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For quality of life

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Abbreviations

BCI	Better Cotton Initiative
Bt	*Bacillus thuringiensis* (toxin)
Canola	CANadian Oil, Low Acid (oilseed rape low in erucic acid and glucosinolates)
CAP	Common Agricultural Policy (of the EU)
CBS	Centraal Bureau voor de Statistiek (Statistics Netherlands)
CGE	Computable General Equilibrium (modelling method for macro-economic analysis (see GTAP)
CIMMYT	International Maize and Wheat Improvement Center
ECB	European corn borer (*Ostrinia nubilalis*)
EJF	Environmental Justice Foundation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute (US)
FSE	Farm Scale Evaluations (large programme of field trials in UK assessing GM impacts on biodiversity)
GAP	Good Agricultural Practice
GDP	Gross Domestic Product
GM	Genetically Modified/Genetic Modification
GMO	Genetically Modified Organism
GRI	Global Report Initiative
GTAP	Global Trade Analysis Project (general equilibrium modelling of macro-economic effects)
ha	hectare
HT	herbicide-tolerant
ICAR	Indian Council for Agricultural Research
IFA	International Fertilizer Industry Association
IFPRI	International Food Policy Research Institute
ILO	International Labour Organization (of the UN)
INTA	Instituto Nacional de Tecnología Agropecuaria (Argentinian National Institute for Agricultural Technology)
IPEC	International Programme on the Elimination of Child Labour (of ILO)
IPR	Intellectual Property Rights
IR	insect resistant
IRMA	Insect-Resistant Maize for Africa programme
ISAAA	International Service for the Acquisition of Agri-biotech Applications
LL	Liberty Link® (glufosinate tolerant GM variant)
LLP	low level presence (of GM in non-GM products)
MVO	Productschap Margarine, Vetten en Oliën (Dutch Product Board for Margarine, Fats and Oils)
NGO	Non-Governmental Organization
OECD	Organisation for Economic Cooperation and Development
OPV	Open-Pollinated Varieties
R & D	Research and Development
ROW	Rest Of the World
RR	Roundup Ready® (glyphosate-tolerant GM variant)
RTRS	Round Table for Responsible Soy
SACU	Southern Africa Customs Union
SAM	Social Accounting Matrix (economic modelling tool)
SDPI	Sustainable Development Policy Institute
SIMPOC	Statistical Information and Monitoring Programme on Child Labour
SSA	Sub-Saharan Africa
UDHR	Universal Declaration of Human Rights
UK	United Kingdom

UN	United Nations
UNDP	United Nations Development Program
UNPFII	United Nations Permanent Forum on Indigenous Issues
US	United States
USD	US Dollar
USDA	Unites States Department of Agriculture
WCA	West and Central Africa
WCR	Western corn rootworm (*Diabrotica virgifera* ssp. *virgifera*)

Abstract

This report addresses the question whether the cultivation of genetically modified (GM) crops abroad for import in the Netherlands, as compared to the cultivation of their conventional (non-GM) counterparts, is in line with Dutch policy and societal aims striving after more sustainable forms of agriculture worldwide and the utilization of the benefits offered by biotechnology in a responsible manner. Three crops were selected as case study objects: soybean, maize and cotton. The sustainability of GM and non-GM crop production was compared with each other based on a review of scientific and other literature. This comparison followed characteristics and criteria associated with the sustainability concept of 'People, Planet, Profit'.

For each crop, an overview of GM events widely used in cultivation and those in the pipeline is given. The GM events common in commercial cultivation and therefore discussed in detail in this review are herbicide tolerance (HT in soybean, maize and, to a lesser extent, cotton) and insect resistance (IR) conferred by Bt (in maize and cotton). First, 'Planet' impacts of these two types of traits are discussed under the subjects: production efficiency (including yields, fertilizers, biocides and energy), soil and water conservation, biodiversity and climate change. Then follows 'Profit' with the subjects: farm income, national income, economic welfare distribution, and financial and other risks (including institutional risks). Finally, 'People' is treated with the subjects: labour conditions (including wage levels, occupational health, employment opportunities, and child and forced labour), land rights, community rights and rights of indigenous people, freedom of choice, competition with food production, and contribution to livelihood of producers and local communities. In the final discussion, a more extensive summary of findings per crop is given, together with a discussion of some general issues with particular relevance to sustainability of GM crops.

Our study clearly showed that no single value of sustainability can be given that is valid for all GM crops under all conditions. The term 'GM crops' encompasses a broad diversity of traits and crops with various goals and accompanying effects, and therefore, sustainability effects cannot be simply summarized for all traits and crops together. Apart from the technology by which they were made (which was not the subject of this review), GM traits in many respects do not represent changes largely or essentially different from other agricultural innovations. Overall, the performance of agriculture varies tremendously between regions and time periods irrespective of the presence of GM crops. Effects of a GM crop on one or more of the sustainability components thus depend on time and place as well, and effects found for a particular crop, region, and year cannot be simply extrapolated to generic conclusions. Moreover, the specific role of GM is often difficult to disentangle from other drivers of change in agriculture. Despite this, our study provides a systematic framework of sustainability aspects and their interrelationships that can be used for future case-by-case assessments of second and subsequent generations of GM crops. In addition, some general trends can be mentioned with regard to sustainability of GM crops.

The first generation GM crops have been developed for various purposes. Insect-resistant GM crops have been developed specifically to produce varieties that are resistant to certain insect pests, thus reducing the use of pesticides, whilst herbicide-tolerant GM crops aim to provide the farmer with more flexibility in weed management. Until now, successful GM traits are those that fulfill a niche or a need for the farmer. The reason that a farmer chooses for GM crops is not necessarily an increase in production but may also be a reduction of risks and/or an increased flexibility of operations.

In general, sustainability of the two types of GM crops discussed in this study (herbicide tolerance (HT) and Bt insect resistance) depends on diligent use. Bt maize and Bt cotton generally contribute to sustainability in the 'Planet' sense. When they are cultivated according to Good Agricultural Practice (GAP) on the basis of recent agronomic and agro-ecological knowledge, also GM HT varieties could contribute to improvement of the sustainability of agricultural production. With regard to 'Profit' and 'People' themes, the contribution of GM crop production to sustainability is highly dependent on local legal and institutional systems. The legal and institutional system should provide an optimal extension infrastructure to farmers, should diminish uncertainties in logistics and trading, should enable freedom of choice and should protect the rights of farmers, employees and consumers.

1. Introduction

1.1 Background

In the Netherlands, genetically modified (GM) crops are not commercially cultivated yet. The Netherlands, however, import GM crop products at a large scale and the Dutch economy is to a large extent dependent on the cultivation of GM crops abroad. The question can then be raised whether the cultivation of GM crops abroad for import in the Netherlands, as compared to the cultivation of their conventional (non-GM) counterparts, is in line with Dutch policy and societal aims striving after more sustainable forms of agriculture worldwide and the utilization of the benefits offered by biotechnology in a responsible manner (Anonymous, Integrale nota biotechnologie, 2000). To answer this question, three crops were selected as case study objects: soybean, maize and cotton. The sustainability of GM and non-GM crop production was compared with each other based on a review of scientific and other literature. This comparison followed characteristics and criteria associated with the sustainability concept of People, Planet, Profit. The study was carried out as a quick scan of the available information and was not exhaustive. Funding for this study has been received from the Dutch Ministry of Economic Affairs, Agriculture and Innovation.

1.2 Methodology

Three crops - soybean, maize and cotton - were selected as case study subjects based on their importance for the Dutch economy and on the commercial availability of GM traits in these crops at present. For each crop, an assessment was made how the sustainability of GM varieties differs from that of their conventional counterparts. As this was a sustainability comparison between GM and non-GM varieties, some issues regarding the absolute sustainability of crop production and the associated chain (for instance how long can current crop production be maintained without depleting particular resources) are briefly mentioned at the beginning of each section on a crop, but are not part of the actual comparison when they are not relevant to the relative performance of GM and non-GM varieties.

