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Biotech crops: the real impacts 1996-2006 - yields

Summary

Biotech crops, through two main traits of insect resistance and herbicide tolerance[1] have, since 1996, added important volumes to global production of corn, cotton, canola and soybeans (Figure 1).

Since 1996, biotech traits have added 53.3 million tonnes and 47.1 million tonnes respectively to global production of soybeans and corn. The technology has also contributed an extra 4.9 million tonnes of cotton lint and 3.2 million tonnes of canola.

In terms of contribution to feeding the world's population, the additional production arising from biotech crops (1996-2006) has contributed enough energy (in kcal terms) to feed 467 million people for one year (equal to 40% of the energy requirement of India's population[2]). The contribution of additional protein and fat was enough to meet the requirements of 1.3 billion and 449 million people respectively. As a significant proportion of these crops and their derivatives are used for industrial or animal feed purposes, the more likely contribution[3] of the additional production arising from biotech crops to meeting global food requirements, since 1996, has been to provide sufficient energy to meet the requirements of about 310 million people for a year (similar to the annual requirement of the combined populations of Indonesia and Vietnam). The more likely contribution of additional protein and fat has been enough to meet the requirements of 920 million and 390 million people respectively.

In 2006, biotech crops are likely to have contributed enough energy, protein and fat[4] to meet the requirements of about 67 million (similar to the population of Thailand), 207 million and 124 million people respectively.

Production of soybeans, corn, cotton and canola on the areas planted to biotech crops, in 2006, were respectively +20%, +7%, +15% and +3% higher than levels would have otherwise been if GM technology had not been used by farmers.

If biotech traits had not been available to the (10 million plus) farmers using the technology in 2006, maintaining global production levels at the 2006 levels would have required additional plantings of 4.6 million ha of soybeans, 2 million ha of corn, 1.8 million ha of cotton and 0.15 million ha of canola.

Farmers using biotech traits have increased their incomes by a total of $33.8 billion (1996-2006). About half of this has been to farmers in developing countries. This has added to farm household incomes which, when spent on goods and services, have had a positive multiplying effect on local, regional and national economies. In developing countries, the additional income derived from biotech crops (of which insect resistant (IR) cotton has delivered the highest levels of income benefit per hectare in countries such as India and China) has enabled more farmers to consistently meet their food subsistence needs and to improve the standards of living of their households. For example, household income levels have typically increased by over a third for many farmers using IR cotton in India and for farmers using IR corn in the Philippines).

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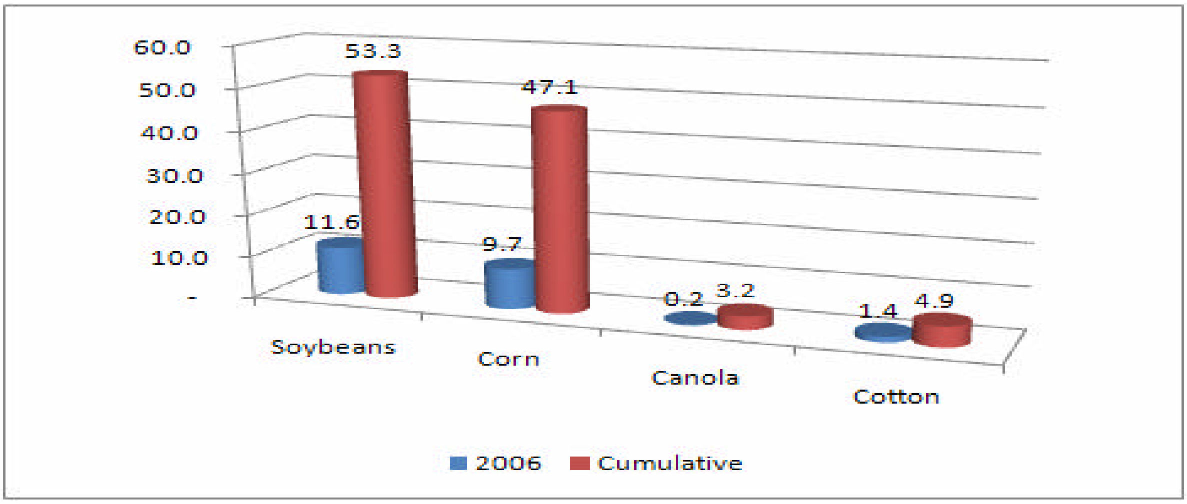
[1] Insect resistance in corn and cotton and herbicide tolerance in corn, cotton, canola and soybeans
[2] Based on recommended daily allowances – see appendix for additional details
[3] See appendix for assumptions
[4] After taking account of non food and feed use

