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RESEARCH PAPER

The farm level economic and environmental contribution of Intacta soybeans in South America: the first five years

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ABSTRACT. This study assesses the economic and environmental impacts that have arisen from the adoption and use of genetically modified (GM) herbicide tolerant (HT) and insect resistant (IR) soybeans in South America in the five years since first planted in 2013/14. A total of 73.6 million hectares have been planted to soybeans containing these traits since 2013/14, with farmers benefiting from an increase in income of $7.64 billion. For every extra $1 spent on this seed relative to conventional seed, farmers have gained an additional $3.88 in extra income. These income gains have arisen from a combination of higher yields (+ 9.2% across the four countries using the technology) and lower costs of weed and pest control. The seed technology has reduced pesticide spraying by 10.44 million kg (−15.1%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops (as measured by the indicator, the Environmental Impact Quotient (EIQ)) by 30.6%. The technology has also facilitated important cuts in fuel use and tillage changes, resulting in a significant reduction in the release of greenhouse gas emissions from the GM cropping area. In 2017/18, this was equivalent to removing 3.3 million cars from the roads.

KEYWORDS. farm income, GM crop impacts, Intacta soybeans, yield

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TABLE 1. GM Intacta soybean plantings 2013/14–2017/18 (million ha).

Country	2013/14	2014/15	2015/16	2016/17	2017/18
Argentina	0.6 (3%)	1.13 (6%)	2.91 (15%)	3.16 (17%)	3.84 (20%)
Brazil	1.16 (4%)	5.87 (18%)	12.76 (38%)	17.29 (51%)	18.17 (52%)
Paraguay	0.01 (3%)	0.78 (23%)	1.22 (36%)	1.48 (45%)	1.53 (45%)
Uruguay	0.26 (18%)	0.22 (17%)	0.28 (25%)	0.36 (33%)	0.43 (33%)
Total	**2.03 (4%)**	**8.0 (14%)**	**17.17 (30%)**	**22.29 (39%)**	**23.97 (41%)**

Sources: derived from Argenbio, ISAAA, Monsanto, Kleffmann Note 2017/18 provisional estimates

INTRODUCTION

GM crop technology has been widely used in South American agriculture for over 20 years, having been first used in Argentine soybean crops in 1996. Since then, its use has been extended to corn and cotton planted in several countries, including Argentina, Bolivia, Brazil, Colombia, Paraguay and Uruguay. GM soybeans, tolerant to the broad-spectrum herbicide, glyphosate that controls both grass and broad-leaved weeds and resistant to specific insect pests of soybeans (velvet-bean caterpillar, soybean looper, bean shoot borer and corn stalk borer), and known as ‘Intacta’ soybeans have been available to farmers in Argentina, Brazil, Paraguay and Uruguay since the 2013/14 crop year. In the fifth year of widespread commercial adoption (2017–18), soybean crops containing this type of technology were planted on nearly 24 million hectares, accounting for 41% of the total plantings of soybeans in these four countries (Table 1).

This paper presents an assessment of some of the key economic and environmental impacts associated with the adoption of ‘Intacta’ soybeans in South America. The analysis focuses on:

- *Gross farm income effects* on costs of production, yield/production and farm income;
- *Changes in the amount of insecticides and herbicides applied to the GM crops relative to conventionally grown alternatives and;*
- *The contribution of towards reducing global greenhouse gas (GHG) emissions.*

The analysis draws on the material presented in the findings of analysis into the global impact of GM crops by the author (Brookes and Barfoot (2017a and 2017b) that covers the three-year period 2013–2015 but has been updated/extended to cover the years 2016 and 2017).

METHODOLOGY

The approach used to estimate the impacts of using Intacta soybeans draws on the farm level and aggregate impacts identified in the global impact studies of Brookes and Barfoot (2017a[1] and 2017b.[2]) These examined farm level economic impacts on crop yield and production gains associated with improved weed control that glyphosate tolerant crops and better pest control with the IR trait in soybeans. They also examined environmental impacts associated with changes in herbicide and insecticide use and carbon emission savings with Intacta soybeans. The material presented in this paper combines data presented in these papers for the period 2013–2015 but extends the analysis to include the years 2016 and 2017. The methodology used in the global impact of biotech crops covering the 2013–2015 period has been applied to the years 2016 and 2017. Additional information about the assumptions can be found in Appendix 1

TABLE 2. Farm income gains derived from GM Intacta soybeans (‘000$).

