good weed control without access to glyphosate), leading to a longer growing season for soybeans and hence fewer opportunities to plant a soybean crop after wheat in the same season. In the USA, Paraguay and Bolivia, almost all production losses would also relate to soybeans, in Brazil, the production losses would largely in corn and in Canada, mostly related to canola. The value of this annual production loss, at 2015 farm

FIGURE 1. Annual loss of GM HT farm level economic benefits if glyphosate use no longer allowed: by country: total $6.76 billion. Source: Derived from Brookes G and Barfoot P[2].



level prices is $6.14 billion, of which 85% is accounted for by soybeans.

As well as the loss of tangible and quantifiable farm profitability and production losses presented above, there are other potential ‘first round’ losses of an economic nature that are more difficult to quantify. These include:

- The loss of the management flexibility and convenience benefit many farmers obtained from a combination of the ease of use associated with glyphosate and the increased/longer time window for spraying. This is likely to result in additional management time being required, reducing time for other farming activities off-farm, income earning activities;
- In a conventional crop, post-emergent weed control is more important than in GM HT crops and relies on herbicide applications after the weeds and crop are established. As a result, conventional crop may suffer ‘knock-back’ to their growth from the effects of the herbicide. Therefore, this problem may increase, if GM HT crops tolerant to glyphosate are no longer grown;
- Increases in the potential damage caused by soil-incorporated residual herbicides to crops. Another common feature of weed control practices in conventional crops that is much less prevalent with GM HT crops is the application of soil-based herbicides pre, and post- emergence. This can have a negative impact on crop growth and yield in a crop and in some cases in follow-on crops. A reversion to conventional crops away from GM HT crops tolerant to glyphosate may therefore result in increased incidence of these problems, for example, if GM HT canola (tolerant to glyphosate) were to be replaced by conventional triazine-tolerant canola;
- Higher harvesting costs. Where GM HT crops resulted in improved weed control, this, especially in the early years of widespread adoption, contributed to reduced harvesting costs – cleaner crops resulted in reduced times for harvesting and improved

harvest quality which in some cases resulted in price bonuses (eg, soybeans in Argentina).

Impacts on the Environmental Impact Associated with Herbicide Use and Greenhouse Gas Emissions and Their Potential Loss

GM HT (tolerant to glyphosate) traits have contributed to a significant reduction in the environmental impact associated with herbicide use on the areas devoted to GM crops. Since 1996, the use of herbicides on the GM crop area was reduced by 259.3 million kg of active ingredient (4.1% reduction), and the environmental impact associated with herbicide use on these crops, as measured by the EIQ indicator, fell by13.5%. If a ban on the use of glyphosate resulted in no more GM HT (tolerant to glyphosate) crops being planted, this would result in the annual loss of the environmental benefits associated with herbicide use change with GM HT crops in 2015 (Table 2). Overall, there would be an annual loss associated with a net increase in the use of herbicides of 8.2 million kg of herbicide active ingredient (+1.7%), and a larger net negative environmental impact, as measured by the EIQ indicator of a 12.4% in the environmental footprint associated with herbicide use on the area that had previously used GM HT crop technology. The higher value for lost environmental benefits, as measured by the EIQ indicator reflects the different environmental profiles of herbicide regimes typically used on conventional and GM HT crops, in which the glyphosate-based herbicide regimes commonly used with GM HT technology is more environmentally benign than the conventional alternative.

At the crop level, all crops where GM HT technology is currently widely used would see environmental losses increasing, as measured by the EIQ indicator arising from a switch back to conventional crops. In terms of amount of herbicide active ingredient used, a switch back to conventional cropping would see a net increase in herbicide usage on all crops except soybeans (Table 2).

