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CEE review 11-002

What have been the farm-level economic impacts of the global cultivation of GM crops?

Systematic Review

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Final Review published on website: 19 February 2013

Cite as: Hall, C., Knight, B., Ringrose, S. & Knox, O. 2013. What have been the farm-level economic impacts of the global cultivation of GM crops? CEE Review 11-002. Collaboration for Environmental Evidence: www.environmentalevidence.org/SR11002.html.

Summary

Background and objective: Globally there continues to be a steady increase in the area commercially cultivated with genetically modified (GM) crops. Alongside this, many publications have reported the economic impacts of GM crop cultivation, finding large variability in farm-level economic impacts between and within countries, across years, and between different crop/trait combinations. Variability may be due to different pest pressures, social, cultural and economic contexts, and seasonal variation in conditions. Policy makers need impartial and robust appraisal of the information. This systematic review therefore aims to answer the question: "What have been the farm-level economic impacts of the global cultivation of GM crops?".

Methods: The question for this review contains the following components:

(1) A Population: economic indicators recorded at the farm level

(2) An Intervention: the cultivation of any commercial GM modification

(3) The Comparator: comparison with a conventional (non-GM) cropping system

(4) Outcome: economic impacts. Change in economic indicators at the farm level

A systematic search for relevant articles was conducted using five databases and one search engine using search statements designed to identify any study in any country measuring economic parameters at the farm level, where there was cropping of a commercial GM trait. All retrieved articles were scanned at title, then abstract and finally full text level using the criteria set out below in order to select those relevant. Following the systematic search and subsequent screening, articles were critically appraised to assess study quality using 10 questions and a three point quality scale. Next, data were extracted from the articles and entered into an Excel spreadsheet. Once cleaned, the data were exported to SPSS to facilitate meta-analysis using ANOVA to conduct comparison of means. Additional narrative synthesis of qualitative data was also conducted.

Main Results: The systematic search generated 3522 extracted titles plus 56 items from grey literature sources. From these, 22 relevant articles were identified. The information within these 22 articles was first assessed using narrative synthesis. Extracted monetary values were assigned to different categories, for example, gross profit, revenue, chemical costs, and others. The categories were examined to establish the average percentage change recorded by each.

- Gross profits were 81% and net profits 66% higher for GM crops
- Seed costs were 97% and total variable costs 23% higher for GM crops

To facilitate further analysis, two additive categories of values were derived, namely profits and costs.

- The additive category of farm level profit[i] suggests there is an average increase in profit of 75% when growing GM crops as opposed to the non-GM equivalent.
- The additive category of farm level costs[ii] suggests there is an average increase in costs of 40% when growing GM crops as opposed to the non-GM equivalent.

Conducting meta-analysis revealed that crop/trait combination, level of development of a country (as measured by the Human Development Index), and date of publication were statistically significantly related to the percentage change recorded in farm level profits and costs.

Conclusions: **Implications for policy -** One of the key findings from the review is that in every case when planting GM crops as opposed to a non-GM equivalent, there was a farm-level economic impact. This was particularly notable for certain economic variables, namely gross profit and seed costs, but less significant for other economic variables such as trading price and energy costs. The change in farm level profit was least positive in the most developed countries. **Implications for research -** Overall, it is important that research continues into conducting and reviewing farm level studies, particularly as there is some suggestion that changes in farm level profit and costs that arise as a result of growing GM crops as opposed to the non-GM equivalent, change through time.

Key words: Genetically modified crops; economic impact; farm; global cultivation.

1. Background

The commercial application of GM technology in agriculture began in the 1990s in the USA. The introduction of GM crops started with a small number of crop types, notably soya engineered to be resistant to certain types of herbicide, and oilseed rape (OSR) with similar modifications (known as Ht crops, after 'herbicide tolerant'). This has since developed into wider adoption, in a number of countries, of additional GM crops, including maize and cotton, and additional modifications including crops engineered to contain soil bacterium proteins that are toxic to certain pests (known as Bt crops, after the soil bacterium 'Bacillus thuringiensis') (Hall, 2010).

There have been many studies that have reported the economic impacts of the cultivation of GM crops globally (see for example, Qaim, 2009; Zilberman *et al*, 2010). At the farm-level, numerous claims have been made about the impacts of GM crop technology. In terms of economic impacts, the cultivation of GM crops involves potential revenue and cost impacts when compared with conventional crops. GM crops can lead to yield increases and reductions in pesticide costs but increases in seed costs (Finger *et al*, 2011). Farmers have identified positive impacts of Ht crops as being simplified management and greater flexibility because of there being a wider window available for spray applications, and less spraying, all of which have impacts in terms of costs, the environment and labour time (Oreszczyn, 2005). There is some expectation that farmers in developing countries should benefit from GM crops, and that, particularly in countries where agri-chemicals are not widely used, there should be most benefit from Bt crops, since those are the countries where pest pressures are most likely to be acute, and where pest control prior to commercialisation of GM crops is likely to be least effective (Zilberman *et al*, 2010).

However, previous reviews of studies of farm-level impacts have noted considerable variation in both the nature and scale of impact. For example, the scale of increase in gross margins from cultivating Bt and Ht crops has been found to vary enormously between countries, from $12US/ha in the USA (for maize) to $470US/ha in China (for cotton) (Qaim, 2009). Further inter-country variability has been demonstrated for GM cotton, with a 12% increase in profits recorded in Mexico, and a 340% increase in profit recorded in China (Pehu & Ragasa, 2007). Since the commercial cultivation of Bt cotton in 2002, there has been found to be a significant positive impact on the economic conditions of cotton growers in India (Chakraborty, 2010). However, farm-level benefits have not been found in all cases, and one review indicated that out of 168 results, 124 showed a yield gain for adopters of GM crops (Carpenter, 2010). Large variability from year to year (Smale *et al*, 2008) and region to region has also been noted (Carpenter, 2010). The more heterogeneous the growing environment, pest pressures, farmer practices and social context, the more variable any benefits are likely to be. Thus the extent of economic benefit associated with different crop-trait combinations is likely to vary widely, and the presentation of averages from across studies may hide the fact that not all farmers profit from the adoption of GM crops (Brookes & Barfoot, 2010). Overall, the farm-level profitability of GM crops is likely to be influenced by variables such as differences in yield, reductions in insecticide costs or weed management costs (depending on the modification present), differences in seed prices, and differences in price received by the farmer, between the GM crop and its conventional counterpart (Gomez-Barbero & Rodriguez-Cerezo, 2006).

Overall, previous studies reveal a number of key points:

- There is large variability in economic impact recorded following the adoption of GM crops.
- This variability has been recorded between countries, across different years and between regions within the same country.
- While some authors continue to claim that the adoption of GM crops provides economic benefits for farmers, particularly in developing countries, the evidence is not consistent across studies.

Generally, studies have found that certain categories of costs are lower following adoption of GM crops (notably chemical costs) while others are consistently higher (specifically, seed costs). Where yields are also higher these sometimes are sufficient to counter the higher seed costs; in other cases this is not so.

The body of literature that has built up, the breadth and diversity of studies, and the opposing reports that are found in the literature relating to the potential economic impacts of cultivating GM crops, point to the need to synthesise and assess similar studies to provide a clear understanding of the evidence that exists. This is where the use of systematic review (SR) has value. SRs are different to traditional literature reviews in that the process of review is transparent, rigorous and replicable. It is considered a preferable option, particularly when there is a large body of evidence, and seeks to avoid the subjective selection by reviewers of certain research findings that are considered to be of most relevance or interest. The SR process thus achieves the removal of reviewer personal views, provides a comprehensive summary of the relevant literature, and, through the use of meta-analysis, can provide improved statistical interpretation of the findings and reasons for variation in the existing data and results.

2. Objectives

2.1 Primary objective

This review aims to provide information about changes to aspects of farm-level finances from the commercial cultivation of GM crops, across the world, as reported in studies published from 2006 onwards. Thus, a systematic review (SR) has been conducted to answer the following question:

- What have been the farm-level economic impacts of the global cultivation of GM crops?

Execution of a SR requires that a specific question be posed containing four key elements. The question for this review contains the following components:

(1) A Population: economic indicators recorded at the farm level
(2) An Intervention: the cultivation of any commercial GM modification
(3) The Comparator: comparison with a conventional (non-GM) cropping system
(4) Outcome: economic impacts. Change in economic indicators at the farm level

3. Methods

3.1 Question formulation

The purpose of the review reported here was to address a UK Department of Environment, Food and Rural Affairs (Defra) tender for an 'Independent systematic review of the published material on the economic and environmental impacts of GM crops'. The initial question was thus provided by Defra. SAC (now SRUC) responded to the tender and proposed to tackle this as two reviews; one focused on the economics and another on the environment. The questions were subsequently refined and additional restrictions agreed. These included limiting studies to those published from 2006 onwards, and focusing on work relating to farm-level impacts.

3.2 Search strategy

3.2.1 Search terms

The following search terms were deemed to be relevant to this study:

- Genetically modified (and variations such as genetic modification) (with or without hyphen)
- Genetically engineered (and variations such as genetic engineering) (with or without hyphen)
- GM
- Transgenic (and variations such as transgenically)
- Herbicide tolerant (and variations such as herbicide tolerance) (with or without hyphen)
- Insect resistant (and variations such as insect resistance) (with or without hyphen)
- BT
- Biotech (and variations such as biotechnology)
- Economic (and variations such as economically)
- Income (and variations such as incomes)
- Margin (and variations such as margins)
- Price (and variations such as prices)
- Cost (and variations such as costs)
- Financial (and variations such as finances)
- Revenue (and variations such as revenues)
- Profit (and variations such as profitable)
- Fee (and variations such as fees)
- Labour

Thus, the following search string was constructed.

((GENETIC*$MODIF*OR ENGINEER*) OR GM OR TRANSGEN* OR HERBICIDE$TOLERAN* OR INSECT$RESISTAN* OR BT OR BIOTECH*) AND (ECONOM* OR INCOME* OR MARGIN* OR PRICE* OR COST* OR FINANC* OR REVENUE* OR PROFIT* OR FEE* OR LABOUR)[iii]

3.2.2 Databases

The following sources were searched. These were selected to cover the peer-reviewed, published scientific literature across disciplines, including the relevant disciplines of economics, agriculture, social sciences and biotechnology. The list provided below ensured that the study covered a diverse range of potentially relevant literature.