Country	2017/18	Cumulative 2013/14–17/18	Cumulative area planted to Intacta (’000 ha)
Argentina	259.4	756.8	11,632
Brazil	1,904.0	6,111.5	55,254
Paraguay	226.3	663.4	5,114
Uruguay	38.7	108.3	1,556
Total	**2,428.4**	**7,640.0**	73,556

Sources: Brookes G and Barfoot P (2017a[2] and updated) (together with examples of calculations of impacts for the year 2017/18). Readers requiring further details relating the methodology should refer to the two references cited above.[3]

RESULTS

Impacts on farm income and crop production

At the farm level, GM 'Intacta' soybeans have provided farmers with a more cost effective (less expensive) and easier weed control system via the HT trait (tolerance to glyphosate), coupled with higher yields from a combination of better pest control (relative to pest control obtained from conventional insecticide technology) via the IR trait and the positioning of the HT trait in the DNA of the germplasm used. The IR trait has also provided for savings in expenditure on insecticides. The combination of these impacts has increased the incomes of farmers using the technology by $7.64 billion over the five-year period 2013/14–2017/18 (in 2017/18 the income gain was $2.43 billion (Table 2)).

The largest share of the farm income benefits has occurred in Brazil - 80% of total. This is mainly because 75% of total plantings of Intacta soybeans have been in Brazil, where the highest levels of pest incidence occur (notably in the Northern half of the country).

Examining the cost farmers pay for accessing the 'Intacta' seed technology, the average cost over the period 2013/14 to 2017/18 was equal to 26% of the total technology gains (inclusive of farm income gains plus cost of the technology payable to the seed supply chain[a]). In terms of investment, over the five years of adoption, this means that for each extra dollar invested in Intacta soybean crop seeds in South America, farmers gained an average $3.88.

The South American farmers who have grown Intacta soybeans commercially have seen an average + 9.2% increase in yields since 2013/14. Based on these yield gains (see appendix 1 for country-specific yield gain information), the 'Intacta' technology has added 20 million tonnes of soybeans to South American production since 2013/14 (Table 3). Brazil accounted for 78% of this additional production, followed by Argentina and Paraguay which accounted for 12% and 8% respectively. This extra production effectively means that farmers have been able to grow more soybeans without needing to use additional land. To illustrate, if Intacta technology had not been available to farmers in 2017/18, maintaining production levels for this year using conventional technology would have required the planting of an additional 2.2 million hectares of agricultural land to soybeans in South America. This equates to about 3.5% of the total arable land in Brazil.

TABLE 3. Additional soybean production from positive yield effects of Intacta soybeans ('000 tonnes).

Country	2017/18	Cumulative 2013/14–17/18
Argentina	798	2,480
Brazil	5,232	15,692
Paraguay	528	1,638
Uruguay	89	302
Total	**6,647**	**20,112**

Sources: Brookes G and Barfoot P (2017a[2] and updated)

Impacts on the environmental impact associated with herbicide use and greenhouse gas emissions

GM Intacta soybeans traits have contributed to a significant reduction in the environmental impact associated with herbicide and insecticide use on the areas devoted to these crops. Since 2013/14, the use of herbicides and insecticides on the GM crop area was reduced by 10.4 million kg of active ingredient (−15.1% reduction), and the environmental impact associated with herbicide and insecticide use on these crops, as measured by the EIQ indicator, fell by 30.6% (Table 4). In terms of active ingredient usage, the fall in total usage is due to the significant decrease in insecticide use, with herbicide use marginally increasing compared to the conventional alternative that would

TABLE 4. Impact of using Intacta soybeans changes in South America: changes in herbicide and insecticide use and associated environmental impact (as measured by EIQ indicator) 2013/14-2017/18

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	Cumulative Intacta area 2013/14-2017/18 (million ha)
GM herbicide tolerance	+ 0.55	–412.8	+ 0.2	–10.3	
GM insect resistance	–10.99	–976.4	–15.9	–21.5	
Totals	–10.44	–1,389.2	–15.1	–30.6	73.56

Source: Derived from Brookes G and Barfoot P[3]

reasonably be expected if conventional soybeans where grown. In relation to the environmental impact associated with both herbicide and insecticide use, as measured by the EIQ indicator, the adoption of GM intacta soybeans has resulted in important environmental improvements, equal to a 10% reduction in the environmental load associated with herbicide use and a 21% cut in relation to the environmental load associated with insecticide use.