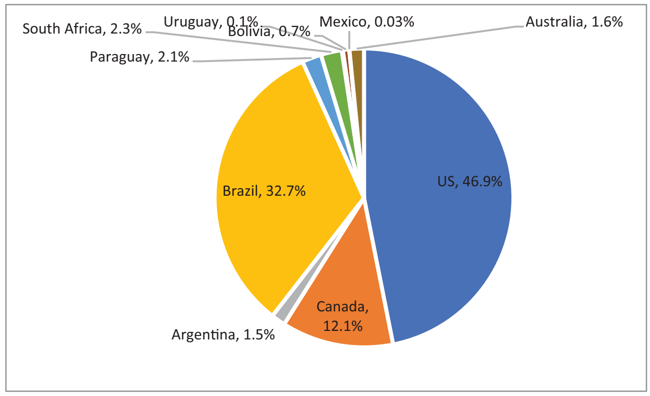
Looking at the loss of environmental benefits associated with herbicide use changes at the national level, Fig. 2 shows that nearly half of these losses would occur in the US. Brazil and Canada would account for 33% and 12%

TABLE 2. Impact of changes in the use of herbicides and insecticides from growing GM HT (tolerant to glyphosate) crops globally 2015 that would potentially be lost if glyphosate use was banned.

Trait	Change in volume of active ingredient used (million kg)	Change in field EIQ impact (in terms of million field EIQ/ha units)	Percent Change in active ingredient use on GM crops	Percent change in environmental impact associated with herbicide & insecticide use on GM crops	Area GM trait 2015 (million ha)
GM herbicide tolerant soybeans	+9.77	−488.7	+10.9	−10.9	76.7
GM herbicide tolerant maize	−12.63	−503.9	−6.2	−12.5	45.3
GM herbicide tolerant canola	−3.04	−90.6	−24.0	−36.0	8.6
GM herbicide tolerant cotton	−2.01	−44.0	−1.2	−12.9	4.2
GM herbicide tolerant sugar beet	−0.25	−1.4	−18.0	−8.8	0.47
Totals	−8.16	−1,128.67	−1.7	−12.4	135.27

Source: Derived from Brookes G and Barfoot P[1].

FIGURE 2. Annual loss of GM HT environmental benefits as measured by EIQ indicator, if glyphosate use no longer allowed: by country: total 1.13 billion EIQ/ha field units. Source: Derived from Brookes G and Barfoot P[1].



respectively of these environmental losses. More specifically:

- In the US, the environmental losses would be split mostly between corn (55% of total) and soybeans (39% of total), with the small balance accounted for by cotton and canola;
- In Canada, about 60% of the losses would be associated with changes in herbicide use in the canola crop, followed by corn (23%) and soybeans (18%);
- In Brazil, the environmental losses would largely be accounted for changes in herbicide use in soybeans (57%) and corn (43%).

The scope for a glyphosate ban resulting in impacts on greenhouse gas emissions associated with GM HT crop use comes from two principal sources:

- Loss of the fuel savings associated with less frequent herbicide applications (where relevant) and reduced energy use in soil cultivation. The fuel savings associated with making fewer spray runs (relative to conventional crops) and the switch to conservation, reduced and no-till farming systems, resulting in permanent savings in carbon dioxide emissions would potentially be lost. Based on 2015, this would amount to 2,582 million kg extra carbon dioxide being released into the atmosphere (arising from extra fuel use of 967 million litres);
- The loss of benefits associated with the use of 'no-till' and 'reduced-till'[3] farming systems. These production systems have increased significantly with the adoption of GM HT crops because the GM HT technology improved farmers' ability to control competing weeds, reducing the need to rely on soil cultivation and seed-bed preparation as means to getting good levels of weed control. As a result, tractor fuel use for tillage has been reduced, soil quality has been enhanced and levels of soil erosion cut. In turn more carbon has remained in the soil and this as resulted in lower GHG emissions. Based on savings arising from the rapid adoption of no till/reduced tillage farming systems in North

[3]No-till farming means that ground is hardly disturbed at planting (not ploughed), while reduced tillage means that ground is disturbed less than it would be with traditional tillage systems. For example, under a no-till farming system, soybean seeds are planted through the organic material that is left over from a previous crop such as corn, cotton or wheat.

and South America, in which glyphosate use with GM HT crops has played a key facilitating role, a ban on the use of glyphosate and GM HT crops no longer being planted in North and South America would potentially result in farmers switching away from reduced and no tillage production systems to a conventional, plough-based system (due to greater difficulty in obtaining good weed control, without access to glyphosate). Based on the 2015 carbon sequestration savings associated with the GM HT (tolerant to glyphosate) technology and RT/NT agriculture, this results in 5,738 million kg less of soil carbon being stored in the soil, resulting in the equivalent of 21,060 million more kg of carbon dioxide being released into the global atmosphere.