The sustainability impact of GM and non-GM crop production was assessed through a number of themes/indicators grouped under the main themes of People, Planet, Profit. The themes were selected based on literature, existing sustainability assessment schemes and international treaties. Details on the choice of sustainability themes is given in the section below. It should be noted that a choice of sustainability themes is always somewhat arbitrary, as a large number of themes have been proposed in the past (e.g. see Bockstaller *et al.*, 2008) and sustainability can be seen as a moving target with changing priorities and standards over time and space. For instance, while the use of fossil fuels was primarily seen as a resource depletion problem 20 years ago, currently, much more emphasis is given to the impact of fossil fuel use on climate change. In some developing countries, sustainable agriculture may be primarily regarded as a type of farming that provides sufficient food to a growing population and livelihoods to rural people. In the Netherlands sustainable farming is associated to a larger extent with reduced environmental impact from farming. Standards also change over time: an agricultural production system that was classified as efficient 20 years ago, may now be seen as inefficient as technological progress has changed standards and expectations.

Among the main themes, planet issues are usually most closely related to changes in field management and other production characteristics associated with the availability of transgenes in crops. Therefore, for each case crop, ‘Planet’ issues are discussed before the other themes in the chapters on specific crops. ‘Profit’ issues are often drivers for the impact of GM crops on ‘People’ issues. Therefore, ‘Profit’ themes are discussed before the ‘People’ section in these chapters. Issues in the different sections of Planet, Profit and People often relate to each other and sometimes overlap. For instance, while the impact of GM traits on land use efficiency (yield) fall under ‘Planet’, changes in yield have a direct impact on the net benefits and farmers’ income. Farmer income is a topic that typically comes under ‘Profit’, but a change in farmers’ income will also affect farmers’ livelihoods and those of other rural people, subjects typically falling under ‘People’. For the benefit of the reader, cross-references will be given to other ‘P’ chapters with the treatment of such subjects as much as possible.

Specific effects of transgenes on sustainability indicators are not easily assessed. The effect depends on the actual agro-ecological conditions, which may vary widely across regions. Moreover, the definition of the conventional, non-GM situation is not straightforward. The ‘conventional practice’ may actually cover a wide range of practices including forms of high-input intensive agriculture, integrated agriculture and organic systems, which all evolve over time. In practice, comparisons are usually made between GM and the common conventional systems in a region, although this becomes difficult if the vast majority of farmers stopped growing non-GM varieties. Experimental field trials with GM and non-GM systems whereby other factors are controlled as much as possible can offer useful data for a sustainability comparison, especially to assess ‘Planet’ issues. However, also here challenges remain, for instance the choice of conventional varieties to compare with. From a scientific point of view, the most basic comparison is between the GM variety and the isogenic line that it is derived from. For a grower, the most relevant comparison would be with the best conventional varieties available at present. Especially at the introduction of GM varieties, often their genetic backgrounds were as yet older varieties. This problem could be complicated by the longer time needed to deregulate GM varieties and when the introduction of the transgenes in locally adapted germplasm is lagging behind. By providing details on the way cited studies were set-up, we aim to clarify how these studies defined the non-GM practice.

This report makes a distinction between information from peer-reviewed scientific literature and other sources of information, such as information from academic institutes, international organizations such as the UN and the FAO, civil society organizations, farmers’ associations, biotech companies, trade databases, etc. References to scientific literature are underlined, while for references to other literature italic font is used. The rationale for this distinction was that peer-reviewed scientific literature has been subjected to a quality control step by peer scientists, which demands authors to present their data, and have independent researchers scrutinizing these and their interpretation before accepting it for publication. This reduces the uncertainty with regard to the objectivity and reliability of the results. Information from other sources did not undergo this external control. The sometimes acrimonious discussions ignited by strong pro- and opponents of GM technology have also led to pressure on this system (cf. Waltz, 2009[1]). For instance, detailed scientific discussions tend to become disproportionately enlarged under media pressure and interests of both sides, which may also creep into the review process. Nevertheless, the peer-review process, which naturally also never can be entirely flawless, will generally guarantee a higher level of control than other types of publishing. Having said that, a lot of good information can be gathered from literature that is not peer-reviewed by scientists. Moreover, this so-called ‘grey’ literature covers a wide array of quality levels, from reports having a level of transparency similar to peer-reviewed papers to pamphlets representing a particular stance in the GM debate. Such pamphlets could be useful to trace important issues, but are more problematic as a source of (scientific) data. For instance, the transparency of how data were obtained and analyzed is often lacking in these publications. There are also some relevant exceptions: some reports may have a high level of peer review because of the involvement of independent reviewer committees and/or information rounds with stakeholders, and on the other hand, some contributions in peer-reviewed scientific journals have been entered as opinions and/or news items (e.g. the Waltz (2009) feature in the peer-reviewed journal Nature mentioned earlier on) and therefore have to be treated differently from normal research papers. In relevant cases, such situations will be mentioned in the text or in footnotes. As far as possible, we give additional information on the methodology used in the studies referred to, as this may provide an indication of the reliability or the relevance of the information and this may help to explain seemingly contrasting findings between studies. Where sources of information had known biases (e.g. reports by industry or NGOs), this was identified as much as possible.

On various sustainability aspects, very few or no scientific literature, or even academic reports, was found at all. A great deal of information on the sustainability of GM crops has not been published in scientific journals, for instance because the information is not of sufficient scientific relevance for publication in a scientific journal or because writing and publishing research papers is a laborious process, which is not always brought as far as successful publication. Lack of publications can also be due to the understandable expectation that specific

[1] News Feature in peer-reviewed journal.

functions of individual transgenic traits are not particularly associated with some of the impacts that we address in this report. For example, in the Planet part, GM insect resistance is expected to have an impact on inputs of insecticides, but not particularly on an input such as fertilizers. In some Profit aspects, such as national income, complex interactions can make it difficult to disentangle GM effects from other economic drivers, which may only be solved by using sophisticated models. Particularly in the People part, it is most of the time hard to distinguish GM effects from other political and social drivers. At the same time, important claims are often put forward based on anecdotal evidence and/or information scattered across not easily retrievable resources, such as news items in local papers or journals. In order to focus the literature search in all such cases, we have hypothesized what effects could in principle be expected and subsequently we treat any references that we could find on the expectations theorized. Again particularly in the People parts, the theorized effects can thus be helpful in finding literature, including references that are not specifically on GM but could shed light on the effects theorized. For more details, the reader is referred to the section 'Study format and limitations' under chapter 1.2.3 below. Texts about hypothesized/theorized impacts are distinguished from other text by their headings in capitals and their placement in boxes.

1.2.1 Planet

Under Planet, the following themes were selected:
1. Production efficiency
2. Soil conservation
3. Water conservation
4. Biodiversity
5. Climate change

Production efficiency

Theme 1 relates to the 'Crop Production Ecology' approach (Haverkort *et al.*, 2009) in which sustainability of crop production is assessed with the help of production efficiencies. Production efficiencies commonly distinguished are:
- Land use efficiency (yield per ha)
- Water use efficiency (yield per litre of water irrigated or evaporated by the crop)
- Biocide use efficiency (yield per kg of active ingredients applied)
- Nutrient use efficiency (yield per kg of nitrogen (N), phosphorus (P) or potassium (K) applied)
- Energy use efficiency (yield per MJ of energy consumed for farm operations and the production of inputs)

Production efficiencies are particularly useful to compare the sustainability of cropping systems with each other and are usually easier to quantify than the impact on the environment. Studies, however, often report input use per area of land (usually per hectare) and not per amount of product, and this can affect comparisons between production systems. For instance, a production system with high nutrient application rates per ha providing high yields can be considered nutrient-efficient when the yield per kg of nutrient applied is also high.