The positive delivery of environmental benefits from the HT trait, as measured by the EIQ indicator reflects the different environmental profiles of herbicide regimes typically used on conventional and GM HT (Intacta) crops, in which the glyphosate-based herbicide regimes commonly used with 'Intacta' technology are more environmentally benign than the conventional alternative.

Looking at the environmental benefits associated with herbicide and insecticide use changes at the national level, Brazil accounts for 92% of these environmental gains, as measured by the EIQ indicator, followed by Argentina, which accounted for 5% of the EIQ gains.

The scope for impacts on greenhouse gas emissions associated with GM Intacta soybean use comes from two principal sources:

- Fuel savings associated with less frequent herbicide and insecticide applications and reduced energy use in soil cultivation. The fuel savings associated with making fewer

TABLE 5. Permanent carbon sequestration impacts 2013/14–2017/18 arising from reduced fuel use: car equivalents.

Crop/trait/country	Permanent fuel saving (million litres)	Permanent reduced carbon dioxide emissions arising from lower fuel use (million kg of carbon dioxide)	Permanent lower emissions from reduced fuel use: as average family car equivalents removed from the road for a year ('000)
HT trait: total	**604.4**	**1,613.7**	**996.7**
Argentina	222.4	593.7	366.7
Brazil	307.1	820.1	506.5
Paraguay, Uruguay	74.9	199.9	123.5
IR trait	**170.1**	**454.2**	**280.5**
Argentina	9.8	26.1	16.1
Brazil	152.0	405.7	250.6
Paraguay, Uruguay	8.3	22.4	13.8
Total	**774.5**	**2,067.9**	**1,277.2**

Notes: Assumption: an average family car in 2017 produces 129 grams of carbon dioxide per km. A car does an average of 12,553 km/year and therefore produces 1,619 kg of carbon dioxide/year
Source: Brookes G and Barfoot P (2017b[3]) and updated

spray runs (relative to conventional crops) and the switch to no-till farming systems, have led to permanent savings of carbon dioxide emissions. Over the five-year period, 2013/14 to 2017/18, this amounted to 2.1 billion kg of carbon dioxide not released into the atmosphere (arising from less fuel use of 774 million litres: Table 5). This is equivalent to taking 1.28 million cars off the road for a year;

- Benefits associated with the use of 'no-till' and 'reduced-till'[b] 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 has resulted in lower GHG emissions. Based on savings arising from the rapid adoption of no till/reduced tillage farming systems in South America, in which glyphosate use with GM HT crops has played a key facilitating role, and applying this to the area planted to Intacta soybeans (which contain the HT trait, tolerance to glyphosate), the 2017/18 carbon sequestration savings associated with this technology and NT agriculture, resulted in 4,759 million kg less carbon dioxide being released into the global atmosphere (Table 6). This is equivalent to taking 2.94 million cars off the road for a year (equal to 10% of all registered cars in the UK).

Looking at these carbon emission changes at the trait and country level:

- the HT trait provides all of the soil carbon savings (as discussed above, relating to its facilitation of NT production systems) and the majority of the fuel savings. These fuel savings are primarily associated with the switch from ploughing to a NT production system, with no change to the frequency of application of herbicides for weed control;
- the IR trait provides carbon emission savings solely from less spraying of insecticides and this accounts for about 22% of the total carbon emission savings associated with fuel use changes;
- Brazil accounts for 59% of the permanent carbon emission savings associated with reduced fuel use with Intacta

TABLE 6. Carbon sequestration impacts 2017/18: car equivalents.