- Web of Knowledge - The Web of Knowledge Service for UK Education provides a single route to all the Thomson Reuters products.

- ScienceDirect - ScienceDirect is a full-text, scientific database offering journal articles and book chapters from more than 2,500 peer-reviewed journals and more than 11,000 books. ScienceDirect is a part of Elsevier.

- CAB Direct - CAB Direct is an extensive source of reference in the applied life sciences, incorporating the leading bibliographic databases CAB Abstracts and Global Health.

- EconLit - The American Economic Association's electronic bibliography, EconLit, indexes more than forty years of economics literature from around the world. EconLit is a comprehensive index of journal articles, books, book reviews, collective volume articles, working papers and dissertations.

- IBSS - The International Bibliography of the Social Sciences (IBSS) is an online resource for social science and interdisciplinary research. IBSS includes over two million bibliographic references to journal articles, books, reviews and selected chapters dating back to 1951. Over 2,800 journals are regularly indexed and some 7,000 books are included each year.

3.2.3 Search engine

In addition to the databases listed above, the following search engine was utilised.

- Scirus - Scirus is a comprehensive scientific research tool on the web. With over 410 million scientific items indexed at last count, it allows researchers to search for journal content, scientists' homepages, courseware, pre-print server material, patents and institutional repository and website information.

3.2.4 Specialist sources

It was also the aim to encompass the grey literature, specialist news services relating to biotechnology, and consultancy reports. Thus the following sources were also searched.

- Agbioview Archives - The AgBioWorld Foundation is a non-profit organisation with headquarters in Alabama. AgBioWorld aims to provide science-based information on agricultural biotechnology issues to stakeholders across the world. AgBioWorld's free electronic newsletter, AgBioView, is a source of news, research updates and commentary on advances in plant science, agricultural research and sustainable food production. This online newsletter is delivered, on average, five times per month to subscribers. Each newsletter contains around 10 articles, or about 600 articles per year.

- BCPC News - This newsletter is published by the British Crop Protection Council and is delivered electronically to subscribers two to three times a month. BCPC news details electronic news items drawn from other online sources under a range of headings, including GM crops. Typically 20 GM crop news items and weblinks are listed each time, providing about 700 per year. The articles/web sites highlighted are from worldwide sources and are relatively broad in scope including publications from NGOs. Many are scientific research and regulatory reports.

3.3 Article screening

The process of screening articles was as follows. Having extracted articles using the search strategy detailed above, articles were screened for inclusion based on title. Any deemed not relevant at this stage were deleted (relevance was determined using the inclusion and exclusion criteria detailed below). The next stage was to check for relevance by reading the abstract of those selected based on the title. Again, any deemed not relevant were subsequently deleted. The third stage was to read the full text of those selected following reading of abstracts in order to establish relevance for final inclusion in the data extraction and synthesis stages.

3.4 Study inclusion criteria

When checking for relevance at each stage, the following inclusion criteria were used:

- Relevant population
    - The unit of study had to be farm level.
    - The study could have been conducted in any country.
    - The study had to have been published from January 2006 onwards[iv].
    - The study could address any GM crop and modification (trait).

- Relevant intervention
    - The study had to refer to commercial GM crop cultivation.
    - The on-farm situation prior to cultivation of the GM crop with the on-farm situation since cultivation of the GM crop, or
    - Conventional crops grown at the same time as GM crops, or

    - Differences between GM and non-GM farms.

- Relevant outcome
    - The study had to report any change in farm level economics (for example, costs/ income/ profit/ gross margins etc) since cultivation of the GM crop.

- Study design criteria
    - The study had to be ex-post.
    - Acceptable study types included farm level interviews, farm income data analysis, and farm-level economic modelling using original farm data.

3.5 Study exclusion criteria

In addition to the inclusion criteria specified above, a number of exclusion criteria were applied and studies were excluded as follows:

- Studies that looked at global economic welfare impacts.
- Studies that presented country-level economic impacts.
- Modelling studies that were not based on actual farm data.
- Studies that provided estimates of impacts.
- Studies that presented prospective or potential impacts.
- Studies that presented simulations of potential impacts.
- Studies that discussed hypothetical impacts.
- Studies that covered GM technologies in agriculture but not crops, e.g. rBST in cattle.
- Studies that investigated costs and benefits for consumers.
- Studies that were themselves reviews of previous studies and that did not present any new data.

3.6 Inter-selector reliability

At each study selection stage two researchers independently applied the inclusion and exclusion criteria detailed above to a sample of 10% of the studies. At the title reading stage and abstract reading stage, an inter-selector reliability analysis was performed using the Kappa statistic[v] to determine consistency among researchers.

Stage one: reading titles: Two members of the research group independently read through an identical sample of 10% of the titles and compared the studies they had selected using Cohen's Kappa test in SPSS (V16). The inter-selector reliability for the two selectors was found to be Kappa = 0.656 ($p < 0.001$).

Stage two: reading abstracts: Two members of the research group independently read through an identical sample of 10% of the abstracts and compared the studies they had selected using Cohen's Kappa test in SPSS (V16). The inter-selector reliability for the two selectors was found to be Kappa = 0.574 (p0.001)

Stage three: reading full publications: Two members of the research group independently read through an identical sample of 10% of the publications and compared their selection of studies. It was not possible to compute Cohen's Kappa because the results of one of the researcher's produced a constant variable (i.e. all cases received the same rating). However, there was agreement between the two selectors in 75% of cases.

Overall, these results show that the inclusion and exclusion criteria were applied in a satisfactory and appropriate way.

3.7 Searching grey literature

Agbioview newsletters were searched from the start of 2006 to June 2011. The BCPC online archive was also searched. The archives were studied methodically and any articles which included information on economics of GM crops were shortlisted, extracted and saved. The saved articles were then studied using the search protocol inclusion and exclusion criteria, and only those articles which met the criteria were taken to full text reading.

3.8 Study quality assessment

An attempt was made to judge the quality of different aspects of the publications in terms of validity and susceptibility to bias. The quality assessment instrument utilised 10 questions, as follows:

1. Did the study include results from one country or more than one country?
2. Did the study include one or more study areas (regions within country)?
3. Did study include data from one year only or more than one year?
4. Was the study area randomly selected or purposively selected?
5. Were farmers randomly selected or purposively selected?
6. Did the study survey farmers growing both GM and non-GM; farmers who were growing non-GM but who had switched to GM; or some farmers who grow GM and some who grow non-GM?
7. How many farmers were surveyed?
8. Were farmers questioned about previous years or only current year?

9. Did the study test for significance of differences between values in non-GM and GM?
10. Did the study test differences in the characteristics of adopters and non-adopters?

Studies were rated against these questions and an average quality score derived (to account for the fact that not all questions were relevant to all studies). For example, only six of the 10 questions were relevant to the study by Bangeree and Martin (2008). Questions 5, 7, 8 and 10 were not relevant thus no score could be assigned to these questions. Therefore, the total score derived after the quality assessment of this study was divided by six to provide an average score (see appendix 2 for the quality assessment results). A three point quality scale was applied such that studies could be judged to be high quality, medium quality or low quality. The three bands were as follows: Less than 1.7 = Low quality; 1.7 up to 2.4 = Medium quality; 2.4 or higher = High quality.

The best quality studies would be ones that: included results from more than one country; included one or more study areas (regions within country); had a study area (or areas) that was (were) randomly selected; had farmers that were randomly selected; included data from more than one year; surveyed farmers growing both GM and non-GM; surveyed more than 100 farmers; questioned farmers only about the current year, thus not relying on recall; tested for differences in the characteristics of adopters and non-adopters; and tested for significance of differences between values in non-GM and GM.

3.9 Data extraction strategy

At the first full text reading, the following data were extracted:

- Author(s),
- Study date,
- Country of study,
- Specific crop(s),
- Specific modification(s)/ trait(s),
- Aim of study,
- Study type (short description of approach used),
- Outcome measure (economic indicator studied): e.g. farm income, seed costs, technology fees, gross margins, farm gate prices, price of end product, etc,
- Descriptive change in economic indicator studied (positive or negative impact), and
- Numerical/percentage change in economic indicator studied (where data provided).

These data were subsequently added:

- Numbers of participants (for those studies that collected data through surveys with farmers),
- Date of data collection.

3.10 Data synthesis

Initially, data derived from the relevant studies were synthesised by tabulating the extracted data using the categories listed in the section 'Data Extraction Strategy'. This provided an overview of the reviewed studies. Following that, narrative synthesis was supported by descriptive statistics for the data extracted, first in relation to the studies, and second in relation to the individual monetary values extracted. Statistical tests (ANOVA) were used to conduct a meta-analysis and to investigate the significance of the differences revealed in impact as measured by the average percentage change in aspects of farm level finances.

4. Results

4.1 Search results

The systematic search, conducted between 16th and 20th June 2011, resulted in a total of 3522 hits, plus 56 items from the grey literature (Table 1). After applying the inclusion and exclusion criteria, and working through the subsequent stages of reading titles, abstracts and full text, the total number of relevant articles to be taken forward for review was 22 (table 2) (see also appendix one for articles excluded after full text reading).

Table 1: Number of hits per search source

Database	**Number of hits**
Web of Knowledge	377
ScienceDirect*	1000
CAB Direct	261
EconLit	582
IBSS	1202
Scirus	100
	3522
Grey literature items extracted from Agbioview and BCPC	56

* In ScienceDirect the maximum number of hits that can be downloaded is 1000. There were 1594 hits. These were sorted by the "relevance" option available in ScienceDirect prior to downloading.