Placing these carbon sequestration losses within the context of the carbon emissions from cars, Table 3 shows that:

- the additional, permanent carbon dioxide released into the atmosphere from higher fuel use is the equivalent of adding 1.15 million cars to roads;
- The additional probable loss of soil carbon sequestration is equivalent to adding 10.62 million cars from the roads;
- In total, the annual, additional combined GM HT crop-related carbon dioxide emissions from higher fuel use and decreased soil carbon sequestration is equal to the addition to the roads of 11.77 million cars, equivalent to 40% of all registered cars in the UK.

From a country perspective, the loss of greenhouse gas emission savings would be largest in the US, which would account for 35% of the total losses. The loss of greenhouse gas emission saving would also be significant in Argentina, Brazil and Canada (31%, 21% and 6% respectively of the total annual losses).

Any reversion to conventional, plough-based tillage will also result in the loss of some of the more intangible benefits associated with the adoption of RT/NT. This would mean that soil quality is likely to deteriorate and levels of soil

TABLE 3. Context of annual carbon sequestration impacts if glyphosate use were banned: car equivalents.

Crop/trait/country	Permanent additional carbon dioxide emissions arising from higher fuel use (million kg of carbon dioxide)	Permanent additional emissions from extra fuel use: as average family car equivalents added to the road for a year (1000 USD)	Potential loss of soil carbon sequestration (million kg of carbon dioxide)	Soil carbon sequestration losses: as average family car equivalents added to roads for a year (1000 USD)
HT soybeans				
Argentina	739	329	7,496	3,332
Brazil	501	223	5,082	2,259
Bolivia, Paraguay, Uruguay	170	75	1,722	765
US	528	235	2,840	1,262
Canada	47	21	247	110
HT maize				
US	387	172	5,495	2,442
Canada	19	8	54	24
HT canola				
Canada	191	85	964	428
Total	2,582	1,148	23,900	10,622

Notes: 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.

Source: Derived from Brookes G and Barfoot P[1].

TABLE 4. Impacts of a ban on the use of glyphosate on crop production.

Data item	Crop	USA	EU	Brazil	Canada	South America	Others	World
Percent Change	Rice	0.2	0.2	−0.1	0.5	−0.6	0.0	0.0
	Wheat	0.4	0.1	−0.4	0.6	−1.1	0.0	0.1
	Coarse Grains	−2.3	0.1	−0.8	0.8	−1.6	0.2	−0.6
	Soybeans	−1.9	7.5	2.7	−5.6	−17.1	1.4	−3.7
	Palm fruit	6.8	3.1	3.6	9.8	4.8	0.5	0.7
	Rapeseed	−0.1	1.7	2.9	−5.6	1.6	0.0	−0.7
	Other oilseeds	3.3	2.3	2.7	2.8	2.5	1.1	1.4
	Sugar crops	0.0	0.0	−0.2	−0.6	0.0	0.0	−0.1
	Other crops	0.2	0.1	−0.5	0.4	−1.1	0.0	0.0
Change in 1000 metric tons	Rice	18.9	5.5	−18.1	0.0	−73.7	−2.9	−70.2
	Wheat	226.2	73.9	−19.9	143.2	−213.6	223.0	432.8
	Coarse Grains	−7518.4	140.8	−482.3	170.3	−751.3	1258.9	−7182.0
	Soybeans	−1604.5	82.4	1988.3	−236.2	−10497.9	528.7	−9739.2
	Palm fruit	0.0	0.0	46.4	0.0	319.6	1272.1	1638.2
	Rapeseed	−0.6	330.0	1.5	−795.3	3.3	10.4	−450.6
	Other oilseeds	93.6	519.3	94.4	14.7	142.4	1484.0	2348.4
	Sugar crops	11.2	−56.5	−1812.1	−4.6	−45.3	−221.8	−2129.1
	Other crops	1605.8	498.1	−458.2	183.8	−2312.6	952.2	469.1