While the idea behind most resource use efficiencies is rather straightforward (the more efficient, the better), biocide use efficiency is a slightly more complex indicator. The amount of biocides used for agricultural production, or the biocide use efficiency, does not directly reflect the environmental impact from these applications, as agents vary in toxicity and burden to the environment. Therefore an additional tool, the Environmental Impact Quotient (EIQ), is frequently used to assess and compare the environmental effects from biocides. Although there are other tools (see e.g. Van Bol *et al.*, 2003), EIQ also has been used most frequently in GM crop studies. The EIQ is based on the estimated impact of the active ingredients in the biocide on ecology, farm workers and consumers (*Kovach et al., 2009*). The EIQ value of a biocide is based on scientific studies on the toxicology of the relevant biocide and is reviewed and updated regularly by a team of scientists. A field EIQ can be obtained by multiplying the application rate of each ingredient with its associated EIQ value.

Soil conservation, water conservation, biodiversity and climate change

A disadvantage of the use of production efficiencies to assess sustainability of cropping systems is that these efficiencies alone do not necessarily explain the impact of farming on the environment. A production system with a high water use efficiency in a dry area could still lead to the depletion of water resources and affect the environment in an unacceptable manner. Similarly, a poor water use efficiency may not cause any problems in an area with plenty of rainfall in the growing season. Therefore, the sustainability themes soil conservation, water conservation, biodiversity and climate change, describing the impact of farming on the environment, have also been taken into account. These themes were taken from existing sustainability assessment schemes for crops such as the Round Table on Responsible Soy (*RTRS, 2010*), the Round Table on Sustainable Palm Oil (RSPO), the Better Cotton Initiative (*BCI, 2010*) and the Sustainable Agriculture Initiative (SAI)[2]. These themes are thus widely considered as the main issues that should be addressed to guarantee the sustainability of agricultural production.

Soil conservation

Farming obviously has a large impact on soils, as farming occupies a large part of the earth's land surface. Farming changes soil physical, chemical and biological properties and often leads to increased erosion rates (Pimentel *et al.*, 1995). The impact of arable farming on soil conservation is dependent on location and management decisions such as the choice of crops and soil cultivation methods.

Water conservation

The farm sector is a large consumer of fresh water resources (Hoekstra *et al.*, 2009). Moreover, farming emits agro-chemicals and leads to increased erosion rates, thereby reducing the quality of water resources. Farming activities in some areas may demand a lowering of ground water tables, thereby reducing water resources for nearby wetlands. Thus, besides the direct use of water for agriculture, the impact of arable farming on water resources depends on the emission of agro-chemicals, erosion rates and changes in water flows.

Biodiversity

Farming affects biodiversity, most importantly by occupying large areas of land surface. Clearing natural lands for expanding agricultural activities is considered one of the main threats to the earth's biodiversity (Myers *et al.*, 2000; *WWF, 2010*). Land use efficiency (i.e. yield per ha) of existing arable lands in part determines the need to clear new lands for arable farming and thus also the impact of farming on biodiversity. Through pollution, farming may also more indirectly affect biodiversity, for instance, through the eutrophication of rivers. Farming may also contribute to the creation of habitats for rare species and some species have become largely dependent on agriculture for their survival, as their niche in their original natural habitat is not available anymore. Biodiversity in and around farmers' fields is often referred to as agro-biodiversity.

Climate change

Farming has an impact on climate change as greenhouse gasses are emitted during farm operations and during the production, storage and transport of agricultural inputs (machinery, fertilizers, biocides, etc.) (*Fluck, 1992*). Moreover, soils produce greenhouse gasses such as CO_2, CH_4 and N_2O through microbial activities. Converting natural lands into arable lands leads to a loss of carbon stored in the natural vegetation and also, in most cases, to increases in soil carbon losses and CO_2 emissions from the soil until a new equilibrium between carbon inputs and losses is reached. Soil carbon reserves and the losses of greenhouse gases from the soil are affected by field management. For instance, reduced ploughing leads to less oxidation of soil organic matter, increased soil carbon reserves (also referred to as soil carbon sequestration) and temporarily reduced CO_2 emissions. Anaerobic soil conditions, as typically occur in paddy rice fields, stimulate the production of CH_4.

[2] RSPO, http://www.rspo.org; SAI, http://www.saiplatform.org.

Overlap between themes

Theme 1, production efficiencies, partly overlaps with themes 2-5. Production efficiencies could act as drivers of change of themes 2-5. For instance, a low land use efficiency can result in a large land area required to satisfy the demand for agricultural produce, at the expense of natural areas. Clearance of natural vegetation for arable farming could lead to a loss of biodiversity, reduced quality of water resources and a temporarily increase in greenhouse gas emissions from the soil. Issues under theme 1 are often narrower in describing the environmental impact from farming than themes 2-5. For instance, energy use efficiency includes the use of fossil fuels required for agricultural production, as does theme 5, climate change, but theme 1 does not take into account changes in soil carbon storage as affected by agricultural practices, which also impacts climate change through emission of greenhouse gases. Themes 2-5, on the other hand, do not include issues regarding the depletion of resources linked to agricultural inputs. For instance, phosphate use efficiency is important for the sustainability of agricultural production, as world phosphate reserves are likely to become scarce in the next decades. The environmental impact of phosphate losses in farming however may be low in a given area and phosphate losses may be of little relevance for themes 2-5.

Another reason to use two types of sustainability themes is that the main agronomic impact from the adoption of the current generation of GM crops is a change in field management, which is usually relatively well documented and has a direct impact on production efficiencies (theme 1). The environmental impacts from the adoption of GM crops further downstream (themes 2-5) are more difficult to assess, if possible at all, and therefore usually poorly documented. As a result, the impact of GM crops on themes 2-5 is often more hypothetical and derived from changes in field management caused by GM crops as assessed under theme 1.

1.2.2 Profit

For the ‘Profit’ aspects, the following issues were selected:

- Farm income
- National income
- Economic welfare distribution
- Financial and other risks

These issues are based on the Global Report Initiative (GRI)[3]. The GRI is a network-based organization that has developed a global framework to support sustainability reporting. The framework contains indicators that organizations can use to measure and report their economic, environmental, and social performance. For a number of sectors, supplements with sector-specific indicators have been developed. For defining the ‘Profit’ issues, the food industry supplement was used.

The GRI guidelines have been put together from the perspective of individual institutions’ and companies’ contribution to sustainability. In this report, we extend the analysis to include also effects at a higher aggregation level. Farm income represents the micro-economic level. National income and economic welfare distribution represent the meso- and macro-economic level. Financial and other risks comprise the variation and uncertainty regarding economic impacts. Below, each issue is explained in more detail.

Farm income

According to the GRI, the core indicator for economic performance is the direct economic value generated and distributed, more in particular, revenues, operating costs including employee compensation, and profits, whether they are retained or distributed to capital providers. For firms, profits are the residual of revenues and costs and are the key variable for capital providers. For farms, farm income is the residual of revenues and costs. Revenues equal acreage times yield times price. Costs equal input quantities times input prices. Most empirical studies measure the impact on farm costs and revenues per hectare (or per acre). Revenues then become yield times price.

[3] GRI, http://www.globalreporting.org.

Farm income is the reward that farmers receive from the labour and capital that they provide to their farming activities. Farm income does not include wages paid for the labour input of farm employees; this aspect is dealt with under 'People'. In the calculation of farm income, these wages are regarded as costs for the farmer (or landowner). Farm households may also receive income from non-farm activities.