Table 2: Article selection stages

Stage	Number of items
1. Titles to read after conducting searches	3522
2. Abstracts to read after reading titles	432
3. Full publications to read after reading abstracts	(77)
4. Grey literature: full text to read after excluding items not relevant	(15)
5. Full publications to read (from databases, search engine and grey literature searches)	92
6. Full publications to be included in SR (including from grey literature) after reading full text	**22**

Details of the 22 articles included in the SR are provided in Table 3. Publication dates of the articles cover five years from 2006 to 2010, with six published in years 2006 and 2009, four in both years 2007 and 2008, and just two in 2010. However, the reported data used in the synthesis of results covered all years from 1997 to 2008. Thirteen of the studies presented data from just one year but nine of them presented data from two or multiple seasons. The studies were conducted in 12 different countries across the Americas, Europe, Africa and Australasia, with the majority carried out in India (nine studies) and South Africa (six studies). The majority of the studies related to cotton (18) and the remaining four to maize.

Table 3: The included articles (ordered alphabetically)

Author(s) / date of publication	Type of public-ation	Country of study	Specific crop and modification (s)	Year(s) of data collection	Short description of study	Study approach	Number of participants*	Outcome measure(s) (economic indicator(s) studied):	Quality assessment score (and quality level – low/medium /high)
Ali & Abdulai, 2010	Journal article	Pakistan	Bt Cotton	2007	Examined the effects of adopting Bt cotton on yields, pesticide demand, and household income.	Survey with 325 farmers. A stratified random sampling technique was used to select the farmers. The sample ensured representation of adopters and non-adopters of Bt cotton.	325	Income; net returns	2.2 (M)
Bangeree & Martin, 2008	Journal article	USA	Bt Cotton	1997-2000	Compared farm level returns from various refuge requirements	Used observed and simulated farm-level yields.	X	Returns	1.33 (L)
Bennett *et al*, 2006b	Journal article	South Africa	Bt Cotton	1998/99; 1999/2000; 2000/01	Researched the economic impact of Bt cotton for smallholders	Survey of 32 smallholders. Also used field measurement and observation and 3 years of company data (1283 records from 1998/1999; 441 records from 1999/2000; 499 records from 2000/2001).	32 surveys	Total revenue; seed costs; pesticide costs; spray labour costs; weeding labour costs; harvest labour costs; total costs; gross margins	1.8 (M)
Bennett *et al*, 2006a	Journal article	India	Bt Cotton	2002; 2003	Assessed the performance of Bt cotton in India.	Questionnaire survey was carried out with 2709 farmers in 2002. A shortened version of the same survey was carried out with 787 farmers in 2003.	2709+787 (yrs 1 & 2)	Seed costs; cost of sucking pest sprays and bollworm sprays; total costs; price; revenue; gross margin	2.22 (M)
Crost *et al*, 2007	Journal article	India	Bt Cotton	2002; 2003	Investigated the yield effect of Bt cotton	Survey of 338 cotton farmers in 6 villages. Obtained farm level information on inputs, technology use and outputs.	338	Pesticide costs; seed price; cotton price	2.15 (M)
Gomez Barbero *et al*, 2008	Correspondence to Editor	Spain	Bt Maize	2005	Investigated agronomic & economic performance of Bt maize through 3 seasons (2002-2004)	Face to face survey with 184 farmers growing conventional maize and 195 farmers growing Bt maize in 3 maize growing regions in Spain in 2005.	379	Revenues; pest spray costs; seed costs; gross margins	2.2 (M)
Gouse *et al*, 2009	Journal article	South Africa	Bt & Ht Maize	2006/07	Investigated the relative efficiencies of conventional, Bt and Ht maize.	Data were collected from 249 farms in three areas in 2006/07. The survey concentrated on output, household characteristics, income, expenses, consumption, farming practices and production budgets.	249	Seed costs; chemical costs; power costs; gross margins	2.14 (M)
Gouse, 2009	Book chapter	South Africa	Bt Cotton	1998/99; 1999/2000; 2000/01; 2001/02; 2002/03; 2003/04; 2004/05; 2005/06; 2006/07; 2007/08; 2008/09	Sought to shed light on the South African Bt cotton experience and to explain the performance of the technology in the historical, political and institutional context.	Reviewed studies analysing the farm-level impact of Bt cotton.	X	Seed prices, technology fees	1.4 (L)

Hofs *et al*, 2006	Journal article	South Africa	Bt Cotton	2002/03; 2003/04	Explored insecticide use in fields cropped with conventional or Bt cotton varieties on smallholder farms.	The study was carried out in 2002/03 and 2003/04. It consisted of an on-farm survey and in-field follow up of the pest management practices. 10 farmers growing Bt cotton and 10 farmers growing non-Bt cotton were randomly sampled within a 10km radius, for 2 growing seasons.	20	Licence fee; crop protection costs; yield income; profit margin	1.56 (L)
Hugar *et al*, 2009	Journal article	India	Bt Cotton	2004/05	Assessed the economic impact of Bt cotton technology.	Farm level economic and ecological parameters were estimated from 89 Bt and 90 non-Bt farmers.	179	Seed costs; plant protection costs; labour costs; gross returns; net returns	1.7 (M)
Morse *et al*, 2007	Journal article	India	Bt Cotton	2002; 2003	Explored the issue of inequality arising from the introduction of GM crops.	Questionnaire survey was conducted in 2002 and 2003 seasons with 63 non-adopting and 94 adopting households.	157	Revenue; seed costs; insecticide costs; labour costs; gross margins.	1.9 (M)
Morse & Bennett, 2008	Article in journal special issue	South Africa	Bt Cotton	2005/06	Assessed livelihood impacts of adoption of Bt cotton	100 semi-structured interviews were conducted with farmers growing Bt cotton. Selection ensured a representative sample of male and female household heads. Questionnaire investigated what had changed since the introduction of Bt cotton, and collected economic data to quantify costs and benefits of Bt adoption. Focused on two cotton seasons: 2003/4 and 2004/5.	100	Income	1.4 (L)
Narayanamoorthy & Kalamkar, 2006	Journal article	India	Bt Cotton	2003	Studied the impact of Bt cotton on pesticide use, costs of cultivation, productivity and profit	Data collected from 150 farmers from 2 districts, 100 growing Bt, 50 not growing Bt.	150	Seed costs; pesticide costs; weeding costs; harvesting costs; total costs; gross value of production; cost of production; profit	1.6 (L)
Peshin *et al*, 2007	Journal article	India	Bt Cotton	2004/05	Investigated the socio-economic dynamics, attributes and rate of adoption of Bt cotton in Punjab.	210 farmers were interviewed using a semi-structured questionnaire focusing on the socio-economic characteristics of the respondents, extent and level of adoption, input use, cost of cultivation, production and returns.	210	Seed costs; insecticide costs; costs of spraying insecticides; costs of picking; total cultivation costs; gross returns; net income.	1.6 (L)
Ramasundaram *et al*, 2007	Journal article	India	Bt Cotton	2002/03; 2003/04	Investigated the performance and constraints of harnessing Bt technology	Based on field data collected during 2 years of cultivation. Also conducted a survey with a random selection of 56 cotton growers in year 1 and 50 in year 2. The survey was conducted in 2 phases, 1 during the season, the other after harvest. Partial budgeting was done for Bt cotton and conventional hybrids to assess their comparative performance.	56+50 (yrs 1 & 2)	Seed and sowing costs; plant protection costs; picking costs; total costs; price; gross return; net return.	1.8 (M)
Sadashivappa & Qaim, 2009	Journal article	India	Bt Cotton	2002/03; 2004/05; 2006/07	Analysed the performance of Bt technology over 5 years of adoption.	Used panel data with 3 rounds of observations. The 1st round of the survey took place in 2002/3. Farmers were selected by stratified random sampling. The 2nd round was carried out 2 years later in 2004/5 and the 3rd 2 years later in 2006-7.	341+376+407 (yrs 1, 2 & 3)	Output price; seed costs; insecticide costs; labour costs; harvesting costs; total variable costs; gross revenue; profit.	2.45 (H)
Skevas *et al*, 2010	Journal article	Portugal	Bt Maize	2007	Measured the costs and benefits of planting Bt maize as a member of a co-operative.	Case study of 5 Bt maize farmers in Portugal. Used economic data from the 5 producers, based on interviews with the growers in 2007.	5	Trading price; gross income; seed costs; insecticide costs; electricity costs; harvesting costs; total variable costs; gross	1.4 (L)

								margins.	
Tripp, 2009	Book chapter	China, US, India, Argentina, Colombia, Mexico, S. Africa, Australia,	Bt Cotton	2007	Reviewed information related to the performance of Bt cotton in order to examine the impact on smallholder farmers.	Considered data on farm level outcomes and analyse adoption patterns. Based on a review of published literature and surveys of current usage of Bt cotton in 8 countries.	X	Seed costs (provided by country consultants)	1.5 (L)
Wang *et al*, 2008	Article in journal special issue	China	Bt Cotton	2004	Investigated changes in pesticide use since introduction of Bt cotton; and subsequent changes in numbers of secondary pests in Bt cotton crops	Used field data. Conducted household survey in 2004 in 5 cotton producing regions. Interviews with farmers lasted 2 hours. Collected information on cotton production and investment in inputs and pesticides. Sample was a stratified random sample. Data was analysed using Stochastic Dominance tests.	481	Price of cotton	2.2 (M)
Wossink & Denaux, 2006	Journal article	USA	Ht and stacked gene (Ht plus Bt) cotton	2000	Focused on the quantification of pesticide use for producers of transgenic cotton versus conventional cotton.	The environmental and cost efficiency of pesticide use was assessed using data envelopment analysis. The data were from a survey of cotton growers in the USA, taken from USDA-NASS Agricultural Resource Management Study of Upland Cotton Production Practices for 2000.	208 (fields not farmers)	Cost of pesticides, technology fee, returns	2 (M)
Yorobe & Quicoy, 2006	Journal article	Philippines	Bt Corn	2003/04	Aimed to determine the economic impact of the Bt corn variety	A descriptive cost and returns analysis, a Cobb-Douglas model and a two-step econometric procedure were applied to a sample of corn farmers in selected regions of the Philippines. Survey interviewed 107 Bt corn growers and 363 non-Bt corn growers during 2003/04.	470	Chemical expense; expenditure on insecticide; price; cost of production; net income; profit	2.2 (M)
Zambrano *et al*, 2009	Book chapter	Colombia	Bt Cotton	2007/08	Analysed experience with Bt cotton.	Used both secondary data from the Columbian Cotton Confederation and results from farm-level surveys carried out during 2007-08	364	Labour costs; seed costs; insecticide costs; fuel costs; total costs; income; net benefit.	2.2 (M)

* for those studies using farm surveys
X – None or not applicable

4.2 Study quality assessment

Based on the 10 quality assessment questions, eight studies obtained an average quality score of less than 1.7 and were judged to be low quality, 13 studies obtained an average quality score of 1.7 up to 2.39 and were judged to be of medium quality, and one study obtained an average quality score of 2.4 or higher and was judged to be of high quality. Overall, the quality of the included studies is assessed to be acceptable. None received the lowest quality score, and the majority were judged to be of medium quality. All were therefore included in the subsequent synthesis. (The quality assessment results are included in appendix 2).