The technology has also resulted in important environmental benefits. Pesticide use on the four crops in the countries where biotech crops have been planted have fallen by 286 million kg (-7.9%), resulting in a larger, 15.4% reduction in the associated environmental impact[5]. Greenhouse gas emission reductions have also been facilitated, equal to 14.76 billion kg of carbon dioxide in 2006, equivalent to removing 6.56 million cars from the roads for a year.

The biotech trait share of global plantings of these four crops (1996-2006) has been 41%, 8%, 17% and 11% respectively for soybeans, corn, cotton and canola. This highlights the considerable scope for wider adoption of these traits. Given the rapid rate of annual growth in adoption, this suggests that the technology will deliver more significant future contributions to global production security in the next few years.

Figure 1: Additional crop production arising from positive yield effects of biotech traits 1996-2006 (million tonnes)



<u>Note to readers – the evidence presented derives from peer reviewed scientific journal articles and is representative of real impacts at the commercial and subsistence farm level</u>. For further information see Appendix & Brookes G & Barfoot P (2008) Global impact of biotech crops 1996-2006: socio-economic and environmental impacts, Agbioforum 11 (1), 21-38 – <u>www.agbioforum.org</u>

Insect resistant (IR) corn

Two biotech insect resistant traits have been commercially used targeting the common corn boring pests (*Ostrinia nubilalis* (European corn borer or ECB) and *Sesamia nonagroides* (Mediteranean stem borer or MSB) and Corn Rootworm pests – *Diabrotica).* These are major pests of corn crops in many parts of the world and significantly reduce yield and crop quality, unless crop protection practices are employed.

The two biotech IR corn traits have delivered positive yield impacts in all user countries when compared to average yields derived from crops using conventional technology (mostly application of insecticides and seed treatments) for control of corn boring and rootworm pests.

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[5] As measured by the indicator, the environmental impact quotient (EIQ) – see Brookes & Barfoot (2008) for further details

The positive yield impact varies from an average of about +5% in North America to +24% in the Philippines (Figure 2). In terms of additional production, on an area basis, this is in a range of +0.31 tonnes/ha to +0.72 tonnes/ha.

Average positive yield and production impact across the total area planted to biotech IR corn traits over the eleven year period has been + 5.7% (+0.45 tonnes/ha). This has added 47 million tonnes to total corn production in the countries using the technology.

In 2006, the technology delivered an average of 0.47 tonnes/ha in extra production which was equal to an extra 9.7 million tonnes of corn production (Table 1).

Figure 2: Corn: yield and production impact of biotechnology 1996-2006 by country

Table 1: Corn: yield and production impact of biotechnology 1996-2006

	Cumulative total corn area (ha)[6]	Cumulative trait area (ha)	% of crop to trait[7]	Average trait impact on yield %[8]	Average yield impact (tonnes/ha)	Additional production from trait (tonnes)

[6] For consistency purposes, the total areas presented refer only to the years in which the IR traits were used by farmers - from 1996 in the US and Canada, from 1998 in Spain and Argentina, from 2000 in South Africa, from 2003 in the Philippines and from 2004 in Uruguay. Corn Rootworm resistant corn has also been available to US farmers from 2003 and to Canadian farmers from 2004

[7] From year of first commercial planting to 2006

[8] Average of impact over years of use, as estimated by Brookes & Barfoot (2008) drawing on references cited in the Appendix

US Corn borer resistant	351,842,503	81,016,473	23%	+5.0%	+0.45	36,078,447
US Corn Rootworm resistant	As above	6,596,520	1.9%	+5.0%	+0.45	3,130,130
Canada Corn borer resistant	13,269,070	4,239,214	31.9%	+5.0%	+0.38	1,628,075
Canada Corn Rootworm resistant	As above	35,317	0.3%	+5.0%	+0.38	14,537
Argentina corn borer resistant	23,951,406	10,024,000	41.9%	+7.6%	+0.49	4,862,787
Philippines corn borer resistant	10,082,808	247,698	2.5%	+24.1%	+0.52	127,920
S Africa Corn borer resistant	21,909,720	2,392,000	10.9%	+14.5%	+0.43	1,034,735
Uruguay Corn borer resistant	184,000	100,000	54.3%	+6.1%	+0.31	30,559
Spain Corn borer resistant	4,013,343	303,656	7.6%	+7.6%	+0.72	218,132
Cumulative totals	**425,252,850**	**104,954,778**	**24.7**	**+5.7%**	**+0.45**	**47,125,322**
2006	**41,751,216**	**20,640,503**	**49%**	**+6.7%**	**+0.47**	**9,734,898**