Crop/trait/country	Permanent reduced carbon dioxide emissions arising from lower fuel use (million kg of carbon dioxide)	Permanent lower emissions from reduced fuel use: as average family car equivalents removed from the road for a year ('000)	Potential additional soil carbon sequestration (million kg of carbon dioxide)	Soil carbon sequestration gains as average family car equivalents removed from the road for a year ('000s)
HT trait: total	**469.48**	**290.0**	**4,758.59**	**2.939.22**
Argentina	141.80	87.60	1,437.38	887.82
Brazil	269.95	166.74	2,736.43	1,690.20
Paraguay, Uruguay	57.73	35.66	584.78	361.20
IR trait	**136.30**	**84.19**	**0**	**0**
Argentina	8.60	5.31	0	0
Brazil	122.30	75.54	0	0
Paraguay, Uruguay	5.40	3.34	0	0
Total	**605.78**	**374.19**	**4,758.59**	**2,939.22**

Notes: Assumption: an average family car in 2017 produces 129 grams of carbon dioxide per km. A car does an average of 12,553 km/year and therefore produces 1,619 kg of carbon dioxide/year
Source: Brookes G and Barfoot P (2017b[3]) and updated

soybeans. It also accounts for 57% of the soil carbon storage saving. This is mainly because Brazil has the highest level of adoption of Intacta seed (75% of the total South America planting in 2017/18). Argentina accounts for about 30% of the total permanent carbon emission savings from reduced fuel use and 30% of the total soil carbon sequestration savings. Paraguay and Uruguay accounted for 11% of the fuel-related carbon savings and 12% of the soil carbon savings.

There is also scope for carbon emission savings to arise indirectly from the additional production that has resulted from adoption of Intacta soybeans. As indicated above, the Intacta technology has allowed farmers to grow additional soybeans, equivalent to an area of 2.2 million ha (if conventional soybeans were planted) based on the 2017/18 crop year. This has contributed to reducing the pressure to bring more land into agricultural production and therefore may have contributed to reducing the pressure for further deforestation in South America. Deforestation is a major source of global carbon emissions, with the average rate of carbon dioxide emissions from Amazonian deforestation estimated to be between 301 tonnes/ha and 499 tonnes/ha (Peng Song et al (2015)).[4] Therefore, whilst the adoption of Intacta soybeans has delivered important carbon emission savings (discussed above) from reduced fuel use and additional soil carbon sequestration relative to conventional soybeans, these emission savings are small relative to the possible savings arising from reduced pressure to deforest for additional agricultural land use.

The adoption of Intacta soybeans has also provided other environmental benefits. The facilitation of NT production practices associated with the HT trait has contributed the intangible benefits of improved soil quality and reduced levels of soil erosion increase. It has also resulted in higher levels of soil moisture conservation and less soil temperature fluctuations from the extra insulating properties of crop residues. The reduced spraying of insecticides has also resulted in water usage savings. Over the five years 2013/14 to 2017/18, these have been equal to a saving of over 200 million litres of water (see appendix 1 for assumptions), with 89% of these savings being in Brazil.

Concluding comments

Intacta soybean technology has now been used by many farmers in South America for five years and, in 2017/18, nearly 24 million hectares were planted to seeds containing this technology (equal to 41% of the soybean area in these four countries). This seed technology has helped farmers grow more food and feed (20 million tonnes of additional soybeans 2013/14–2017/18), using fewer resources and therefore contributed to reducing the pressure to bring new land into agriculture. The extra production and reduced costs of production have provided farmers with higher incomes equal to an average of +$104/ha and an average return on investment equal to +$3.88 for each extra $1 spent on 'Intacta' seed relative to conventional seed. The additional farm income from growing Intacta soybeans has boosted farm household incomes and so provided an economic boost to the rural and national economies in each of the four countries. It has also contributed to a more reliable and secure food and feed supply base.

The more efficient use of herbicides and insecticides has reduced their environmental impact, and helped farmers adopt and maintain the more sustainable practices of reduced and no tillage. This has lowered fossil fuel use and facilitated more carbon being retained in the soil so that the carbon footprint of agriculture has been reduced.

Overall, the impact evidence from the first five years of adoption of Intacta soybeans points to a positive contribution towards addressing the food and environmental challenges facing each of the four countries of South America.

NOTES

[a] The cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers.

[b] 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.