GM crops influence farm income because there are differences between GM and conventional crops in terms of yield and input use and as a result differences in revenues and costs. Farmers save on pesticides use, crop insurance, *et cetera*. They may need less (seasonal) workers for weed control. On the other hand, they spend more money on more expensive GM seeds. Farmers and their relatives also save time on weed control. The time saved may be used to improve farm operations or to undertake a second job. Farm and household income rise as a result. The 'Profit' part monetarizes the impact of GM crops on yield and prices (revenues) and pesticides, labour and other inputs (costs). At this point, 'Planet' and 'Profit' issues overlap.

Macro-economic effects of GM crop introduction by individual farmers may cause price shifts, which in turn affect farm income (see National income). This aspect is not accounted for in the Farm income section as it is a secondary effect, which occurs at a higher level of integration in response to initial changes at the farm level. Moreover, also the conventional substitutes are subject to these price shifts at the same time, so it will not affect the farmer's decision to switch from a non-GM to a GM variety, the more so as this individual farmer's choice has very little direct influence on these price shifts.

National income

At the national level, GDP (Gross Domestic Product) represents the value of all income generated in an economy. It is the final result of all production activities in the economy. GDP is aggregated over companies and sectors. The national accounts determine for each sector income (value added) as the difference between the value of production and the value of intermediary use (*Mankiw, 2009*). There are four types of income - wages, profits, interest and rent - which accrue to the production factors labour, capital and land.

Analyzing the impact of the GM crops on income at the sector or national level requires more than aggregating the impact on farm income for at least three reasons. (1) Analysis of the impact on farm income presumes that input and output prices remain constant. However, if yield rises and input requirements fall, supply of the crop may rise and prices may fall. One may assess the impact of changes in yield and input use on input and output prices in partial and general equilibrium models. (2) Analysis of the impact on farm income also presumes there are no major shifts in employment and land use in the economy. This is not always the case, especially in small countries. An increase in the use of land for soy or maize production may have a negative impact on the availability of land for other uses, such as other arable crops or nature. (3) An increase in supply and a fall in prices of GM crops may have a positive impact on a country's exports. If exports of the crop are substantial and considerable amounts of foreign exchange enter the country, this may have an upward effect on the exchange rate and negatively influence the exports of other products in the economy (this is commonly known as the 'Dutch Disease' effect).

Hence, in order to determine the impact of the introduction of GM crops on income at the sector and national level, but also in industries upstream and downstream in the supply chain (biotechnology, seed, livestock, meat and textiles), one needs to take account of price effects, shifts in land use and possible exchange rate effects.

Economic welfare

The economic impact of GM crops can also be evaluated using concepts from economic welfare theory. Economic welfare is captured in the concepts of producer surplus and consumer surplus. Producer surplus is the difference between revenues and costs and coincides with firm income or profits as outlined above. Consumer surplus is used to measure the difference between the price paid by consumers and the price they are willing to pay (reflecting the true value to the consumer). The resulting surplus can be considered as a 'profit' to the consumer, equivalent to a company's profits or producer surplus.

GM crop products are likely to be supplied at lower prices than those from conventional crops, if they require less inputs per unit output. If grower prices fall, the buyers of agricultural commodities – the fodder, livestock, meat and textile industry – are better off. Their input prices fall, as a consequence of which their value added goes up (all else being equal). If their output prices fall as well, *i.e.* if the fall in grower prices is transmitted to the final consumers in terms of cheaper meat, dairy and textiles, consumers are better off (their consumer surplus increases).

Producer and consumer surpluses (together with the government surplus of revenues over expenditures) may be used to evaluate economic welfare in a static world, *i.e.* given consumer preferences and production technologies. However, consumer preferences and production technologies change due to process, product and organizational innovations. From a welfare point of view, innovations are welcomed because they make products cheaper, improve product quality and widen product variety, which enhances producer and consumer surpluses. A theoretical framework for weighing consumer versus producer welfare following the introduction of GM products is given by Fulton & Giannakas (2004). They illustrate that the impact of GM crops on overall social welfare depends critically on consumer attitudes towards GM crops, the costs of segregating GM versus non-GM crops and the price strategies of life science companies.

GM crops may be interpreted as a process technology in the sense that they may reduce costs. This may be measured by the impact on costs (and prices) of GM crops (see above). GM crops may also improve product quality, *e.g.* have a higher nutritional content (*e.g.* golden rice: see Anderson *et al.*, 2004). The innovation rate depends, among other things, on the concentration in the biotechnology and seed industry. The biotechnology industry is concentrated in the sense that there few suppliers. Moreover, the suppliers are protected by intellectual property rights (IPR). This may give the seed companies substantial market power, which could be used in essentially two ways: (1) by raising seed prices and (2) by reducing risky and costly investments in the development of new seeds. In both cases welfare may be negatively affected. If seed prices go up, consumer surplus goes down. If the companies reduce R&D (Research and Development), biotechnology companies may reduce the innovation rate which could lower welfare in the long run.

Financial and other risks

GM crops are likely to have an influence on risks associated with variation in yields, market access and liability. GM crops may reduce risks at the farm level (variation in crop yield), but can raise risk at the sector level (*e.g.* market access).

Risk may be defined as the possibility that undesirable situations arise with negative consequences, such as losses. Two elements matter when talking about risk: the chance that an undesirable situation occurs and the (financial) consequences of this situation. There are many important risks in the agriculture sector, such as (*Harwood* et al*., 1999*):

- Production risks refer to the production process. There is uncertainty about crop yield and quality due to (partly) uncontrollable factors such as weather conditions and disease and pest incidence. Crop choice influences the risks taken. Production risks also include uncertainties regarding the availability and quality of inputs, such as seed and fertilizers.
- Institutional risks refer to changes in law and legislation, *e.g.* with respect to market access of GM crops.
- Legal / compliance risks refer to a company's or farm's non-conformance with or violations of laws, regulations, prescribed practices or ethical standards, for instance, in relation to products, personnel, business partners, the environment or community. This might result in liability or responsibility for loss or damage.
- Financial risks refer to the possibility that the company's or farm's capital or income is affected, i.e. by production, institutional, or legal risks.

The ability to deal with risks depends on a company's liquidity and solvability, which are the ability to obtain money in the short run and the ratio between debt and equity, respectively. Liquidity indicates whether one is able to meet one's short run financial obligations. Solvability indicates whether a firm is able to meet its long run financial obligations.

Most empirical studies discussed below provide qualitative information on the impact of GM crops on production risks. This information is related to the analysis of the agricultural system in the 'Planet' part (*e.g.* production efficiencies). There is limited evidence on the other risks.

1.2.3 People

For the 'People' aspects, the following themes were selected:

- Labour conditions
- Land rights, rights of indigenous people and community rights
- Freedom of choice
- Competition with food production
- Contribution to livelihood of producers and local communities

These issues were identified from a wide variety of sources, and are primarily based on the Universal Declaration of Human Rights (UDHR). Conventions and standards like those of the International Labour Organization (ILO), the Dutch NTA 8080 (standard for biofuel production and use), and the crop-specific Round Table on Responsible Soy (*RTRS, 2010*) provide ways to apply the principles of the UDHR in contexts of agricultural production[4]. Each issue is described here to identify the reason for its selection, matters that must be considered when examining it, and limitations in data availability and to the ability to make empirical generalizations.

It should be kept in mind that many issues overlap considerably with 'Planet' and 'Profit' considerations. As one example, the use of GM crops can change the amount and type of agrochemicals used on-farm. This will have an effect on environmental impacts ('Planet'), as well as farm income and income distribution if this change in agrochemicals means a change in costs ('Profit'). However, there is also a potential effect on the health and safety of workers and nearby communities ('People').

Study format and limitations:

As the introductory section of this report states, the comparison of the sustainability of GM and non-GM crop production is based on a review of scientific and other literature. Compared to other sections of this report, there is a relatively limited amount of literature that analyzes 'People' aspects in a thorough and scientific manner. It is also very difficult to attribute the causation of some social impacts to GM or non-GM crop cultivation, particularly since GM crop cultivation is only one part of the transformations that have taken place in many countries' agriculture sectors over the past years, and in many countries, it only happened recently. Since this review relies on existing studies and information, isolating GM or non-GM crop production as a causal factor is, in many cases, not possible.