4.3 Narrative synthesis

The 22 articles to be included in the SR provided 305 separate monetary values for extraction relating to the changes in aspects of farm level finances as a result of the cultivation of GM crops compared to non-GM crops. The number of values was larger than the number of studies because many of the studies included values from more than one year, or from different regions, or in a few cases, different countries (Table 4). Many studies also included more than one category of values. The values that were extracted from the papers were all presented as monetary values, and (nearly) all included the comparative value for both GM and non-GM. The full collection of 305 values encompassed values in a wide range of different currencies (South African Rand, Indian Rupees, Euros, US$ and others). Some of the values related to costs incurred and others to income or revenue etc. Including only monetary values excluded data on yields, and figures that related to quantities of pesticides but not costs of chemicals. In order to synthesise and analyse the extracted data it was necessary to compute the percentage difference between the GM and non-GM values. In a limited number of cases, the author only presented a monetary value for the difference, and not the original two values for GM and non-GM. In these cases it was possible to analyse the descriptive change between GM and non-GM but not to compute the percentage difference. Of the 305 values, 38.5% of them were from studies judged to be of low quality, 53.8% were from studies judged to be of medium quality and 7.9% were from studies judged to be of high quality.

Table 4: Selected studies – Number of values extracted

Author(s) and publication date	Number of values extracted
Ali & Abdulai, 2010	2
Bangeree & Martin, 2008	4
Bennett *et al*, 2006b	21
Bennett *et al*, 2006a	14
Crost *et al*, 2007	6
Gomez Barbero *et al*, 2008	36
Gouse *et al*, 2009	8
Gouse, 2009	33

Hofs *et al*, 2006	8
Hugar *et al*, 2009	5
Morse *et al*, 2007	20
Morse & Bennett, 2008	1
Narayanamoorthy & Kalamkar, 2006	9
Peshin *et al*, 2007	12
Ramasundaram *et al*, 2007	14
Sadashivappa & Qaim, 2009	24
Skevas *et al*, 2010	40
Tripp, 2009	10
Wang *et al*, 2008	1
Wossink & Denaux, 2006	6
Yorobe & Quicoy, 2006	10
Zambrano *et al*, 2009	21

In the sections that follow, detailed descriptive statistics for the 305 values are presented, as well as a number of variables that were also extracted from the papers. The choice of variables was dictated by the information contained within the selected publications. Only when that information was common across publications was inclusion possible.

Publication date and data collection date

As noted above, 305 separate monetary values were extracted from the studies. Of these, 33% of the values were from studies published in 2009, 22% were from studies published in 2006, 17% from studies published in 2007, 14% from studies published in 2010, and 13% from studies published in 2008. The largest proportion of values were data that were collected in 2007 (25%), and the three years from 2002-2004 (52%) (see figure 1).

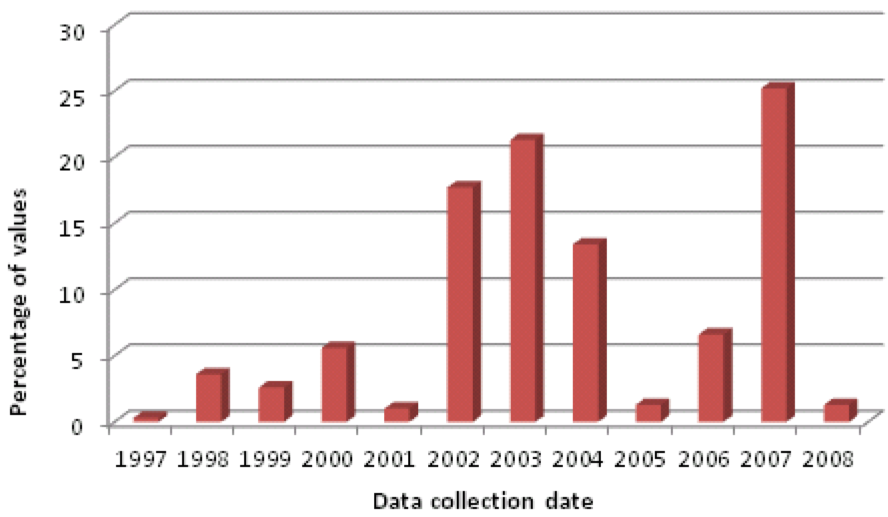

Figure 1: Percentage of values in each ‘data collection date’ category

Country of study

The majority of the 305 values were collected from India (35%) and South Africa (24%), but also Portugal (13%) and Spain (12%) (see figure 2).

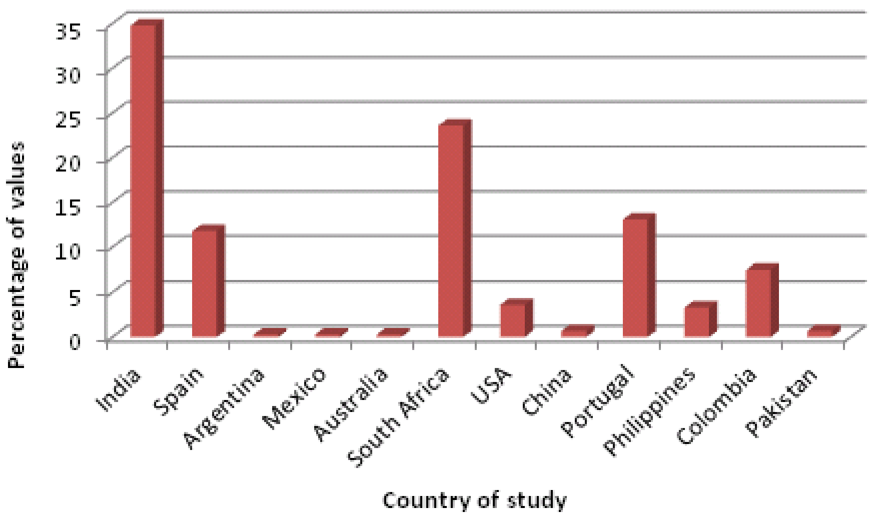

Figure 2: Percentage of values in each ‘country of study’ category

Crop/trait combination

Sixty seven percent of the values extracted related to Bt cotton, a further 30% to Bt maize, and the remainder to Ht maize, Ht cotton and stacked gene cotton.

Number of farmers surveyed

Two hundred and thirty one of the 305 values were from studies that conducted surveys with farmers. The category with the largest number of values was between 300-399 individuals, but 27% of the values elicited through surveys were obtained from studies conducted with less than 100 farmers (figure 3). The average number of farmers surveyed was 318.

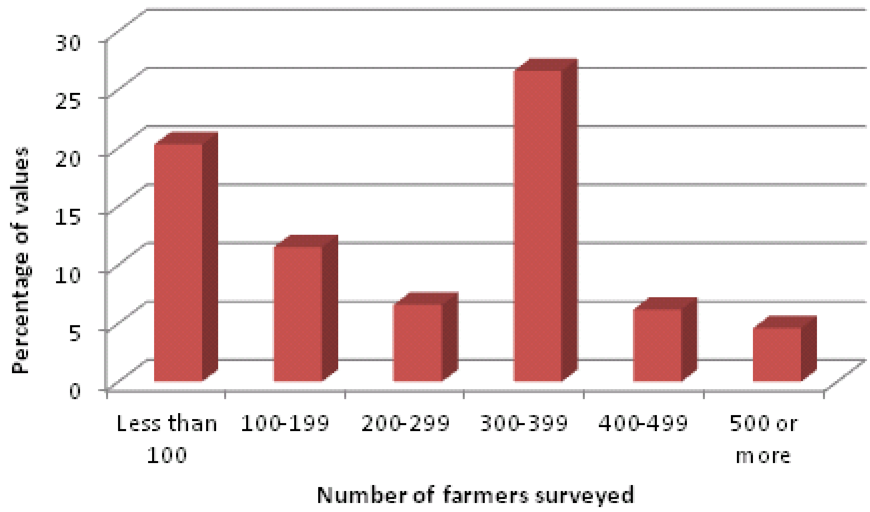

Figure 3: Percentage of values in each 'number of farmers surveyed' category

4.3.1 Change to farm level finances: Positive, negative or neutral?

Value categories

The 305 values covered different value categories of farm level finances, and different authors utilised different terminologies. In all there were 50 different terms that had been used by authors. Thus it was necessary to classify the values according to common assigned terms. Table 5 shows the categories assigned and the original terms used by

Table 5: The categories of values extracted and new categories assigned

Category assigned	Original terminology
Gross profit*	Gross income; Gross returns; Gross margin
Revenue**	Income; Yield income; Returns; Total revenue; Revenue; Gross revenue; Gross value of production
Net profit***	Net income; Net returns; Profit; Returns above costs; Net benefit
Profit margin***	Profit margin
Trading price	Trading price; Price of cotton; Cotton price; Output price; Price
Seed costs	Seed costs; Costs of cotton seed; Seed price
Chemical costs	Pesticide costs; Costs of sucking pest sprays; Costs of bollworm pest sprays; Pest spray costs; Crop protection costs; Plant protection costs; Insecticide costs; Chemical costs; Chemical expense
Labour costs	Labour costs; Spray labour costs; Insecticide spraying costs; Weeding labour costs; Harvest labour costs; Harvesting costs; Picking costs
Total variable costs	Total costs; Costs of production; Total cultivation costs; Seeds and sowing costs; Total variable costs
Energy costs	Power costs; Electricity costs; Fuel costs
Technology fee	Technology fee; Licence fee

* Gross profit is the farm's profit after selling a product and deducting the cost associated with its production.
** Revenue is calculated by multiplying the price at which goods are sold by the number of units or amount sold.
*** Net profit is calculated by taking revenues and deducting the cost of doing business, depreciation, interest, taxes and other expenses.
**** Profit margin is calculated by finding the net profit as a percentage of the revenue. Profit margin= (Net income/ Revenue) X 100

authors. For example, the assigned category of 'gross profit' incorporates those values that were referred to by authors as gross income, gross returns and gross margin. Similarly the category 'net profit' includes those values referred to in the individual publications variously as net income, net returns, profit, returns above costs, and net benefit. This process of reclassification of terms reduced the number of different value categories from 50 to 11. The distribution of values amongst these 11 categories is shown in figure 4. The most common category is seed costs (21% of values), followed by chemical costs (15%), gross profit, revenue and labour costs (all 11%).