erosion increase[4]. There would also be likely lower levels of soil moisture conservation and wider soil temperature fluctuations from the loss of the insulating properties of crop residues.

ECONOMY-WIDE IMPACTS

Crop Production

A ban on the use of glyphosate that resulted in GM HT (tolerant to glyphosate) no longer being grown will affect global crop production. Production of soybeans, corn, rapeseed, cotton and sugar beet will be affected directly in regions using GM HT seed technology. As shown in Table 4, production of soybeans will drop significantly in the US, Canada, and South America by 1.9% (1.6 million tonnes), 5.6% (0.2 million tonnes), and 17.1% (10.5 million tonnes) respectively. In response to these reductions, soybean production is likely to increase in some other regions, notably in Brazil. While Brazil makes widespread use of GM HT technology and its production cost is expected to increases if it no longer used this technology, its soybean production is forecast to increase by 2.7% (2 million tonnes), and this partly compensates for the shortfall in the global market for this commodity. Overall, if GM HT crops were no longer grown, global production of soybeans would fall by 9.7 million tonnes (3.7%). South America is expected to lose a significant portion of its soybeans production if a glyphosate ban resulted in GM HT crops no longer being grown.

If GM HT crops were no longer grown, there will be a moderate reduction in rapeseed/canola production in Canada of 0.8 million tonnes. However, additional production in the EU and other countries compensates about half of this (Canadian) loss. Hence, overall, global production of rapeseed falls by 0.45 million tonnes only.

While a loss of GM HT crop technology negatively affects production of soybeans and rapeseed at the global level, it will enhance global production of palm oil and other oilseeds by 1.6 million tonnes and 2.3 million tonnes respectively (Table 4). These unintended

[4]The International Panel on Climate Change (IPCC) has agreed that conservation/no till cultivation leads to higher levels of soil carbon. http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=174.

impacts, in particular, the expansion in palm oil in Malaysia and Indonesia, will generate major land use emissions (see below for further discussion).

A loss of GM HT crops is also expected to significantly reduce production of corn. As shown in Table 4, the global production of coarse grains (mainly corn) will drop by 7.2 million tonnes (-0.6%). This is mainly caused by the reduction in corn production in US, where production of coarse grains is expected to drop by 7.5 million tonnes (-2.3%). Brazil and the rest of South America will experience reductions in coarse grain outputs by 0.5 million tonnes and 0.75 million tonnes respectively. However, the EU and other countries jointly will increase coarse grain production by 1.4 million tonnes to compensate for some of the shortfall in corn production in the US and South America.

If GM HT crops tolerant to glyphosate were no longer grow, this would result in a global reduction in the production of sugar crops. There would be a direct reduction in the production of sugar beet in US and Canada, where GT HT technology is widely used to produce this crop. On the other hand, a loss of GM HT technology in North American sugar beet production will also indirectly lead to reduced production of sugar cane in Brazil (by 1.8 million tonnes) because of land use changes in which some cropland (currently in sugar cane) is switched to soybeans.

If GM HT cotton was no longer grown, global production of cotton (imbedded in the category of other crops in the GTAP model) would fall in several countries including US, Brazil, Argentina, Colombia, Mexico, Australia, and South Africa. However, these reductions are only visible for Brazil and South America in Table 4. Production of other crops (including cotton) drops by 0.5 million tonnes and 2.3 million tonnes respectively in these two regions. Finally, as shown in Table 4, there would be minor impacts on global production of rice and wheat.