To overcome this limitation as much as possible and to ensure that information which may be relevant is not dismissed, the 'People' sections of this report first present general overviews of the production issues in the respective crop species. Subsequently, hypotheses of how GM crop cultivation could have relevant impacts (theorized effects) are described in the same way as in several sections of the 'Planet' and 'Profit' parts with a comparable lack in published studies. These hypotheses are formed based on an understanding of the existing production systems and the expected changes arising from the characteristics of the GM crop. The hypotheses are tested by an examination of the available information in order to determine whether there is evidence that the theorized impacts have or have not occurred. It must be stressed that a lack of evidence does not necessarily support the conclusion that the hypothesis is incorrect. It is also possible that simply not sufficient scientific information has been found to draw a firm conclusion.

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[4] UDHR, http://www.un.org/en/documents/udhr;.ILO, http://www.ilo.org; Dutch NTA 8080 standard for biofuel production and use, http://www.duurzame-biomassa.org/publicaties/3938; RTRS, http://www.responsiblesoy.org.

Labour conditions

The International Labour Organization's (ILO) conventions and recommendations set international labour standards that form the basis of most initiatives and standards dealing with labour. ILO's Forced Labour Convention, Right to Organize and Collective Bargaining Convention, and Safety and Health in Agriculture Convention contain the issues chosen to use in examining this issue[5].

When examining the impact of GM crop cultivation on labour conditions, it will be necessary to consider several different factors. These may include the technology's effects on barriers to organization and collective bargaining of labourers, the existence of forced labour and/or child labour, the presence of working conditions that threaten health and safety and/or worker dignity, gender issues and workplace discrimination, and the situation of migrant and seasonal workers. Not all of these factors will necessarily be relevant in all of the cases studied.

The impact of GM cultivation on labour intensity and employment opportunities can be considered either positive or negative, depending on the perspective chosen. From the farm-level profit perspective, a reduction of required labour inputs is a potential positive impact of GM crops. However, the unequal distribution of this economic benefit (*e.g.* unemployment of farm workers) could also be considered as a possible negative impact. In the 'People' sections of the report, only direct (on-farm) labour impacts are examined. Employment elsewhere may also be affected by the adoption of GM crops, but these potential national-level developments are addressed in the 'Profit' (national income and economic welfare) sections.

Land rights, and indigenous and community rights

The importance of considering the rights of local communities and/or indigenous people is recognized by the UDHR as well as ILO Convention 169 on Indigenous Peoples' Rights (*ILO, 1989*) and the UN Declaration on the Rights of Indigenous People of 2007 (*UNPFII, 2007*). Though international law recognizes the importance of customary land rights, some national legal systems fail to offer sufficient protection, and so, examining legal compliance as such does not adequately address this issue.

Examining the impact of GM crop cultivation on land rights and the rights of indigenous peoples and communities means potentially considering the crop's effects on the existence of land conflicts which demonstrate insufficient participation and consent processes or lack of appropriate compensation for land, on the involvement of indigenous people in these conflicts, and/or on threats to the preservation of cultural heritage and to local traditional practices.

Freedom of choice

Maintaining the fundamental principle of enabling farmers and consumers to choose, in this case between competing technologies, has not been addressed by mainstream international conventions or standards relating to the production or use of agro-commodities. However, most stakeholders involved in the debate on GMOs consider the freedom of choice an important issue as some groups of producers and consumers strongly oppose GM technologies.

It is therefore relevant to consider whether or not GM crop introduction is accompanied by safeguards to preserve this autonomy and freedom of choice between different methods of production. Freedom of choice and autonomy for farmers are not absolute rights, and may be limited by factors such as the rights of others or technical developments and the availability of alternative techniques. Successful innovations may eventually lead to the total replacement of other methods or techniques, for instance because older methods or techniques are not economically or commercially viable anymore.

Measuring freedom of choice requires examination of issues such as the availability of a seed market and of a market outlet for both GM and non-GM production, the existence of infrastructure necessary to maintain segregation of GM and non-GM production, the availability of financial support for cultivation of GM and non-GM varieties, the

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5 ILO's Forced Labour Convention, http://www.ilo.org/ilolex/cgi-lex/convde.pl?C029, Right to Organize and Collective Bargaining Convention, http://www.ilo.org/ilolex/cgi-lex/convde.pl?C098 and Safety and Health in Agriculture Convention, http://www.ilo.org/ilolex/cgi-lex/convde.pl?C184.

extent to which farmers are able to influence and partake in technical developments, the influence of existing intellectual property right and technology fee systems, and/or the likelihood of 'technical lock-in'. The term 'technical lock-in' is used to describe a situation in which it is impossible to reconsider the choice of technology (and switch back to non-GM crops). Technical lock-ins can occur because of agronomic characteristics of the crop that result in persistence of the GM materials, as well as because of the associated infrastructural changes on a farm or 'deskilling' of farmers that may occur as they adopt a new technology package, thereby limiting farmer's flexibility and capacity to accept change. Access to timely and reliable information for all stakeholders is regarded as a necessary requirement to exercise one's freedom of choice, especially when it concerns matters surrounded by controversy, such as GMO's (Wolson, 2007). Limited or biased information on the characteristics of GM and non-GM crops may limit the freedom of choice.

It should also be realized that there is a difference between a limitation in choice due to, for example, the financial capacity of a farmer, and limitations to the *freedom* of choice due to, for example, external pressures. When a farmer cannot afford to buy GM seed, this may limit the farmer's choice but it does not affect the farmer's freedom of choice. When the farmer is forced to buy GM or non-GM seed because this is a condition to a loan, when a farmer would only receive technical assistance when cultivating GM crops or when non-GM seed is not available on the market any more, this is considered to limit the farmer's freedom of choice.

Freedom of choice can also be related to the freedom of consumers to choose GM or non-GM products. However, this report focuses on changes in production systems and does not examine issues of consumer choice, labelling requirements, etc.

Competition with food production

This issue is a macro-level effect that generally cannot be addressed effectively by conventions and standards, but has emerged in international debate as a critically important consideration, particularly in the light of changing food prices over the past years. The UDHR recognizes a human 'right to food,' as does the Dutch NTA 8080. Here we examine what impact the changing patterns of land use may have on the resources that local populations depend on.

Large-scale agricultural production for export is an existing trend causing competition with food production for local markets in many regions. However, a farmer's choice to grow 'cash crops' rather than, or next to subsistence crops is influenced by many different factors, which may or may not include the availability of GM crops. The choice to grow cash crops also may or may not have an impact on food security, depending on the extent to which local populations are able to access alternative sources of food (*i.e.*, have sufficient purchasing power to buy food on the market). Determining the impact of GM crop cultivation requires looking not only at the impact on local food production, but also the resulting impact on food prices and food availability, since other sources may compensate for reduced local or regional food production. In making these observations, though, it can be very difficult to distinguish the impact of GM cultivation from broader trends in agricultural sectors.

Contribution to livelihood of producers and local communities

The UDHR recognizes a right to an adequate standard of living, and some standards, like that of the Sustainable Agriculture Network or Round Table on Responsible Soy, require certain contributions to local communities. For example, producers are often assessed based on the amount of local employment opportunities that they provide or locally-sourced inputs they purchase. This issue is examined here to determine the impact of GM versus non-GM crop cultivation on producer and community livelihoods, with an understanding that these impacts may be distinct from the direct financial consequences of GM versus. non-GM crop cultivation.