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STATISTICAL SOURCES

Kleffmann and AMIS Global are subscription-based data sources (derived from farm surveys) on pesticide use

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The Argentine crop biotechnology company trade association (Argenbio)

References to Monsanto (Argentina, Brazil, Paraguay and Uruguay) - this is unpublished data kindly provided to the author

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Appendix 1: Details of application of data and methodology to calculating 2017/18 farm income gain and insecticide use changes for Intacta soybeans and key assumptions

Farm income gains

Country	Area of trait (000′ ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price: $/tonne)	Cost of tech ($/ha)	Impact on costs, net of cost of tech ($/ha)	Change in farm income ($/ha)	Change in farm income at national level (‘000 $)	Production impact (‘000 tonnes)
Brazil	18,471	+ 9.4	3.06	316	+ 37.59	–13.91	+ 104.78	1,904,024	5,232
Paraguay	1,530	+ 11.5	2.99	318	+ 24.75	–38.04	+ 147.88	226,256	528
Argentina	3,840	+ 7.1	2.93	248	+ 24.71	–16.02	+ 67.54	259,367	798
Uruguay	429	+ 7.0	2.96	333	+ 29.87	–21.07	+ 90.29	38,734	89

Sources:
Areas planted: ISAAA, Kleffmann, Monsanto
Yield gain: Monsanto pre-commercial trials in 2011 and 2013 plus post production farm surveys (unpublished post market monitoring: Monsanto)
Cost of technology: Monsanto, Kleffmann
Weed control cost comparisons: Brookes and Barfoot (2017a) which compares GM HT weed control practices derived from Kleffmann usage data, with conventional weed control practices that would deliver similar levels of weed control as the GM HT system as advised by extension and industry sources (see below)
Insecticide use changes based on Monsanto pre-commercial trials in 2011 and 2013 plus post production farm surveys (unpublished post market monitoring: Monsanto) and Kleffmann insecticide use data
Notes:
1. Weed cost changes (GM HT versus conventional): Brazil: -$40.05/ha, Argentina: -$26.13/ha, Paraguay: -$22.75/ha, Uruguay: -$36.94/ha
2. Insecticide cost changes: Brazil: $11.46/ha, Argentina: $14.6/ha, Paraguay: $40.04/ha, Uruguay: $14/ha
3. The cost of the technology represents the value paid by farmers to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers. It does not represent the value accruing to the technology providers but to the whole seed supply chain. The range in values across countries for cost of technology reflects reasons such as the price charged by different stages in the supply chain, exchange rates and average seed rates
4. Yield gains derive from a combination of reduction of pest damage (IR trait) and the positioning of the HT trait in the DNA of the germplasm of Intacta soybean varieties

Insecticide use change

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)
Brazil	18,471	1.43	1.6	30.65	47.9	3,134.0	313.5
Paraguay	1,530	0.23	0.31	6.18	9.28	122.4	1.9
Argentina	3,840	0.23	0.31	6.18	9.28	307.2	4.8
Uruguay	429	0.23	0.31	6.18	9.28	34.3	0.5

Sources: Insecticide use changes based on Monsanto pre-commercial trials in 2011 and 2013 plus post production farm surveys (unpublished post market monitoring: Monsanto) and Kleffmann insecticide use data
Note:

1. The area on which insecticide use changes are calculated in each country is constrained to the lower of the area planted to Intacta soybeans or the maximum area traditional treated with insecticides for control of the pests that Intacta soybeans provides control. For Brazil and Paraguay, the maximum area treated is assumed to be 30% of the total crop and in Argentina and Paraguay, it is 40% of the total crop
2. The insecticide savings relate only to savings associated with treatments that targeted the pests that the Intacta technology controls and do not relate to total insecticide use. This is deliberate because total insecticide use includes use of insecticides applied for control of pests that the Intacta technology does not target. Use of insecticides for this purpose will vary on a yearly basis according to pest pressures. The baseline assumptions for what insecticides are used for control of pests now controlled by Intacta technology, their typical usage levels and frequency of application are based on Kleffmann data from the immediate years before Intacta was commercially available and field-based experience of Monsanto in-country staff

Estimated typical herbicide regimes for GM HT reduced/no till and conventional reduced/no till soybean production systems that will provide an equal level of weed control to the GM HT system in Argentina 2016