IR corn traits have contributed an extra $3.63 billion worth of farm income for those farmers using the technology over the 1996-2006 period. Almost all of this derived from yield gains.

As well as these quantifiable direct impacts on yield, production and profitability, there have been other important, indirect impacts, notably reduced production risk, convenience, reduced exposure of farmers and farm workers to insecticides and improved crop quality. These less tangible benefits have often been cited by IR corn adopting farmers as having been important influences for adoption of the technology.

The adoption of IR corn technology has also resulted in a 5% reduction (-8.2 million kg of insecticide active ingredient) in the total amount of insecticide applied to (all) corn crops in the biotech IR adopting countries during 1996-2006.

Insect resistant (IR) cotton

Insect resistant traits have been commercially used targeting various *Heliothis* pests (eg, budworm and bollworm). These are major pests of cotton crops in all cotton growing regions of the world and can devastate crops, causing substantial reductions in yield, unless crop protection practices are employed.

The biotech IR cotton traits used have delivered positive yield impacts in all user countries (except Australia[9]) when compared to average yields derived from crops using conventional technology (mainly the intensive use of insecticides) for control of *heliothis* pests.

The positive yield impact varies from an average of about +6% in South America to +54% in India (Figure 3). In terms of additional production, on an area basis, this is in a range of +0.05 tonnes/ha to +0.17 tonnes/ha (of cotton lint).

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[9] This reflects the levels of *Heliothis* pest control previously obtained with intensive insecticide use. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings (on insecticides) and the associated environmental gains from reduced insecticide use

The average positive yield and production impact across the area planted to insect resistant cotton over the eleven year period has been + 11% (+0.1 tonnes/ha). This has added 4.9 million tonnes to total cotton lint production in the countries using the technology.

In 2006, the technology delivered an average of 0.12 tonnes/ha in extra production which was equal to an extra 1.37 million tonnes of cotton lint production (Table 2).

Figure 3: Cotton: yield and production impact of biotechnology 1996-2006 by country

Table 2: cotton: yield and production impact of biotechnology 1996-2006

	Cumulative total cotton area (ha)[10]	Cumulative trait area (ha)	% of crop to trait[11]	Average trait impact on yield %[12]	Average yield impact (tonnes/ha)	Additional production from trait (tonnes)
US	63,237,303	21,887,554	35%	+9.7%	+0.08	17,044,194
China	46,756,000	19,737,000	42%	+9.9%	+0.11	21,032,470
South Africa	529,595	126,730	24%	+24.1%	+0.10	54,373
Australia	3,860,391	1,353,004	35%	0%	Not applicable	Not applicable

[10] For consistency purposes, the total areas presented refer only to the years in which the insect resistant traits were used by farmers - from 1996 in the US and Australia, from 1997 in China, from 1998 in South Africa and Argentina, from 2002 in India and Columbia and from 2006 in Brazil

[11] From year of first commercial planting to 2006

[12] Average of impact over years of use, as estimated by Brookes & Barfoot (2008) drawing on references cited in the Appendix

Mexico	1,562,842	362,344	23%	+10.4%	+0.11	39,585
Argentina	3,093,000	805,100	26%	+27%	+0.10	82,483
India	42,095,000	5,744,500	14%	+54.1%	+0.17	994,206
Columbia	228,923	62,817	27%	+6.7%	+0.05	2,920
Brazil	1,000,000	134,000	13%	+6.2%	+0.08	11,187
Cumulative totals	**162,363,054**	**50,213,049**	**31%**	**+11.1%**	**+0.1**	**4,887,263**
2006	**22,726,880**	**11,584,810**	**51%**	**+15%**	**+0.12**	**1,371,525**

Since 1996, IR cotton traits have contributed an extra $9.6 billion worth of income to farmers using the technology. Within this, 58% has derived from yield gains (less pest damage) and the balance (42%) from reduced expenditure on crop protection (spraying of insecticides).