The direct financial impacts of GM cultivation are relevant for consideration here, but are primarily addressed in the 'Profit' sections of this report. The 'People' sections examine the effects of these financial impacts on income security, the distribution of benefits to small farmers, and where relevant, potential impacts on community development, threats to community safety and security and/or prosperity-related investments. This issue can also include long-term potential livelihood impacts if, for instance, adopting a GM technology package results in farmer's loss of agricultural skills ('technical lock-in', see also under 'Freedom of choice' above) or has impacts on the environment on which communities depend.

2. Soybean

2.1 General characterization of cultivation and trade

In terms of area and production volume, soybean or soya bean (*Glycine max* (L.) Merr.), in short soy (US) or soya (UK), is the most important oil and protein crop in the world. In many respects, soybean is an excellent crop to produce plant proteins. Soybean, being a legume crop fixing atmospheric nitrogen, needs little to no nitrogen fertilizer and achieves a high protein yield per ha. Soybean can be produced efficiently on a large scale with a minimum of labour inputs. The non-perishable beans have a high protein concentration and contain an amino acid composition that is particularly favourable for use in poultry and pork feed. These characteristics, combined with EU policy decisions to abandon subsidies on the production and processing of domestically produced protein-rich seed crops in 1993, and to restrain the use of animal proteins in livestock feed, have contributed to a tremendous increase in the use of soybean meal in poultry and pork feed in the EU in the last 20 years. By 2008, soybean covered 68% of the total demand for proteins used in animal feeding in the EU (*Bouxin, 2009*). Soybean oil has a wide range of applications in the food and chemical industry, while the use of soybean products in human foods is minor in the EU. In the Netherlands, 93% of the soybean consumption is used in animal feed, 0.5% in industrial applications and 6.5% in human food (*Hoste & Bolhuis, 2010*).

Soybean is produced on relatively small areas within the EU (Italy, Romania, France). In 2008, the EU-27 produced 0.65 million tonnes of soybean (*FAOSTAT, 2010*). The EU annually imports about 15.4 million tonnes of soybeans and 24-25 million tonnes of soybean meal (*MVO, 2009*). The three main suppliers of soybean products to the EU were Brazil (46%), Argentina (38%) and the US (10%) in 2008 (*Eurostat, 2010*). Several minor suppliers of soybean products to the EU (6%), for instance Norway, do not cultivate soybean themselves, and most of this soybean probably also originated from the Americas. Assuming that these other suppliers obtained their soybean from Brazil, Argentina and the US in the same ratio as the EU did, the soybean products imported in the EU would be cultivated in Brazil (49%), Argentina (40%) and the US (11%). Paraguay, Bolivia, Canada, the Ukraine and Russia export small amounts of domestically produced soybean to the EU, which is not considered here. Countries in Asia, such as China and India, are major producers of soybean, but their production is almost entirely consumed within the region. China's strong demand also largely absorbed recent increases in production in the Americas (*MVO, 2009*). Because of the prominent role of the harbour of Rotterdam in Europe, the Netherlands are responsible for a large share of the annual soybean imports in the EU. The Netherlands imported 8.9 million tonnes of soybean products in 2006, while the export equalled 5.9 million tonnes of soybean products (*Fediol, 2009*). A large part of the beans imported in the Netherlands is processed into oil and meal, which are subsequently exported to other EU countries.

While the amount of soybean produced in the US has been relatively stable, soybean production increased from 16 to 57 million tonnes in Brazil and from 12 to 32 million tonnes in Argentina between 1990 and 2009 (*USDA, 2010*). Most of the future expansion of soybean cultivation, among others to fulfil the rapidly growing demand for soybean products in China, will probably occur in Latin America as well (*FAPRI, 2009*). The expansion of the soybean production in Latin America has been an engine behind socio-economic development in the region, but also raised sustainability concerns among actors in the soybean chain and consumers of soybean products in the EU. Especially the risk of overexploitation of the enormous biomes in Latin American countries, most notably the Amazon, the Cerrado, the Pampa and the Chaco, received lots of attention. Other aspects of the cultivation practices of soybean also raised concerns, such as the large scale of operations, the pollution due to the use of agro-chemicals, and the social implications for rural people. In response to these concerns, the global platform Round Table for Responsible Soy (*RTRS, 2010*) was established with the aim to promote responsible soybean production, bringing together some of the main stakeholders in the soybean chain (*RTRS, 2010*). The RTRS developed a set of principles and criteria for responsible soybean production and aims to implement these in the near future. With regard to the animal production chain in the EU, the question can be raised whether feeding livestock with soybeans produced on other continents is an acceptable practice for a sector that strives after a high level of sustainability. These general sustainability issues in the soybean chain and the associated livestock chain will not be assessed in further detail in this chapter, as the focus is on those sustainability issues that are affected specifically by the availability of genetic modifications in soybean.

2.2 Genetic modifications

2.2.1 Current events

Farmers in the world's main soybean exporting nations – the US, Brazil and Argentina– adopted genetically modified (GM) soybean at a large scale. In the US, 92% of the planted soybean was GM in 2008; in Brazil this was 65%; in Argentina this was 99% (*USDA/FAS, 2009*). Up to 2008, the only type of GM soybean commercially grown was the so-called Roundup Ready® soybean (RR soybean). Thus in the rest of this chapter on soy, GM soy will refer to RR soybean, unless stated otherwise. RR soybean contains a trait leading to tolerance to the broad-spectrum herbicide glyphosate. While glyphosate may also be used in non-GM soybean as a pre-emergence herbicide, RR soybean enables the application of glyphosate before and after crop emergence. RR soybean has been launched with the aim to facilitate weed control in soybean, as glyphosate application after crop emergence may provide more effective weed control than application of the herbicides used in non-GM soybean. Moreover, RR soybean may allow a more flexible timing of herbicide application and a reduction in the number of herbicide applications, providing opportunities to save labour. These advantages were important drivers behind the high adoption rate of RR soybean by farmers. The RR trait has been patented by Monsanto Company, which implies that all RR soybean varieties (the RR event is nowadays present in many varieties) are produced by Monsanto Company or under licence of Monsanto Company. The patent on RR soybean will expire in 2014 (*Kaskey, 2010*). The US patent on glyphosate expired in 2000 and many companies produce and sell glyphosate these days.

In Northern America, the commercial cultivation of the new Roundup Ready® 2 soybean was initiated at a small scale in 2009. This soybean line, also marketed by Monsanto Company, has the same glyphosate tolerance as RR soybean, but this resistance has been incorporated into a different line in a position next to non-GM genes that are claimed to lead to a higher yield potential. This type of soybean is therefore called Roundup Ready®2Yield (RR2Y) soybean. According to Monsanto Company, RR2Y has a 7-11% higher yield potential than comparable soybean varieties without these traits. This yield increase has not been confirmed through independent field research yet and there is little practical field experience with the cultivation of RR2Y soybean up to now.

The company Bayer CropScience commercially launched a new type of GM soybean, Liberty Link® (LL) soybean, on the northern American seed market in 2009 (*Bayer CropScience, 2009*). The LL trait in soybean leads to tolerance against the broad-spectrum herbicide gluphosinate-ammonium. LL soybean has been commercially launched with the aim to facilitate weed control in soybean and can offer the same advantages to farmers as RR soybean. Moreover, LL soybean helps to reduce the reliance on glyphosate that has become the main pillar in weed control for the many soybean farmers that adopted RR soybean.

RR, RR2Y and LL soybean have all been approved for import and processing in the EU (*GMO Compass, 2010*), but not for cultivation within the EU.