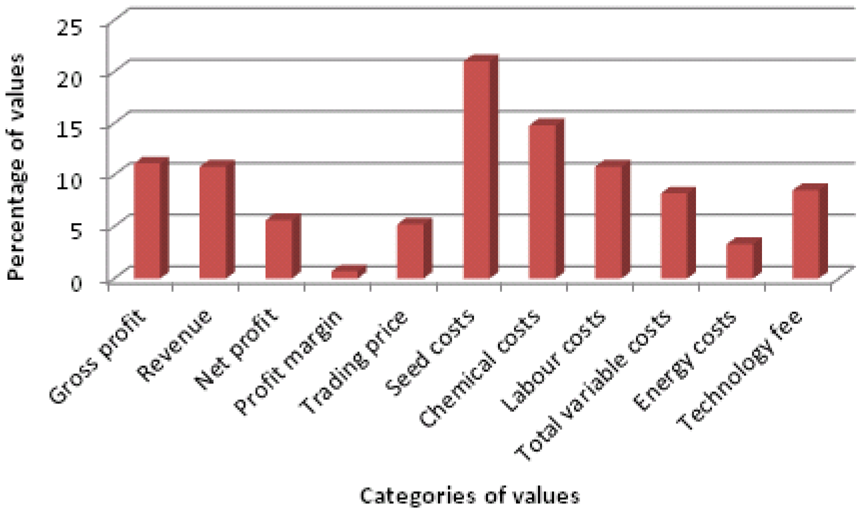

Figure 4: Percentage of values in each value category

In order to begin to investigate what the values showed to be the impact of commercial GM crops on farm-level finances, the question was posed:

> *"Do the 305 values demonstrate a positive change, a negative change, or no change to farm-level finances?"*

To examine this, a descriptive variable was derived, with a three point scale. When using the scale to examine the differences between the individual value categories, it is shown that 100% of the values in the 'gross profit' category demonstrate a positive change to aspects of farm level finances. Likewise 97% of the 'revenue' values reveal a positive change, as do 88% of the 'net profit' values. Further, the values under the category of 'chemical costs' reveal a positive change in 78% of cases. However, when considering 'seed costs', 'labour costs', 'technology fees' and 'total variable costs' the reverse is true. Thus 83%, 61%, 100% and 72% of the respective values, reveal a negative change (figure 5).

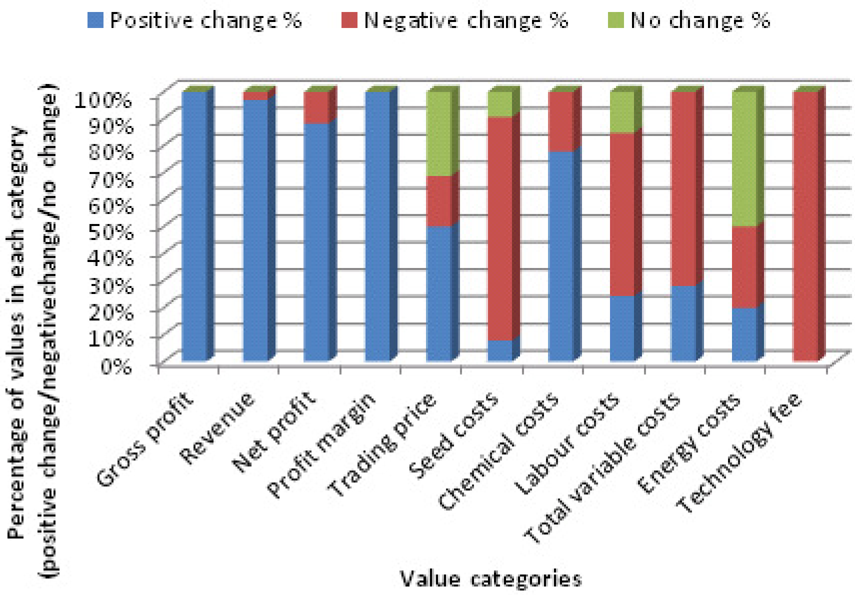

Figure 5: Value categories: Do GM crops lead to positive, negative or no change to aspects of farm level finances compared to non-GM crops?

In order to examine the impact of removing the studies judged to be of 'low quality' figure 6 contains only the 188 values extracted from studies judged to be of 'medium quality' or 'high quality'.

As can be seen, the most notable effect of this is that there are no values that suggest no percentage change from non-GM to GM, that is, switching from non-GM crops to GM crops always effects some change to farm level finances. In addition, there are now no values at all in the 'profit margin' value category. Other aspects of farm level finances where there appears to be a different impact on removal of the low quality studies are 'trading price', 'seed costs', 'total variable costs' and 'energy costs'.

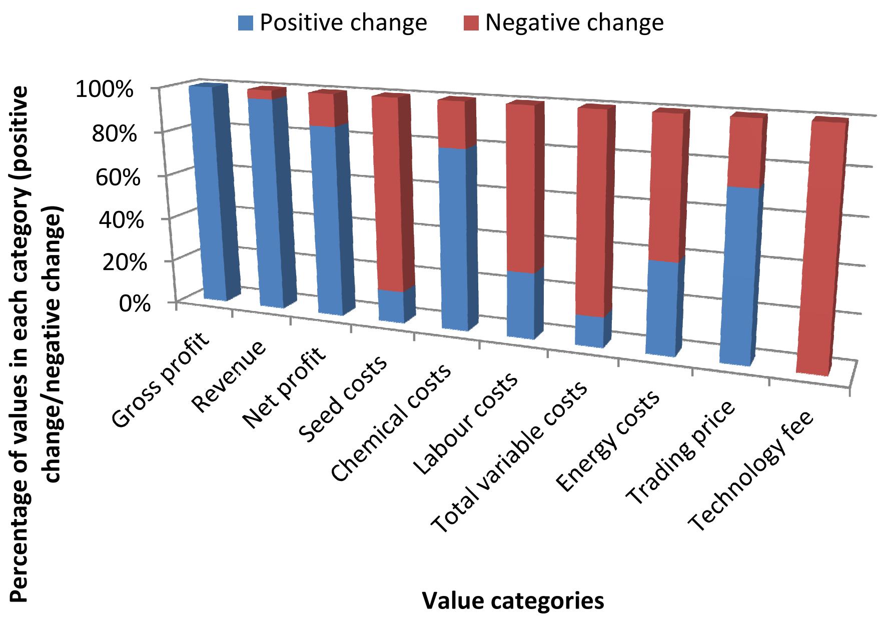

Figure 6: Value categories: Do GM crops lead to positive or negative change to aspects of farm level finances compared to non-GM crops? (excluding values extracted from studies judged to be of 'low quality')

4.3.2 Average percentage change to aspects of farm level finances from non-GM to GM

Value categories

In order to better understand the magnitude of the changes to aspects of farm-level finances, arising from cultivation of GM crops as opposed to non-GM crops, the percentage change reported by the values is considered[vi].

Broken down into the individual value categories, average percentage change demonstrated by the values in the gross profit category is 81%, while in the seed costs category it is -97%. In the net profit category it is 66%. These and values for all categories are shown in Table 6[vii] and figure 7. The standard deviations shown in Table 6 are large due to the global nature of the dataset which means there is inevitably large variation. Table 6 also shows the effect of excluding the values from studies judged to be of low quality. Importantly, removing values from low quality studies does not alter the percentage impact from negative to positive or vice versa for any of the value categories.

The boxplots shown in figure 7 further demonstrate the amount of variability in the dataset and show that a large amount is accounted for by outliers and extreme values. The boxes themselves (which represent the 'middle half' of the samples) do not appear particularly elongated.