As well as these quantifiable direct impacts on yield, production and profitability, there have been other important, indirect impacts, notably reduced production risk, convenience and reduced exposure of farmers and farm workers to insecticides. These less tangible benefits have often been cited by biotech IR cotton adopting farmers as having been important influences for adoption of the technology.

The adoption of IR cotton technology has also resulted in a 23% reduction (-128.4 million kg of insecticide active ingredient) in the total amount of insecticide applied to (all) cotton crops in the biotech IR cotton adopting countries during 1996-2006.

Herbicide tolerant soybeans

Weeds have traditionally been a significant problem for soybean farmers, causing important yield losses (from weed competition for light, nutrients and water). Most weeds in soybean crops have been reasonably controlled, based on application of a mix of herbicides.

Although the primary impact of biotech herbicide tolerant (HT) technology has been to *provide more cost effective* (less expensive) and *easier* weed control versus improving yields from *better* weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless occurred - delivering higher yields. Specifically, HT soybeans in Romania improved the average yield by over 30 per cent (Figure 4).

Biotech HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 53.1 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2006. In 2006, the second crop soybean production in these countries was 11.6 million tonnes (Table 3).

Table 3: Second crop soybean production facilitated by biotech HT technology in South America 1996-2006 (million tonnes)

Country	Year first commercial use of HT soybean technology	Second crop soybean production from date of first commercial use to 2006
Argentina	1996	50.9
Paraguay	1999	2.2
Total		**53.1**

Cumulatively since 1996, the farm income benefit from using biotech HT soybeans has been $17.45 billion. This benefit mostly derives from cost savings, although 20% ($3.5 billion) was due to yield gains and ‘2nd crop soybeans’.

HT soybean adoption has also delivered important environmental benefits from reduced herbicide use and made a significant contribution to reducing carbon emissions. For further details, see Brookes G & Barfoot P (2008) Global impact of biotech crops 1996-2006: socio-economic and environmental impacts, Agbioforum 11 (1), 21-38

As well as these quantifiable direct impacts on farm profitability, there have been other important, indirect impacts from the HT technology, especially the facilitation of adoption of reduced/no tillage systems and greater flexibility/convenience. These less tangible benefits have often been cited by HT soybean adopting farmers as having been important influences for adoption of the technology.

Herbicide tolerant canola

Weeds represent a significant problem for canola growers contributing to reduced yield and impairing quality by contamination (eg, with wild mustard seeds). Conventional canola weed control is based on a mix of herbicides which has provided reasonable levels of control although some resistant weeds have developed (eg, to the herbicide trifluralin). Canola is also sensitive to herbicide carryover from (herbicide) treatments in preceding crops which can affect yield.

The main impact of biotech HT canola technology, used widely by canola farmers in Canada and the US, has been to provide more cost effective (less expensive) and easier weed control, coupled with higher yields. The higher yields have arisen mainly from more effective levels of weed control than was previously possible using conventional technology. Some farmers have also obtained yield gains from biotech derived improvements in the yield potential of some HT canola seed.

The average yield gains have been about +6% (+0.1 tonnes/ha) in the US and about +10% (+0.15 tonnes/ha) in Canada (Figure 4).

Over the 1996-2006 period, the additional North American canola production arising from the use of biotech HT technology was +3.2 million tonnes (Figure 4).

Since 1996, the farm income benefit from using biotech HT technology in canola has been $1.1 billion. Within this, about 70% has been due to yield gains and the balance (30%) has been from cost savings.

As with other HT crops, the indirect benefits of greater convenience/flexibility and facilitation of no/reduced tillage production systems have been important factors influence adoption.

Biotech HT canola adoption has also delivered important environmental benefits from reduced herbicide use and made a contribution to reducing carbon emissions (see Brookes G & Barfoot P (2008)).