	Active ingredient (kg/ha)	Field EIQ/ha value
GM HT soybean	3.59	54.53
Source: Kleffmann dataset on pesticide use 2015/16		
Conventional soybean		
Option 1		
Glyphosate	2.27	34.80
Metsulfuron	0.03	0.50
2 4 D	0.4	8.28
Imazethapyr	0.10	1.96
Diflufenican	0.03	0.29
Clethodim	0.19	3.23
Total	**3.02**	**49.06**
Option 2		
Glyphosate	2.27	34.80
Dicamba	0.12	3.04
Acetochlor	1.35	26.87
Haloxifop	0.18	4.00
Sulfentrazone	0.19	2.23
Total	**4.11**	**70.92**
Option 3		
Glyphosate	2.27	34.80
Atrazine	1.07	24.50
Bentazon	0.60	11.22
2 4 D ester	0.4	6.12
Imazaquin	0.024	0.37
Total	**4.36**	**77.01**
Option 4		
Glyphosate	2.27	34.80
2 4 D amine	0.4	8.28
Flumetsulam	0.06	0.94
Fomesafen	0.25	6.13
Chlorimuron	0.05	0.96
Fluazifop	0.12	3.44
Total	**3.15**	**54.54**
Option 5		
Glyphosate	2.27	34.80
Metsulfuron	0.03	0.50
2 4 D amine	0.8	16.56
Imazethapyr	0.1	1.96
Haloxifop	0.18	4.00
Total	**3.38**	**57.82**
Option 6		
Glyphosate	2.27	34.80
Metsulfuron	0.03	0.50
2 4 D amine	0.8	16.56
Imazethapyr	0.1	1.96
Clethodim	0.24	4.08
Total	**3.44**	**57.90**
Average all six conventional options	**3.58**	**61.21**

Sources: AAPRESID, Kleffmann AMIS Global, Monsanto Argentina

Estimated typical herbicide regimes for GM HT reduced/no till and conventional reduced/ no till soybean production systems that will provide an equal level of weed control to the GM HT system in Brazil 2016

	Active ingredient (kg/ha)	Field EIQ/ha value
GM HT soybean	3.10	48.95
Source: Kleffmann dataset on pesticide use 2015/16		
Relatively high weed problem		
Mato Gross South: regime 1		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Clomozone	0.93	18.26
Diclosulam	0.03	0.29
Imazethapyr	0.3	5.88
Lactofen	0.07	2.90
Clethodim	0.2	3.40
Total	3.94	70.45
Mato Gross South: regime 2		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Sulfentrazone	0.36	4.22
Diclosulam	0.03	0.29
Cloransulam	0.04	0.45
Lactofen	0.07	2.90
Clethodim	0.2	3.40
Haloxyfop	0.05	1.11
Total	*3.16*	*52.10*
Mato Gross South: regime 3		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Imazethapyr	0.3	5.88
Diclosulam	0.03	0.29
Cloransulam	0.04	0.45
Fomesafen	0.2	4.95
Clethodim	0.2	3.40
Haloxyfop	0.05	1.11
Total	*3.23*	*55.81*
Mato Gross North		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Chlorimuron	0.04	0.77
Lactofen	0.07	2.90
Clethodim	0.2	3.40
Total	*2.72*	*46.79*
Piaui		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Clomozone	0.93	18.26
Diclosulam	0.03	0.29
Imazethapyr	0.3	5.88
Lactofen	0.07	2.90
Haloxyfop	0.05	1.11
Total	*3.79*	*68.16*
Average (mean) all	**3.37**	**58.66**
Relatively low weed problem		
Mato Gross South: regime 1		

(*Continued*)

(Continued)

	Active ingredient (kg/ha)	Field EIQ/ha value
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Imazethapyr	0.3	5.88
Lactofen	0.07	2.90
Clethodim	0.2	3.40
Total	2.98	51.90
Mato Gross South: regime 2		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Cloransulam	0.04	0.45
Lactofen	0.07	2.90
Clethodim	0.2	3.40
Haloxyfop	0.05	1.11
Total	*2.77*	*47.59*
Mato Gross South: regime 3		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Diclosulam	0.03	0.29
Cloransulam	0.04	0.45
Fomesafen	0.2	4.95
Clethodim	0.2	3.40
Haloxyfop	0.05	1.11
Total	*2.93*	*49.98*
Mato Gross North		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Chlorimuron	0.04	0.77
Lactofen	0.07	2.90
Clethodim	0.2	3.40
Total	*2.72*	*46.79*
Piaui		
Glyphosate	1.89	28.97
2 4 D	0.52	10.75
Imazethapyr	0.3	5.88
Lactofen	0.07	2.90
Haloxyfop	0.05	1.11
Total	*2.83*	*49.35*
Average (mean) all	**2.85**	**48.80**
Weighted average: all regions and weed levels	**3.16**	**54.72**