Table 6: Value categories: Average percentage change to aspects of farm level finances from non-GM to GM

Category	Mean (S.D.) (all 305 values)	N	Mean (S.D.) (188 values - excludes those from low quality studies)	N
Gross profit	81.0 (97.7)	25	125.3 (118.7)	13
Revenue	31.6 (31.6)	33	33.2 (32.7)	25
Net profit	65.7 (56.6)	16	67.2 (61.4)	13
Trading price	1.5 (4.1)	16	2.2 (4.9)	11
Seed costs	-97.0 (141.3)	64	-88.2 (102.7)	35
Chemical costs	36.2 (48.6)	45	32.9 (39.5)	35
Labour costs	-10.2 (32.2)	33	-11.3 (37.0)	24
Total variable costs	-22.7 (49.6)	25	-34.4 (60.6)	15
Energy costs	1.5 (25.4)	10	3.0 (38.1)	5
Technology fee	-100.0 (.00000)	26	-100.0 (.0)	2

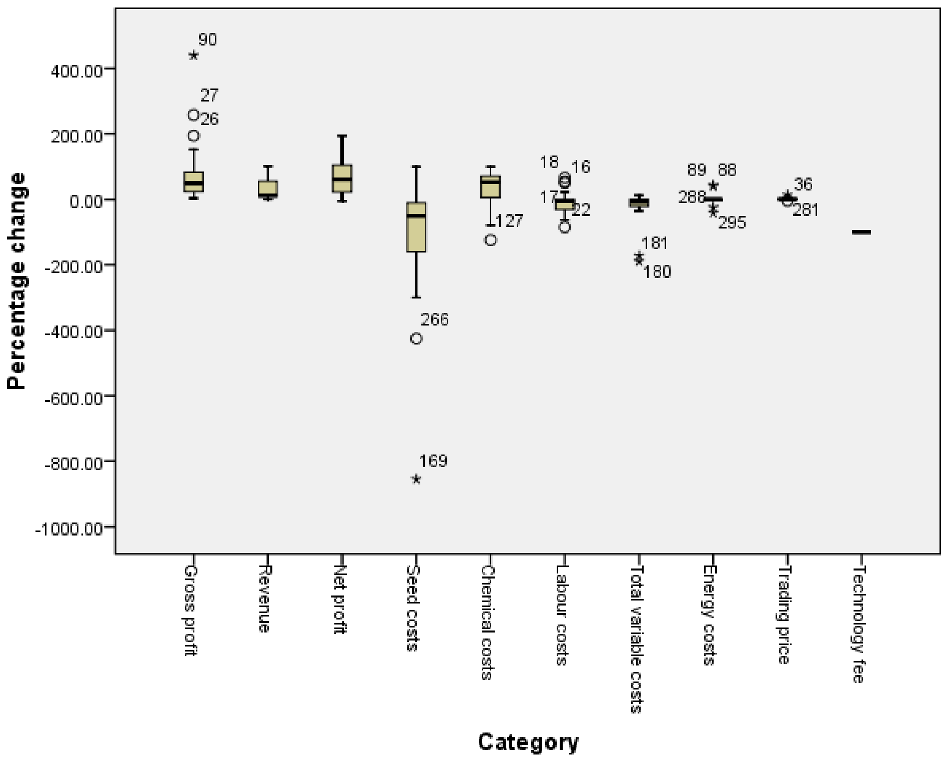

Figure 7: Boxplots of average percentage change to aspects of farm level finances from non-GM to GM, by value category. The boxplot shows the smallest value (the end of the lower whisker – note this excludes outliers); the lower quartile (the bottom half of the box); the median (the line across the middle of the box); the upper quartile (the upper half of the box); and the largest value (the end of the top whisker). The boxes represent the middle half of the samples thus the box length gives an indication of the sample variability. The line across the box shows where the sample is centred.

4.3.3. Profit and costs

The 11 categories of values measure different aspects of farm level finances. Thus they cannot be treated as equal measures and combined. For the remaining results presented in this report two further additive categories have been derived as follows:

- Gross profit and net profit have been combined to produce a 'profit' category of values. This includes 51 values.
- Seed costs, chemical costs, labour costs, total variable costs, energy costs and technology fees have been combined to produce a 'costs' category of values. This includes a total of 203 values.

A number of categories are not included in the following analysis, namely, revenue, profit margin and trading price as these do not fit into either of the additive categories. Thus the subsequent synthesis is based not on the full 305 values but a smaller group of 254 values.

Do GM crops lead to positive, negative or no change to farm level profit compared to non-GM crops?

Results show that 96% of the values in the profit category record a positive impact for farm level profit, with only 4% recording a negative impact (Table 7).

Table 7: Do GM crops lead to positive, negative or no change to farm level profit compared to non-GM crops?

	Frequency	**Percent**
Positive change	49	96.1
Negative change	2	3.9
Total	51	100.0

Do GM crops lead to positive, negative or no change to farm level costs compared to non-GM crops?

64% of the values included in the costs category of values demonstrate a negative impact on farm level finances, 28% a positive and 8% no change (Table 8).

Table 8: Do GM crops lead to positive, negative or no change to farm level costs compared to non-GM crops?

	Frequency	**Percent**
Positive change	57	28.1
Negative change	130	64.0
No change	16	7.9
Total	203	100.0

Average percentage change in profit and costs from non-GM to GM

In the additive category of farm level profit, there is an average increase in profit of 75% when growing GM crops as opposed to the non-GM equivalent[viii].

In the additive category of farm level costs there is an average increase in costs of 40% when growing GM crops as opposed to the non-GM equivalent.

The following results present the differences in the average percentage change recorded in profit and costs for the categories of a number of variables, including, crop/trait combination, publication date and country.

Publication date

The percentage change in profit is highest when the publication date is 2009 and lowest when the publication date is 2010. The percentage change in costs is highest (most negative for the farmer) when the publication date is 2007 or 2009, and costs for producing GM crops as opposed to non-GM crops are lower when the publication date is 2008 or 2010 (lowest of all) (Table 9).

Table 9: Percentage change in farm level profit and costs by publication year

Publication date	Mean percentage change (profit)	Mean percentage change (costs)*
2006	87.6	-24.9
2007	55.6	-78.5
2008	-	26.3
2009	131.2	-64.8
2010	36.1	17.3

* Note that a negative percentage figure denotes a cost increase, i.e. negative economic impact for the farm business.

Date of data collection

The percentage change figures for the date of data collection suggest that the earliest studies (from 1997-1999) demonstrated the highest increases in farm level profit but that, since then, profits have levelled off at an increase of between 68% and 76% for GM crops over non-GM crops. Likewise, the increase in costs was smallest in the earliest studies and since then costs for GM crops as opposed to non-GM crops have consistently been between 38% to 45% more (Table 10).

Table 10: Percentage change in farm level profit and costs by data collection date

Data collection date	Mean percentage change (profit)	Mean percentage change (costs)
1997-1999	194.2	-26.1
2000-2002	70.1	-45.4
2003-2005	68.2	-38.6
2006-2008	76.2	-40.1

Country

There may be value in studying whether the farm level impact of GM crops compared to non-GM crops is different in different countries. However, this is problematic with the current data as there are so few values for a number of the countries included. Therefore, countries were classified according to the UN Human Development Index[ix]. This reduced the categories to three: 'Very high human development', 'High human development' and 'Medium human development', as shown in Table 11.

Table 11: Human Development Index (HDI) country classification 2010

	HDI ranking 2010	Country classification according to HDI
Australia	2	Very high human development
USA	4	Very high human development
Spain	20	Very high human development
Portugal	40	Very high human development
Argentina	46	High human development
Mexico	56	High human development
Colombia	79	High human development
China	89	Medium human development
Philippines	97	Medium human development
South Africa	110	Medium human development
India	119	Medium human development
Pakistan	125	Medium human development

Twenty nine percent of the values are drawn from studies conducted in countries classified as 'Very high human development' countries (Australia, USA, Spain and Portugal); 8% of the values are from countries classed as 'High human development' countries (Argentina, Mexico and Colombia); and the remaining 63% of the values have been elicited from studies conducted in countries that are classified as having a 'Medium human development' level (China, Philippines, South Africa, India and Pakistan) (Table 12).

Table 12: HDI category descriptives (305 values)

HDI category	Frequency	Percent
Very high human development	88	28.9
High human development	25	8.2
Medium human development	192	63.0
Total	305	100.0

When considering only the values included in the profit category, 53% of values are from 'Medium human development' countries, 41% from 'Very high human development' countries and the remaining 6% from the 'High human development' category countries. When considering the values in the cost category, 67% of values are from the 'Medium human development' countries, 24% from 'Very high human development' countries and the remaining 9% from the 'High human development' category countries (Table 13).

Table 13: HDI category descriptives (51 profit values and 203 costs values)

	Frequency (profit)	Percent (profit)	Frequency (costs)	Percent (costs)
Very high human development	21	41.2	49	24.1
High human development	3	5.9	19	9.4
Medium human development	27	52.9	135	66.5
Total	51	100.0	203	100.0

The percentage change figures suggest that the highest increases in profit have occurred in the countries with the lowest level of development but that those countries have also experienced the greatest increases in farm level costs (Table 14).

Table 14: Percentage change in farm level profit and costs by HDI category

HDI category	Mean percentage change (profit)	Mean percentage change (costs)
Very high human development	29.7	4.4
High human development	88.3	-50.6
Medium human development	94.4	-54.2

Crop/trait combination

Growing Bt maize as opposed to non-GM maize is shown to result in both an increase in farm level profits and a reduction in farm level costs. However, while Bt cotton shows a greater increase in profits than maize, it also shows a large increase in farm level costs. Ht cotton and stacked gene cotton demonstrate both a reduction in farm level profits and an increase in costs. The figures for Ht maize suggest a very large increase in farm level profits, however, these figures should be treated with caution as they are based on very few values (Table 15).

Table 15: Percentage change in farm level profit and costs by crop/trait combination

Crop/trait combination	Mean percentage change (profit)	Mean percentage change (costs)
Bt cotton	80.9	-61.9
Bt maize	45.1	21.0
Ht maize	440.2	-37.0
Ht cotton	-5.4	-48.3
Stacked gene cotton	-2.1	-56.3

Number of farmers surveyed

There are occasions when study design can have an impact on results. In this study this point is investigated by including the variable relating to the numbers of farmers surveyed. This shows that the studies with the smallest number of participants recorded the smallest increase in farm level profits and also one of the smallest increases in costs. The largest recorded increases in profit came from those studies conducted with between 100-299 participants, and these studies also demonstrated the highest increases in costs (Table 16).

Table 16: Percentage change in farm level profit and costs by number of farmers surveyed

Number of farmers surveyed	Mean percentage change (profit)	Mean percentage change (costs)
Less than 100	34.7	-6.8
100-199	101.0	-55.4
200-299	116.0	-70.4
300-399	82.6	-20.5
400-499	61.9	3.1
500 or more	61.5	-37.7

Overall, there appear to be differences in the percentage change recorded in farm level profit and costs when considering the different categories of numerous variables. In the section that follows, these differences are tested for statistical significance.