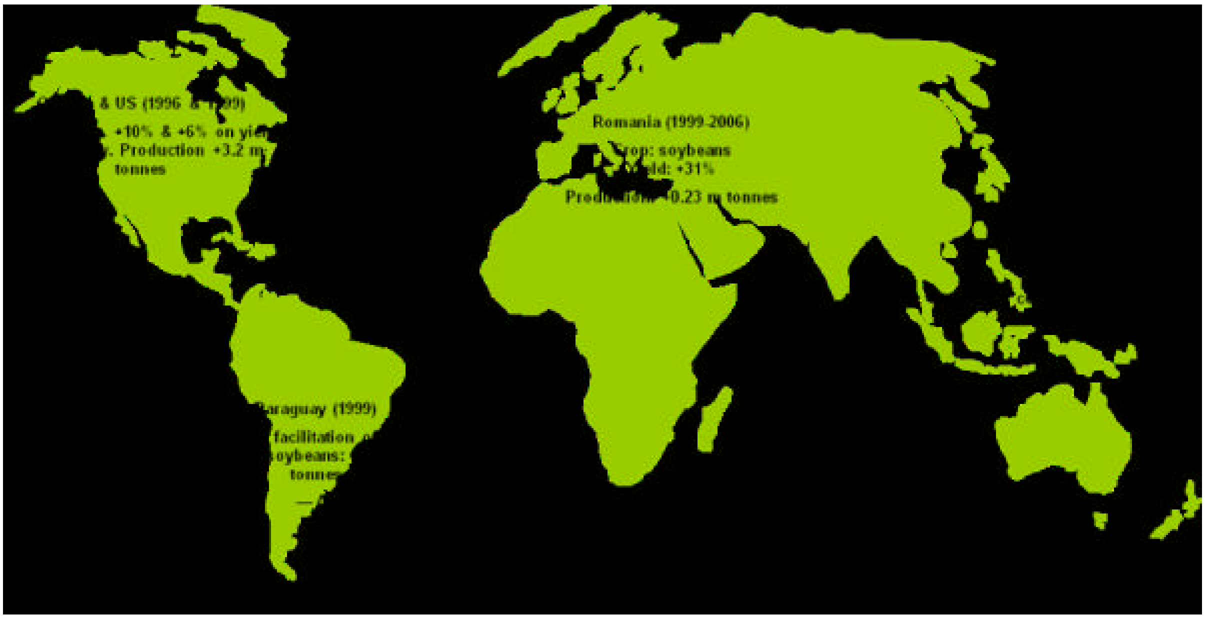
Herbicide tolerant corn & cotton

Weeds have also been a significant problem for corn and cotton farmers, causing important yield losses. Most weeds in these crops have been reasonably controlled based on application of a mix of herbicides.

The HT technology used in these crops has mainly provided more cost effective (less expensive) and easier weed control rather than improving yields from better weed control (relative to weed control levels obtained from conventional technology).

Improved weed control from use of the HT technology has, nevertheless, delivered higher yields in some regions and crops (Figure 4). For example, in Argentina, where HT corn was first used commercially in 2005, the average yield effect has been +9%, adding +0.36 tonnes/ha to production. Similarly in the Philippines, (first used commercially in 2006), early adopters are finding an average of +15% to yields (+0.72 tonnes/ha).

Figure 4: Herbicide tolerant crops: yield and production impact of biotechnology 1996-2006 by country



Since 1997, the farm income benefit derived by farmers using HT technology in corn has been $1.11 billion. Of this, 98% has been due to cost savings and 2% to yield gains.

The total farm income benefit derived from using biotech HT cotton over the same period has been $814 million. Of this, 97% has been due to cost savings and 3% to yield gains.

As with other HT crops, the indirect benefits of greater convenience/flexibility and facilitation of no/reduced tillage production systems have been important factors influence adoption.

HT corn and cotton use has also delivered important environmental benefits from reduced herbicide use and made a contribution to reducing carbon emissions (see Brookes G & Barfoot P (2008)).

Appendix

Data sources

The analysis presented is drawn from Brookes G & Barfoot P (2008) Global impact of biotech crops 1996-2006: socio-economic and environmental impacts, Agbioforum 11 (1), 21-38 – www.agbioforum.org. This paper updates the findings of earlier analysis presented by the authors in AgbioForum 8 (2&3) 187-196 and AgBioforum 9 (3) 1-13.