Crop Prices

If GM HT crop technology was no longer used, there would increases in global prices of a number of crops. These price changes vary by crop and region (Table 5). At the global scale the price of soybeans increases more than other crops (by 5.4%). Global prices of rapeseed, palm, other oil seeds, and coarse grains increase by 2%, 0.9%, 1.1% and 1.4% respectively. The global prices of rice, wheat, sugar crops, and other crops increase by 0.5%. In general, price increases in US, Canada, Brazil and other South American countries are larger than the rest of the world.

Welfare Impacts

If GM HT crops were no longer grown world-wide welfare would fall (Table 6). Most countries/regions lose welfare, but a few make small gains. The welfare impacts are divided in two main categories. The first column of table 6 shows welfare losses associated with

TABLE 5. Impacts of a ban on the use of glyphosate on crop prices.

Crop	USA	EU	Brazil	Canada	South America	Others	World
Rice	0.5	0.4	1.0	0.3	1.0	0.4	0.4
Wheat	0.5	0.5	0.7	0.5	1.0	0.4	0.5
Coarse Grains	2.9	0.7	2.4	0.8	2.7	0.6	1.4
Soybeans	5.0	1.0	3.2	5.5	11.0	1.4	5.4
Palm fruit	0.1	0.1	1.2	0.1	2.9	0.9	0.9
Rapeseed	2.7	0.7	1.2	5.1	2.0	1.3	2.0
Other oilseeds	1.2	0.7	1.2	1.3	2.3	1.1	1.1
Sugar crops	0.0	0.5	0.8	2.7	1.2	0.4	0.6
Other crops	0.6	0.6	1.0	0.6	1.5	0.5	0.6

TABLE 6. Annual welfare impacts of banning the use of glyphosate (million USD at 2011 prices).

Regions	Efficiency losses	Terms of trade	Total welfare impacts
United States of America	−3,521	1,651	−1,870
European Union	−329	−604	−933
Brazil	−731	996	265
Canada	−427	366	−61
Japan	−59	−592	−651
China and Hong Kong	−172	−1,971	−2143
India	−52	47	−5
Central America	−128	−136	−264
South America	−1,954	1,186	−768
East Asia	−59	−422	−481
Malaysia and Indonesia	−6	79	73
Rest of South East Asia	−5	−91	−96
Rest of South Asia	−17	−52	−69
Russia	3	−76	−73
Other CEE and CIS countries	−17	77	61
Other Europe	40	−46	−6
Middle East and North Africa	98	−616	−518
Sub Saharan Africa	−50	48	−2
Oceania	−23	157	134
Total	−7,408	0	−7,408

the loss of the GM HT technology; this raises crop production costs and reduces crop yields in almost all regions. The main welfare losers are US, South America, and Brazil with efficiency losses of $3,521 million, $1,954 million, and $731 million per year respectively. The global efficiency loss is about $7,408 million per year.

The second column of Table 6 show the changes in welfare due to changes in the terms of trade. Some countries gain and some countries lose, with the main loser being China (with an annual reduction in welfare of $1,971 million). This is due to its reliance on large volumes of oilseed imports, which will have higher prices. Other major losers in terms of trade are the Middle East/North Africa, Japan, and the EU which are also significant oilseed importers. On the other hand, the US and South American countries, which are the main producers and exporters of oilseeds, make welfare gains arising from changes in the terms of trade associated with higher crop prices. The terms of trade changes in favour of these regions are $1,651 million, $1,186 million and $996 million per year respectively for US, South America (excluding Brazil) and Brazil.

The sum of the first two columns in Table 6 shows the overall welfare impacts. In sum, the main welfare losers are China, US, EU, South America and Japan with welfare losses of $2,143 million, $1,870 million, $933 million, $768 million and $651 million respectively per year. Among these regions China, EU, and Japan lose welfare because the terms of trade changes against them (high reliance on imports that will become more expensive). Whilst, the US and South America gain due to changes in the terms of trade (higher world prices), as these regions are the main producers of GM HT crops, they make total welfare losses because the efficiency losses associated with shifting away from GM HT technology to inferior conventional production technology are greater than the terms of trade welfare gains.