4.4 Meta-data analysis

4.4.1 Average percentage change to farm level profit and costs from non-GM to GM: The significant variables

Analysis of Variance was conducted to meta-analyse the data and investigate whether the differences between the means presented above (that is, the mean percentage change in farm level profit and costs) were statistically significant for the variables reported. Thus the variables that were investigated were: publication date, date of data collection, Human Development Index category, crop/trait combination, and number of farmers surveyed. Results revealed a significant difference in the mean percentage change in farm level profits and costs for the following variables (see Tables 17 & 18):

- Crop/trait combination
- HDI group
- Publication date

These results show that the average farm level impact (as measured by the percentage change in profit from non-GM to GM) is greater for Bt cotton than Bt maize. The figures for Ht maize, Ht cotton and stacked gene cotton should be treated with caution as there are so few values in these categories, however there is a suggestion that the change in profit is positive for Ht maize but negative for both Ht cotton and stacked gene cotton. When examining changes to costs, the results show that there are very large increases in costs for farmers for all GM crop/trait combinations included in the study, with the exception of Bt maize.

The level of development of a country (as measured by the UN HDI) is also shown to be significant. Thus the change in farm level profit is most positive for those countries classified as having ‘Medium human development’, and least positive for those countries classified as having 'Very high human development level' (this includes EU countries). Increases in farm level costs are also much greater in the countries classified as either 'Medium human development' or 'High human development' (the least developed countries in this study).

Publication date is shown to be significant, with a suggestion that the most recent studies have revealed the lowest increase in profit. Results also suggest that in the most recent studies costs are shown to be lower for GM crops than the non-GM equivalent.

Table 17: Significant variables: Average percentage change to farm level profit from non-GM to GM

Variable	Mean values					F statistic	P-value
Crop/trait combination						11.618	0.000*
	Bt cotton	Bt maize	Ht maize	Ht cotton	Stacked gene cotton		
	80.9	45.1	440.2	-5.4	-2.1		
Human Development Index						2.722	0.079**
	VHHD	HHD	MHD				
	29.7	88.3	94.4				
Publication date						2.958	0.045***
	2006	2007	2009	2010			
	87.6	55.6	131.2	36			

* Significant at 99% level

** Significant at 90% level

*** Significant at 95% level

Table 18: Significant variables: Average percentage change to farm level costs from non-GM to GM

Variable	Mean values					F statistic	P-value
Crop/trait combination						7.289	0.000*
	Bt cotton	Bt maize	Ht maize	Ht cotton	Stacked gene cotton		
	-61.9	21.0	-37.0	-48.3	-56.3		
Human Development Index						6.473	0.002*
	VHHD	HHD	MHD				
	4.4	-50.6	-54.2				
Publication date						7.387	0.000*
	2006	2007	2008	2009	2010		
	-24.9	-78.5	26.3	-64.8	17.2		

* Significant at 99% level

5. Discussion

The SR process revealed 22 relevant articles (including a large number uncovered by previous reviews) which provided a not unsubstantial number of relevant data points for synthesis and analysis (305).

5.1 Evidence of economic impact

A number of variables were revealed to be important when investigating the impact on farm level profit and costs from the commercialisation of GM crops in different countries across the world, as reported in studies published from 2006 onwards.

In no cases was there revealed to be no change from cultivating conventional crops and GM crops. Thus there was some evidence of economic impact in every case. This was particularly notable for certain economic variables, namely gross profit and seed costs, but less significant for other economic variables such as trading price and energy costs. In some cases the economic impact was positive for farmers, in other cases it was negative.

100% of the values in the ‘gross profit’ category demonstrate a positive change to farm level finances. Likewise 97% of the ‘revenue’ values reveal a positive change, as do 88% of the ‘net profit’ values. While the values under the category of ‘chemical costs’ reveal a positive change in 78% of cases, this suggests that in any given scenario there could be 22% of farmers whose chemical costs would increase if they chose to grow GM crops. Further, when considering ‘seed costs’, ‘labour costs’, ‘technology fees’ and ‘total variable costs’ the economic impact is shown to be overwhelmingly negative at the farm level. Thus in 83% of cases, seeds costs would increase for farmers, in 61% of cases labour costs would increase for farmers, in all cases any technology fees would be a new and additional cost, and in 72% of cases farmers would be faced with higher variable costs if they chose to grow GM crops. One reason for the increase in labour costs seems to be that some farmers have to use more labour for harvesting due to greater yields in, for example, Bt cotton crops.
However, it is also informative to consider the average scale of the impact on farm level economics. For example, while the average increase in revenue is 32%, the average increase in seed costs is 97%. And while chemical costs are on average 36% lower for GM cropping, total variable costs work out at 23% higher.

In the additive category of farm level profit (which combines gross profit and net profit), there is an average increase in profit of 75% when growing GM crops as opposed to the non-GM equivalent.

In the additive category of farm level costs (which combines six cost categories) there is an average increase in costs of 40% when growing GM crops as opposed to the non-GM equivalent.

There is shown to be negligible difference in trading price between cultivation of GM and non-GM crops. The finding demonstrates that there is unlikely to be a significant price difference for GM crops, either positive or negative. Zilberman *et al* (2010) note that increased yields, and therefore supply, suggests that substantial price effects (downwards) are likely over time, all things being equal.

There is shown to be negligible difference in energy costs between cultivation of GM and non-GM crops. The result found in this SR for energy costs is interesting because one of the arguments in favour of GM crops is that it is labour (and therefore time) saving because fewer field operations are required for controlling pests and weeds. This is expected to be connected to a positive environmental impact also, as less fuel is required for field operations. The fact that there is only a negligible positive percentage difference between GM and non-GM recorded for the category ‘energy costs’ (which includes fuel costs) suggests that this was not particularly relevant in the studies reviewed here.

Economic impact is shown to vary by crop/trait combination, development status of the country and through time. The average farm level impact (as measured by the percentage change in profit from non-GM to GM) is greater for Bt cotton than Bt maize. The figures for Ht maize, Ht cotton and stacked gene cotton should be treated with caution as there are so few values in these categories, however there is a suggestion that the change in profit is positive for Ht maize but negative for both Ht cotton and stacked gene cotton. When examining changes to costs, the results show that there are very large increases in costs for farmers for all GM crops included in the study, with the exception of Bt maize.

The level of development of a country (as measured by the UN HDI) is also shown to be significant. Thus the change in farm level profit is most positive for those countries classified as having ‘Medium human development’, and least positive for those countries classified as having 'Very high human development level' (this includes EU countries). Increases in farm level costs are also much greater in the countries classified as either 'Medium human development' or 'High human development' (the least developed countries in this study).

Publication date is shown to be significant, with a suggestion that the most recent studies have revealed the lowest increase in profit. However, the most recent studies also suggest that costs are lower for GM crops than the non-GM equivalent.

5.2 Reasons for variation in impact

Farmers in the least developed countries (as measured by the HDI) received greater increases in profit than farmers in the more developed countries but also much higher increases in costs, when growing GM crops as opposed to the non-GM equivalent. Many studies have suggested there are likely to be benefits for small-scale, resource poor farmers (i.e. those likely to be in HDI category countries that are not 'Very high human development') from cultivating GM crops. However, while some previous studies (for example, Zilberman *et al*, 2010) claim that developing countries in which chemicals are not widely used should benefit the most from Bt technologies, others note that conditions are likely to be more widely heterogeneous on more marginal agricultural land, thus leading to large variation in impacts over time, and therefore meaning that the possibility of gaining positive economic impact for farmers is less certain (Pehu & Ragasa, 2007). Although the results from this SR have demonstrated that the largest gains in farm level profit have occurred in the countries with the least level of development, it is important to point out that the increases in costs incurred have also been extremely high. This initial outlay could be extremely problematic for resource poor farmers where cash flow is a major issue.

Cost categories that are particularly high for GM crops when compared to non-GM crops are seed costs and technology fees (the latter are an entirely additional cost not incurred with conventional crops). Carpenter (2010) also noted that seed costs have been shown to rise in almost all cases, when GM cultivation is compared to non-GM cultivation, as did Zilberman *et al* (2010). While chemical costs are generally lower (although this depends on modification, and in this study this positive result is largely as a result of the fact that the majority of studies included related to Bt modifications), labour costs are higher, as a result of additional harvesting labour costs due to higher yields, but also in some cases due to higher weeding costs associated with the removal of non-target weeds.

Changes in farm level profit and costs have been shown to vary through time but the results are inconclusive as to how. When examining the descriptive statistics for the data collection date there was some suggestion that the greatest benefits had been recorded by the earliest studies (profits were highest and cost increases were lowest) and that the benefits from cultivating GM crops had declined since then. However, this was not found to be statistically significant. From the publication date figures[x] there is some suggestion that the most recent studies have recorded the smallest profit increases, but also that costs in the most recent studies were lower for GM crops when compared to the non-GM equivalent. They had previously been higher. This may suggest a process of equalisation is underway. Finger *et al* (2011) found that the analysis of trends of GM crop effects over time did not reveal significant changes, although they also noted that long term effects, particularly with respect to infestation levels, pesticide costs and crop yields (all of which impact farm level finances), might not be adequately addressed by combining several short term studies.

The increase in farm level profit was greater for Bt maize than Bt cotton, and there was a decrease in farm level profit for both Ht cotton and stacked gene cotton when compared to non-GM cotton. The results show that there are very large increases in costs for farmers for all GM crops included in the study, with the exception of Bt maize. By way of contrast, Qaim (2009) found that on average (when reviewing 19 studies) the gross margin gains were higher for Bt cotton than Bt maize, suggesting that farm level economic impacts from cultivating GM cotton were likely to be more positive for farmers than cultivating GM maize. However, when reviewing 49 previous studies, Carpenter (2010) found evidence of negative economic impact of GM cotton in a range of countries, including Australia, China, Colombia, India and South Africa. Similarly, Wang *et al* (2008) found that those farmers who had planted Bt cotton in some Chinese villages made less money than the farmers who planted conventional cotton. These varied results suggest that a combination of underlying factors including local socio-economic and cultural factors, and structural farm and farmer variables are interacting in a complex manner that is not being satisfactorily accounted for by the reviews and analyses (including this one) being carried out. This is likely largely due to a lack of homogeneity between studies limiting the availability of sufficient variables for synthesis and comparison.