Specific sources of data used in these references (as related to yield impacts) are detailed below;

HT soybeans	**Sources of data for yield impacts**
Romania	Brookes (2005)
HT maize	
Argentina	No studies identified - based on Monsanto Argentina & Grupo CEO (personal communications 2007)
Philippines	No studies identified - based on Monsanto Philippines (personal communications 2007)
HT canola	
US	Sankala & Blumenthal (2003 & 2006))
Canada	Canola Council (2001)
IR maize	
US	Carpenter & Gianessi (2002) Gianessi & Carpenter (1999) Sankala & Blumenthal (2003 & 2006) Marra et al (2002)
Canada	No studies identified – as US - impacts qualitatively confirmed by industry sources (personal communications 2005 & 2007)
Argentina	Trigo E (2002) James (2003) Trigo personal communication (2007)
Philippines	Gonzales (2005) Yorobe (2004) Ramon (2005)
Spain	Brookes (2003 & 2007)
South Africa	Gouse et al (2005) Gouse et al (2006 a &b)
Uruguay	No studies identified -as Argentina
IR cotton	
US	Sankala & Blumenthal (2003) & (2006) Marra et al (2002) Mullins & Hudson (2004)
China	Pray et al (2002) Monsanto China personal communication (2007)
Australia	Fitt (2001) Doyle (2005) James (2002) CSIRO (2005)
Argentina	Qaim & De Janvry (2002 & 2005)
S Africa	Ismael et al (2002) James (2002) Kirsten et al (2002)
Mexico	Traxler et al (2001) Monsanto Mexico (2004 & 2007)

India	Bennett et al (2004) APCOAB (2006) IMRB (2007)
Brazil	Unpublished (to be published in 2008) farm survey – source: Monsanto (2008)
Others	
US & Canada: IR corn rootworm maize	Sankala & Blumenthal (2003 & 2006) Rice (2004)

Food security assumptions and calculations

Human food requirements per day (recommended daily allowances)

	Male	Female	Average
Energy (kcal)	2,900	2,200	2,550
Protein (grams)	63	50	56.5
Fat (grams)	100	78	89

Crop key nutrition composition (per kg of edible material)

	Energy (kcal)	Protein (grams)	Fat (grams)
Corn	3,650	94	47
Canola oil	8,840	0	1,000
Canola meal	3,540	380	38
Soybean oil	8,840	0	1,000
Soybean meal	3,370	485	10
Cottonseed oil	8,840	0	1,000
Cottonseed meal	3,450	410	21

Source: USDA - Nutritional database for standard reference www.ars.usda.gov

Main constituents of oilseeds (source: Soya & Oilseed Bluebook)

- Soybeans: 79.2% meal, 17.8% oil, 3% waste
- Canola: 59% meal, 38% oil, 3% waste
- Cottonseed: 44.9% meal, 16.2% oil, 8.2% lintners, 26.7% hulls, 4.1% waste

Assumption on corn utilization – 99% usable

Assumptions for uses of crops

	Food	Feed	Industrial (non food)
Corn	30%	50%	20%
Soy oil	98%	0%	2%
Soy meal	0%	100%	0%
Canola oil	60%	0%	40%
Canola meal	0%	100%	0%
Cotton seed oil	50%	0%	50%
Cotton seed meal	0%	50%	50%

Source: derived from USDA ERS Feed Grains database www.ers.usda.gov

Use of corn and oilseeds in meat production assumptions

The following simplifying assumptions were used:

- As most corn and oilseeds are used in pig and poultry rations, all usage is assumed to be in these two sectors;

- ? Corn: 2.6 kg corn produces 1 kg of poultry meat at the consumer level, 6.5 kg of corn produces 1 kg of pig meat at the consumer level (source: USDA ERS – www.ers.usda/amberwaves/february2008). Readers should note these are conservative estimates;
- ? Feed conversion ratios of 1.8 kg feed produces 1 kg of chicken (live weight) and 3 kg of feed produces 1kg of pig (live weight) – typical feed conversion rates in developed countries for poultry are 1.7/1.75:1 and for pig meat are 2.5/2.8:1, hence the conversion rates used are conservative;
- ? Conversion of live weight to meat eaten by a consumer – for poultry assumes 50% of live weight converted to meat and for pig meat assumes 35% conversion;
- ? corn constitutes 70% of a typical poultry feed ration and 75% of a typical pig ration;
- ? meals (from soy, canola and cottonseed) are assumed to supply the main part of the protein requirement in the feed ration with incorporation rates of 25% in poultry feed and 20% in pig feed;
- ? Based on the above assumptions, it takes 0.93 kg of meal to produce 1 kg of poultry meat (at the consumer level) and 1.73 kg of meal to produce 1kg of pig meat (at the consumer level).

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