2.2.2 Events in the commercial and regulatory pipeline

It is expected that several new events in soybean will be launched for commercial cultivation in 2011-2012:

- The seed company Pioneer Hi-Bred received approval in the US to market a GM line with traits providing resistance against glyphosate and herbicides belonging to the class of the ALS inhibitors. This so-called Optimum® GAT® soybean has not been commercialized yet, and approval for import and processing in the EU is still pending.
- Embrapa, the Brazilian Agricultural Research Corporation, together with the multinational BASF, has developed a type of GM soybean that is resistant against the herbicide imidazoline (class of the ALS-inhibitors). This so-called Cultivance® (CV) soybean was approved by Brazil's national Technical Biosafety Committee, CTNBio, for

commercial release in Brazil late 2009 (*CTNBio, 2010*). The product will probably be commercially launched from the 2011/2012 season onwards (*BASF, 2010*). In Europe, CV soybean has been submitted for registration.

- The international seed companies working with GM are all developing events in soybean that lead to an altered oil or amino acid composition. Probably Pioneer Hi-Bred will be the first with the commercial launch of a GM soybean with altered grain qualities (i.e. an increased content of oleic acids). This event may be commercially launched at a small scale in the US in 2010. A request for registration of this event in the EU has been submitted. Other events in soybean that lead to altered grain qualities are currently in the research phase. This includes beans with an increased content of Omega 3 fatty acids and beans with an amino acid composition targeted at the demand of the animal feed industry.
- In China, a GM soybean line with insect resistance is apparently in the regulatory pipeline (*Stein & Rodríguez-Cerezo, 2009*). This event has not been submitted for authorization in the EU.

Biotech companies and public research institutes are also working on incorporating events in soybean that lead to the resistance to various pests and diseases and to tolerance to abiotic stresses such as heat and drought. However, it will probably still take at least several years until these events may be commercially released. In addition, the company Syngenta has a GM soybean in the research pipeline with resistance against particular nematodes (for a more extensive review on traits in the pipeline, see*Stein & Rodríguez-Cerezo, 2009*).

2.3 GM-related sustainability – Planet

Up to 2008, the only event in commercially cultivated soybean worldwide was the RR trait and lots of experimental and farmers' field data have been gathered on the management and environmental impacts of RR soy. The new events (LL and RR2Y) were only cultivated at a small scale in the US in 2009 and data on the performance of the new events, relative to non-GM soy, are scarce. In this assessment of the sustainability impacts of GM in soybean, most emphasis is therefore put on the observed impacts of RR soy. The anticipated impact of recently released events or events in the pipeline are briefly discussed.

2.3.1 Production efficiencies

2.3.1.1 Land

RR soybean was introduced with the aim to facilitate weed control and not with the aim to increase soybean land use efficiency (yield). Experimental data on the yield of soybean varieties in Argentina in 1984-2000 showed that the RR trait in soybean in the early years after the introduction of RR soybean (1996-1997) came with a yield penalty (*Santos* et al.*, 2000*[6]). These differences in yield between RR soybean and non-GM soybean were possibly caused by a higher sensitivity of RR soybean to drought stress (Keller & Fontanetto, 1998) or by the use of old or poorly adapted varieties for the production of RR soybean. In later RR varieties (e.g. in 2001), yield differences were overcome in Argentina (Qaim & Traxler, 2005). Also in Canada, RR soybean lines were reported to give 4% lower yields in variety trials than non-GM soybean and this was attributed to the use of poorly adapted germplasm in the early years after the introduction of RR soybean (*OOPSCC, 2005* in: Beckie *et al.*, 2006). Canadian farmers did not confirm the lower yield of RR soybean and sometimes reported higher yield of RR soybean because of an improved weed control (Beckie *et al.*, 2006). Similarly in Brazil, RR soybean was reported to give lower yield than non-GM soybean in experimental trials (Furlaneto *et al.*, 2008), but this was not confirmed by farmers. In case weed pressure in non-GM soybean is limiting yield, RR soybean can give a higher yield than non-GM soybean. Farmers' yields of RR soybean in Romania and in Mexico, for instance, were reported to be higher than those of non-GM soybean (Brookes, 2005; Brookes & Barfoot, 2008). In Argentina, a so-called 'second crop benefit' associated with RR soy has been identified (Brookes & Barfoot, 2009). As RR soy in combination with zero tillage (see below) requires less field operations and allows sometimes a more flexible timing of field operations, it provides opportunities to grow a second crop after soybean. This second crop is usually wheat in Argentina. Through such an

[6] Paper in conference proceedings.

intensification of the crop rotation, more produce can be obtained from an area of arable land, and thereby the available arable land is used more efficiently.

Also the new events in GM soybean that lead to tolerance to broad-spectrum herbicides are unlikely to have much impact on yield. Only the recently introduced RR2Y soybean has, according to the owner Monsanto Company, the potential to give 7-11% higher yield in the Mid West of the US than comparable non-GM varieties, but these findings have not been confirmed through independent field research yet. In a more distant future, the availability of GM soybean with traits leading to drought tolerance, heat tolerance or insect resistance could increase yield under specific growing conditions, namely when drought, heat or particular pest insects are yield-limiting in non-GM soybean.

Conclusion

While there is some evidence that the RR trait came with a reduction in land use efficiency ('yield drag') in the early years after its introduction in soybean, field experience with the cultivation of RR soybean in later years provided no evidence that RR soybean yields are structurally different from those of non-GM soybean. If RR soy allows a more intense cropping pattern, *e.g.* in Argentina where RR soybean allows a second crop to be cultivated within the same growing season, RR soy could contribute to a more efficient land use.

2.3.1.2 Fertilizers

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
RR soybean has been engineered to facilitate weed control and not to alter nutrient management in soybean. It is therefore expected that the availability of RR soybean has no direct impact on nutrient use by the plant or on farmers' fertilizer application strategies.

Evidence of difference between GM and non-GM production

There is evidence from experimental trials that post-emergence glyphosate applications associated with RR crops could affect the crop's nutrient uptake. Glyphosate affects an enzyme involved in the synthesis of aromatic amino acids. This pathway is present in plants as well as in fungi and bacteria. Glyphosate can be released from the roots of glyphosate-resistant crops and thereby affect the activities of rhizosphere bacteria and fungi that assist in making nutrients available for plant uptake (Kremer *et al.*, 2005).

A field experiment in the US by *Gordon (2007)* indicated an interaction of the RR trait with the response to manganese (Mn) applications. In this study, RR soybean showed a higher sensitivity to Mn stress than isogenic non-GM soybean lines. It was hypothesized that glyphosate applications in RR soybean may interfere with the plant's Mn metabolism and also adversely affect populations of soil micro-organisms responsible for the reduction of Mn into a plant-available form. Increased application rates of Mn corrected the deficiencies in RR soybean. Also Kremer & Means (2009) noticed in field trials with RR soybean and maize an impact of root-exudated glyphosate on Mn transformation and availability.

In greenhouse experiments in the US, nitrogen fixation by bacteria in the nodules of RR soybean varieties was shown to be reduced when the crop was treated with glyphosate at an early stage (5 and 10 days after emergence) (King *et al.*, 2001). Also nitrogen accumulation and biomass growth in plants were reduced. Plants had recovered however by 40 days after emergence. In growth chamber studies, nitrogen fixation was more sensitive to water deficits in glyphosate-treated plants. Also, it was noticed in field studies that glyphosate formulations can inhibit nodule development in RR soybean, but soybean had the potential to recover from glyphosate stress (Reddy & Zablotowicz, 2003). Kremer & Means (2009) noticed in a field experiment in the US that RR soybean treated with glyphosate had less nodules (providing symbiotic bacteria with conditions required for nitrogen fixation) than non-GM soybean untreated with glyphosate, which suggests a reduced capacity of RR soybean to fix nitrogen. Also a field experiment in Brazil indicated that RR soybean treated with glyphosate showed a reduction in nodule mass and nitrogen fixation and this could not be assigned to the genetic modification of the plant (Bohm *et al.*, 2009). Yield was not affected by glyphosate applications, suggesting that soybean plants treated with glyphosate more heavily depended on soil nitrogen reserves. Application of the herbicide imazethapyr, commonly used in non-GM soybean, did not have such effects on nitrogen fixation, but did reduce soybean yield.