It should be noted that the quality (as measured using the 10 criteria listed earlier) of the studies reported in the papers included in the SR may also be a cause of variation in impact. However, as pointed out above (see Table 6) excluding values extracted from studies judged to be of low quality did not appear to change the direction of impact for any of the financial value categories. Testing the difference in quality score between the different categories of the variables 'publication date', 'level of human development of a country' and 'crop/trait combination' revealed that for the 'publication date' and the 'level of human development of a country', the differences in quality scores were statistically significantly different between categories. The cross-tabulations for these are shown in Tables 19 and 20. With regards to publication date it appears that the quality of studies has declined over time. There is no clear pattern in the results for the HDI group.

Table 19: Crosstabulation Publication date by quality category

	Publication date				
Quality category	**2006**	**2007**	**2008**	**2009**	**2010**
Low quality	25.0% (17)	24.5% (13)	9.8% (4)	42.6% (43)	95.2% (40)
Medium quality	75.0% (51)	75.5% (40)	90.2% (37)	33.7% (34)	4.8% (2)
High quality	-	-	-	23.8% (24)	0

Table 20: Crosstabulation HDI group by quality category

	HDI group		
Quality category	**Very high human development**	**High human development**	**Medium human development**
Low quality	52.3% (46)	16.0% (4)	34.9% (67)
Medium quality	47.7% (42)	84.0% (21)	52.6% (101)
High quality	-	-	12.5% (24)

5.3 Review limitations

5.3.1 The scope of the review

Overall, the scope of this review was specified by the requirements of the funder, thereby restricting the review to farm-level data published from 2006 onwards. It is important to acknowledge that there may well be a larger evidence base that would potentially be useful for informing this policy area and that might lead to other conclusions.

A number of additional limitations are described here, limitations that had implications for the studies that were included, the values that could be extracted for analysis, and the analysis that could subsequently be carried out. All the points that follow may be considered by some readers as limiting the usefulness of the findings and should be taken into consideration when examining the conclusions drawn from this study.

5.3.2 Time available for conducting the review

The relatively short amount of time available for conducting this review may have limited the selection of studies included, and the analysis that was feasible. Additional time for conducting a SR such as this one would allow the inclusion in the search process of additional databases that were excluded because it was not possible to directly export results to Reference Manager Database[xi]. An extended review on this topic would be a potentially valuable contribution to the 'GM debate'. More time would also have enabled the inclusion of additional resources that were deemed to be relevant, but that were not easily accessible and that were not immediately available through inter-library loans[xii]. More statistical analysis might also be possible given additional time, including investigating possible interactions between variables.

5.3.3 The search terms

Trade names were included in the scoping study (for example, Bollgard and Round-up Ready), but not in the final search terms as they were not shown to be useful in eliciting additional hits. Future reviewers may view this as a potential limitation and choose to include trade names.

It should be borne in mind that this SR, and the studies included in it, are based on the search term as presented in section 3.1.1. It is of course possible in any SR that the use of a modified search term would result in a different selection of studies for review and thus different findings for the policy debate.

5.3.4 The selected studies and the extracted data

A number of the variables included in this SR contained only small numbers of values in some categories (notably, country of study and data collection date). This can limit analysis. However, this was overcome by recoding these variables into a smaller number of categories. While this aids analysis it leads to a loss of resolution.

As with any review there was considerable heterogeneity between the studies collated. This related to many aspects of the studies, including terminology (as illustrated clearly by Table 5). Study heterogeneity limits comparability between studies which in turn limits the possibilities for analysis.

Very few of the studies included in the review surveyed farmers growing both GM and non-GM. This can be problematic as any differences in the impact of GM adoption may be due to characteristics of different farmers or farms, and not primarily to the technology. A number of studies addressed this by testing for differences in the characteristics of adopters and non-adopters.

While the majority of studies tested for significance of differences between values in non-GM and GM, not all did (or at least, this was not reported), instead only reporting descriptive statistics.

Very few studies included data from more than one country.

The approach taken to sampling of areas and farmers to be surveyed varied across studies. In some cases authors reported using a form of random sampling. However, a number of studies utilised purposive sampling, for example, specifically targeting areas known to have high adoption of GM crops. While this is not bad practice it can limit wider relevance of findings.

This SR did not uncover any relevant studies on canola (oilseed rape) or soybean that could be included, despite these being important GM crops, alongside maize and cotton[xiii]. Whether this was due to the search process (unlikely as the term 'herbicide tolerant' was included in the search string), or the lack of studies, is unclear. However, it suggests that there is a lack of relevant studies that have considered the impact of oilseed rape or soybean. Finger *et al* (2011) similarly found a dearth of studies for Ht canola and soybean suitable for inclusion in their meta-analysis. One suggestion is that the publication date restriction placed on this SR effectively excluded studies reporting on canola and soybean as they were among the earliest commercialised crops and thus any studies investigating economic impacts may be have been published prior to 2006.

In addition, this SR included studies that mainly considered Bt crops (97% of values). This suggests again that there may be a lack of relevant studies that have investigated the farm-level impacts of Ht crops (or that have been published during the period covered by this SR). Again, this may be due to the fact the Ht crops were commercialised earlier.

Overall, ex-post studies of farm level impacts were not found to be commonplace. There was particular interest in certain countries, notably India, where a number of different authors had conducted such studies. Studies from other countries appear to be much rarer, thus the values in this SR rely on one or two studies in other countries, from a limited number of authors.

6. Reviewer's conclusions

6.1 Implications for Policy

One of the key findings from the review is that in every case when planting GM crops as opposed to a non-GM equivalent, there was a farm-level economic impact. This was particularly notable for certain economic variables, namely gross profit and seed costs, but less significant for other economic variables such as trading price and energy costs. In some cases the economic impact was positive for farmers, in other cases it was negative. Generally, the change in gross profit, revenue and net profit was positive, while the change in seed costs, labour costs and total variable costs was negative. As trading price was generally not differentiated, the profit and revenue increases are likely largely due to increased yield (decreased losses).

Economic impact was shown to vary by crop/trait combination, indicating that treating ‘GM crops’ as one homogenous technology is an unhelpful approach and that impact of each crop/trait combination should be examined individually. Economic impact was also shown to vary by development status of the country demonstrating that the baseline state of agricultural production at the time of commercialisation is a key factor influencing economic impact. The change in farm level profit was least positive in the most developed countries.

It should be noted that the quality assessment of the studies included in this review revealed eight studies to be low quality, 13 studies medium quality, and only one to be high quality. Had more of the studies achieved the necessary score to be assessed high quality the evidence base could be judged to be of greater reliability, with less potential of bias.

It is also important to note the additional restriction that was added to the review question, namely that the answer should be based only on evidence that could be extracted from studies published from January 2006 onwards. This should be borne in mind when considering the conclusions that have been drawn. The implication for policy here is that the answer may well have been different, had additional studies, published earlier been included. In addition, it should be further noted that searches were conducted in June 2011 and additional studies may well have been published subsequently. Thus, were the same review to be conducted now or in the future, the answer to the review question may well be different. Nevertheless, the reviewers are confident that the results presented in this review go some way to answering the question posed, and largely reflect conclusions drawn elsewhere in the literature. It is, however, important to always bear in mind the limitations described above.

6.2 Implications for research

In light of the review limitations acknowledged above there are a number of implications for future research in this area. Firstly, a more targeted question might be more informative, for example, investigating the impact for farmers on chemical costs when growing Bt crops. Future reviews on the topic should consider being this specific. In addition, reviewers might find it more informative not to have an imposed timeframe excluding studies published before a certain date.

There may be merit in a study such as this one in investigating whether variables such as farm size, age (experience) of farmer, specific trait, and others, affect the extent to which changes in profit and costs are positive or negative for growers of GM crops. However, this is entirely dependent on the data contained within the included studies and requires that sufficient studies report comparable information to avoid the problem of many missing values.

Further, there were some data in some studies relating to changes in yield and quantities of inputs. If it were possible to access data on the trading price and input costs for the relevant countries and the relevant years this could provide additional values for inclusion in the analysis. There may be additional external factors that impact on farm level profits, such as commodity prices and input prices. Use of external data such as these could add value to the analysis conducted although this would take the study beyond the scope of a SR.

Overall, it is important that research continues into conducting and reviewing farm level studies, particularly as there is some suggestion that changes in farm level profit and costs that arise as a result of growing GM crops as opposed to the non-GM equivalent, change through time.

7. Acknowledgements

This work has been funded by the UK government, Department for Environment, Food and Rural Affairs. Thanks are due to Dr Davy McCracken, Dr Klaus Glenk, Corinne Balcombe and Alistair McVittie for providing useful comments on early drafts of the report.

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End notes

[i] This additive category includes net profit and gross profit

[ii] This additive category includes seeds costs, chemical costs, labour costs, total variable costs, energy costs and technology fees

[iii] This search string was slightly modified for use in IBSS and EconLit. The former did not recognise $, and in the latter it was necessary to add NOT pharmaceut* and NOT drug* as many hits elicited using the string above related to medical biotechnology.

[iv] The date was specified by the funder.

[v] Cohen's Kappa statistic measures inter-rater reliability, and is used to examine the agreement between two people (raters/observers) on the assignment of categories of a categorical variable. It determines how well an implementation of some coding system works. In this case it was applied to see how two people independently applied the same inclusion and exclusion criteria to the selection of studies and decided on relevance. Cohen's Kappa ranges from 0 to 1.0 where large numbers mean better reliability, values near or less than zero suggest that agreement is attributable to chance alone.

[vi] Note that this computation is available for 293 of the values extracted.

[vii] Note that the profit margin category is not included

[viii] Note that there are only 41 values included in the profit category for this part of the results.

[ix] The human development index (HDI) is a composite index that measures development by combining indicators of life expectancy, educational attainment and income (http://hdr.undp.org/en/statistics/hdi/).

[x] Publication date and data collection date are correlated. Correlation is significant at the 0.01 level (0.7).

[xi] For example, in the protocol, Agecon was proposed as a possible source to be searched. However, it was not feasible to include this, given the timescale of the project.

[xii] This includes three books and four journal articles.

[xiii] One study that had investigated the impact of herbicide tolerant canola in Canada and that met all of the inclusion criteria was excluded because of issues over the quality of the publication.