Land use Impacts

No longer growing GM HT crops results in higher production costs for soybeans, rapeseed, corn, cotton, and sugar beet and lower yields in those regions where GM HT technology has been used. This generates important global land use changes (Table 7) including an increase in the global harvested area of crops of 762,000 hectares. Multiple cropping and or conversion of idled land to crop production accounts for more than 47% of this expansion, with the rest (53%) arising from new croplands of 402,000 hectares. This is generated from a world-wide increase in deforestation of 167,000 hectares and conversion of 235,000 hectares of pasture land to cropland. In addition, farmers in the US, Brazil, and Canada convert about 487,000 hectares of 'cropland pasture' (a marginal cropland used by livestock industry) to crop production.

Carbon Emissions

The induced land use changes discussed above generate an additional 233,563 million

TABLE 7. Land use impacts of banning the use of glyphosate (1000 hectares).

Land type	US	European Union	Brazil	Canada	Sub Saharan Africa	Other Countries	World
Forest	13	−5	−22	−1	−79	−73	−167
Pasture	−17	−11	−75	−1	−77	−53	−235
Cropland	4	16	98	2	156	126	402
Harvested area	19	81	212	9	206	234	762
Cropland pasture	−118	0	−352	−16	0	0	−487

kg of carbon dioxide emissions. Drawing on Taheripour et al[3,4] which estimated that the induced land use emissions for US corn ethanol is about 12 g CO_2e/MJ, the level of induced land use emissions caused by a ban on the use of glyphosate resulting in GM HT crops no longer being grown, is equivalent to the land use emissions induced from the production of 29.5 billion litres of corn ethanol in the US. It should also be noted that the additional carbon emissions of 233,563 million kg of carbon dioxide induced by the land use changes associated with a global ban on the use of glyphosate (leading to GM HT crops no longer being grown) are equal to about 27% of the total additional global carbon dioxide emissions that would arise if there was a global ban on the use of GM crops (Mahaffey et al[5]).

METHODOLOGY

The approach used to estimate the impacts of the loss of glyphosate in GM HT crops is examined from two perspectives.

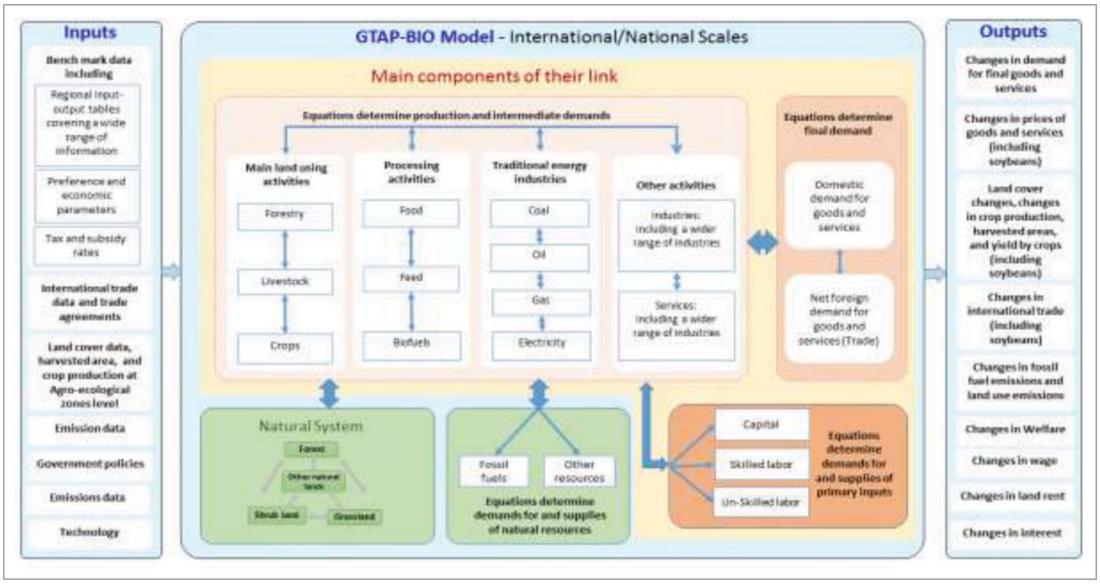
First, the farm level and aggregate impacts based on ‘removal’ of the benefits identified in the global impact studies of Brookes and Barfoot.[1,2] This is largely ‘static’ analysis and examines:

- *Economic (farm level) impacts*: possible loss of crop yield and production gains associated with improved weed control that glyphosate tolerant crops have experienced in some countries, the potential loss of ‘second crop soybean’ benefits associated with adoption and maintenance of no/reduced tillage production systems in which glyphosate has played a key role (Argentina and Paraguay) and the potential loss of cost savings that many farmers achieved with the adoption of glyphosate-based weed control systems;
- *Environmental (farm level) impacts*: Possible changes associated with herbicide use away from a glyphosate-based to alternative (conventional) weed control system. This includes examination of changes to the amount of herbicide active ingredient usage and the associated environmental impact, as measured by the EIQ indicator. Also, changes associated with the possible reversal of carbon emission savings associated with reduced fuel use and additional soil carbon storage with no/reduced tillage facilitated by HT (tolerant to glyphosate) crops.

The second perspective is the examination of the global welfare impacts based on input of the farm level data impacts referred to above into the Computable General Equilibrium (CGE) model GTAP-BIO[7] that analyzes land use and economy-wide impacts and takes into account linkages in the global economy. This analysis covers:

- *Economic impacts*: These will arise from changes in yields and second cropping referred to above and impact global production of crops their trade and prices. Land use changes are likely to arise, with changes in both the mix of cropping and the amount of land used by agriculture. Overall welfare impacts for different countries or regions may be positive for some production countries but negative for mainly importing countries due to the trade effects associated with commodity price increases that are likely to occur;

FIGURE 3. Structure of GTAP-BIO model.



- *Environmental impacts*: These will arise from the yield and production cost changes leading to land use changes. Farmers are likely to change planted areas of crops to 'compensate' for the yield/production cost changes and this may affect the balance between land used for agricultural and non-agricultural purposes as well as crop allocation. These changes will have an impact on greenhouse gas emissions. In effect, the GTAP-BIO model is 'shocked' to take account of the yield and production cost changes and the model then solves for the new production levels.

The GTAP-BIO is a well known CGE model which has been frequently used to examine the economic and environmental impacts of energy-agriculture-environment-trade subjects (eg, Mahaffey et al[6]). Fig. 3 shows the structure of this model and its main components. The model uses a database (known as GTAP data base) which includes: Social Accounting Matrices (SAMs) of 140 countries; comprehensive information on trade of good and services among the nations; data on land cover items (forest, pasture, cropland), crop production and harvested area by crop by Agro-Ecological-Zone (AEZ); and Greenhouse Gas emissions associated with production, consumption, and trade of good and services. This database classifies all goods and services into 57 groups and represents their production, consumption and trade by country. The most recent version of this database (Version 9) represents the world economy in 2011. In this paper an advanced version of this database was used, which unlike the standard GTAP data base, explicitly covers production and consumption of biofuels at the global scale.[5]

The GTAP-BIO model represents: production functions for goods and services; derived demand equations for intermediate and primary inputs (including land by AEZ, labour, capital, and resources); equations to represents households and government demands for good and services; and equations to model bilateral trade among each pair of countries. In this model market clearing conditions maintain equilibrium conditions in all markets. These equations endogenously determine quantities of demands and supplies for all goods and services. The model takes into account multiple cropping and conversion of unused cropland to crop production.

To measure the economy-wide impacts of GM HT crops no longer being grown, costs of chemicals, labour, capital, and productivity of land were 'shocked' according to our 'first round' farm level impact data. These shocks directly affect production costs of affected crops and alter relative prices and derive changes in the global economy. The outputs of the model represent the impacts of these shocks.

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