1. Sources: Kleffmann AMIS Global, Monsanto Brazil
2. Note: Weighting: relatively high weed levels 60%: relatively low weed problems 40%

Reduction in fuel use from less frequent insecticide applications and a reduction in the energy use in soil cultivation

For insecticide applications, the quantity of energy required to apply the insecticide is based on use of a 50-foot boom sprayer which consumes approximately 0.84 litres/ha (Lazarus 2015).[5] In terms of carbon emissions, each litre of tractor diesel consumed contributes an estimated 2.67 kg of carbon dioxide into the atmosphere (so 1 less application reduces carbon dioxide emissions by 2.24 kg/ha).

In relation to tillage, it is assumed that the adoption of NT farming systems in soybean production reduces cultivation and seedbed preparation fuel usage by 27.12 litres/ha compared with traditional conventional tillage (CT). These are conservative estimates and are in line with the USDA Fuel Estimator (2013)[6] for soybeans. The adoption of an NT system in respect of fuel use therefore results in reductions of carbon dioxide emissions of 72.41 kg/CO_2/ha for soybeans. It is acknowledged that these assumptions are drawn from US-based research. However, these assumptions are probably conservative when compared to the findings from the limited research available from South America. For example, the Brazilian Federation of 'direct planting' (FEBRAPDP) and the Brazilian Agricultural Research Corporation (Embrapa) estimated that the conversion from CT to NT results in fuel savings of between 60%-70% (Plataforma Plantio Direto (2006)).[7] This compares with the 55% reduction in the US referred to above (21.89 litres/ha for NT and 49.01 litres/ha for CT).

Soil carbon storage/sequestration

It is assumed that soil carbon retention/storage is 175 kg carbon/ha/year for NT/RT soybean cropping compared to conventional (ploughing: CT) systems, which release 25 kg carbon/ha/year (a difference of 200 kg carbon/ha/year). carbon/ha/year.

As above, these assumptions draw on a variety of research, mostly in the US (see Brookes and Barfoot 2017b.[3]) Specific research into soil carbon sequestration in South America is limited:

- Fabrizzi *et al* (2003)[8] confirmed that a higher level of total organic carbon was retained in the soil with NT system compared with a CT system in Argentina, but no quantification was provided;
- Alvarez et al (2014)[9] reported on a 15-year experiment in the semi-arid Argentine Pampa to evaluate a combination of three tillage systems (no tillage (NT), no tillage with cover crop in winter and reduced tillage (RT)) and two crop sequences (soybean–maize and soybean monoculture). This identified that total organic carbon stock, up to a depth of 100 cm was 8% higher for NT and NT with cover crop than RT. Soybean–maize had 3% more organic carbon up to 100 cm depth than the soybean monoculture. Up to 100 cm depth, the NT treatments accumulated 333 kg total organic carbon (TOC)/ha/year more than RT, while the soybean-maize sequence accumulated only 133 kg TOC/ha/year more than soybean monoculture. At 0–30 cm depth, the NT treatments had 267 kg TOC/ha/year more than the RT treatment;
- Bayer *et al* (2006)[10] estimated the mean rate of carbon sequestration in NT Brazilian tropical soils to be 350 kg carbon ha/year, similar to the 340 kg carbon/ha/year reported for soils from temperate regions, but lower than the 480 kg/ha/year estimated for southern Brazilian subtropical soils. Amado & Bayer (2008)[11] estimated an average carbon sequestration rate of 170 kg carbon/ha/year (0.0 – 440 kg carbon/ha/year) for NT soils in the south (sub-tropical) and middle-west (tropical) regions of Brazil. The highest level of carbon sequestration (360 to 420 kg carbon/ha/year) occurs in intensive cropping systems because of relatively high crop residue levels in the maize/soybean rotation or where winter and summer cover crops are used.
- We are not aware of any country-specific studies into NT/RT systems in Paraguay and Uruguay. However, analysts consulted in each country have confirmed that the availability of GM HT technology in soybeans has been an important driver behind the use of NT/RT production systems. We have applied carbon change assumptions in these countries based on findings from Argentina because this represents the only available data from a neighbouring country. We acknowledge this represents a weakness to the analysis and the findings should be treated with caution.