Conclusion

There is evidence from experimental trials that nodulation and nitrogen fixation, as well as the uptake of manganese by the soybean plant can be negatively affected by the use of glyphosate in RR crops. Nevertheless, we found no studies indicating that nutrient management strategies in farmers' fields are any different between RR and non-GM soybean.

2.3.1.3 Biocides

When RR crops were introduced in the 1990s, RR soybean and other RR crops were expected to offer the opportunity to replace a cocktail of herbicides used in non-GM crops with a relatively strong environmental impact by glyphosate that has less impact on the environment. At the same time, weed scientists were already concerned that the reliance on a single herbicide, glyphosate, could lead to a shift in the weed species composition and to the development of glyphosate-resistant weeds (Lotz *et al.*, 1999).

Evidence from the field confirmed that when US farmers shifted from non-GM to RR soybean, their herbicide use changed dramatically with a strong increase in the use of glyphosate and a strong decrease in the use of more selective herbicides. The impact of RR soybean on the total amount of herbicides used was less obvious. Based on USDA NASS data, Bonny (2008) noticed that the total amount of herbicides applied on soybean fields in the US (kg active ingredients per hectare or kg a.i. per ha) in 1996-2006, a period in which RR soybean almost entirely replaced non-GM soybean, decreased between 1996-2001 and increased irregularly between 2002-2006. In 2006, the herbicide application level in soybean (around 1.6 kg a.i. per ha) exceeded that in 1996. *Benbrook (2009)* confirmed this trend and noticed a further increase in herbicide use in soybean in the US between 2006 and 2008, also on the basis of USDA NASS data. In this period, herbicide use in non-GM soybean declined.

A strong reliance on glyphosate for weed control in RR crops most likely resulted in a shift in weed species and in the development of glyphosate-resistant weed biotypes (Powles, 2008). Since the introduction of RR crops in the US, at least nine weed species developed glyphosate-resistant weed biotypes in the US (*Heap, 2009*). No glyphosate-resistant weeds were recorded before the introduction of RR crops. Although the observed increase in the use of herbicides in soybean cannot be directly attributed to the emergence of herbicide-resistant weed biotypes, it is likely that a reduced efficacy of glyphosate due to herbicide-resistant weeds stimulated RR soybean producers to increase the dose of glyphosate or apply other additional herbicides to soybean.

The use of herbicides in soybean in Latin America has not been documented as extensively as in the US, but it is likely that similar developments occurred (Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2007). Data on herbicide use in RR and non-GM soybean in the main soybean production area of Argentina (Districts of Buenos Aires and Santa Fe) collected by extension officers in 2002-2007 suggested that RR soybean received substantially more herbicides than non-GM soybean (an increase of 1.25-2.88 kg active a.i. per ha) due to high glyphosate application rates in RR soybean (*Bindraban* et al.*, 2009*). Since the introduction of RR crops in Argentina, Brazil and Paraguay, six weed species developed glyphosate-resistant biotypes, while none was recorded before their introduction (*Heap, 2009*).

Rotating RR soy with non-GM soy offers opportunities to diversify weed management and slow down or prevent the development of glyphosate-resistant weeds. The forthcoming GM events in soybean that lead to tolerance to broad-spectrum herbicides, such as LL soybean, also offer opportunities to reduce the reliance on glyphosate as the central pillar in weed control and thereby lower the risk of the emergence of glyphosate-resistant weed biotypes. However, if these new GM events in soybean lead to a reliance on a single herbicide for weed control as occurred in RR crops, similar problems with herbicide-resistant weeds and gradually increasing herbicide application rates could be anticipated.

Glyphosate has a relatively low environmental impact as indicated by a low EIQ value attached to it (Table 2.1). Glufosinate-ammonium associated with LL soybean has an average EIQ value, in comparison with the other herbicides used in soybean. In the US the herbicides trifluralin, pendimethalin, chlorimuron ethyl, imazaquin and imazethapyr are typically used in non-GM soybean (Bonny, 2008). In Argentina, herbicides used in non-GM soybean include haloxyfop, 2,4-D, imazethapyr, metsulfuron, dicamba, metribuzin and glyphosate (pre-emergence) (*Bindraban* et al.*, 2009*). In Brazil, it concerns imazethapyr, chlorimuron-ethyl, haloxyfop, 2,4-D, fluazifop-P butyl and lactofen (*Osaki & Batalha, 2009*). Various studies compared field EIQ values (i.e. EIQ values multiplied by application rates) of herbicides applied in RR and non-GM soybean in northern and Latin America (Brookes & Barfoot, 2008; Bonny, 2008; Kleter *et al.*, 2007) and concluded that, although the total amount of active ingredients applied in both systems was not very different, the field EIQ of RR soybean was slightly lower than that of non-GM soybean because of a low toxicity of glyphosate in comparison with the herbicides used in non-GM soybean. The study by *Bindraban* et al. *(2009)* on the other hand reported a higher field EIQ of RR soybean in Argentina in comparison with non-GM soybean due to a high application rate of active ingredients in RR soybean.

Conclusion

Evidence from various countries confirmed that RR soybean offers the possibility to improve the environmental profile of the herbicides used in soybean but also entails the risk of gradually increasing glyphosate application rates leading to an environmental impact that is equal or worse compared to that of non-GM soybean. The development of glyphosate-resistant weeds in RR crops appears to have stimulated farmers to increase the applications rates of herbicides in RR crops in recent years.

Table 2.1. Herbicide EIQ values and energy consumption for the production of herbicides associated with non-GM, RR and LL soybean in northern and Latin America.

Type of soybean	Active ingredient	EIQ [1] (per kg a.i.)	Energy (MJ per kg a.i.)
non-GM	2,4-D	24.0	85 [2]
	Chlorimuron ethyl	19.2	365 [2]
	Dicamba	25.3	295 [2]
	Fluazifop-P butyl	28.7	518 [2]
	Haloxyfop	Not available	385 [3]
	Imazaquin	15.3	
	Imazethapyr	19.6	298 [4]
	Lactofen	Not available	
	Metribuzin	28.4	200 [3]
	Metsulfuron-methyl	16.7	337 [4]
	Pendimethalin	30.2	
	Trifluralin	18.8	150 [2]
RR soybean	Glyphosate	15.3	454 [2]
LL soybean	Glufosinate-ammonium	20.2	

[1] *Environmental Impact quotient, see Kovach et al. (2009).*
[2] *Green (1987) in: Helsel (2006).*
[3] *Nagy (1999).*
[4] *Johnston & Cowell (1997).*

2.3.1.4 Energy

Energy use in a crop is determined by the direct use (e.g. energy necessary for soil tillage, applications of agro-chemicals, transport of grain) and energy required to produce inputs and implements (e.g. the production of herbicides and tractors) (Hülsbergen *et al.*, 2001).

THEORIZED EFFECTS
Any difference in energy use efficiency between RR and non-GM soybean can be expected to arise from differences in weed management and soil cultivation methods between RR and non-GM soybean. The amount of energy required to produce or apply herbicides is expected to be more or less similar in both types of soybean. Fewer land cultivation operations in RR soybean (see section 2.3.2 on soil conservation), relative to non-GM soybean, is expected to save energy.

Evidence of difference between GM and non-GM production

The energy required for weed management depends on the amount and type of herbicides used and the application methods. From Table 2.1 it is clear that the production of glyphosate is energy-intensive relative to that of other herbicides applied in soybean. If the total amount of herbicides applied in RR and non-GM soy is the same, a switch from herbicides used in non-GM soy to glyphosate is thus likely to increase the energy demand for the production of herbicides. The application of biocides with a tractor and a tank sprayer requires 1-2 litres of diesel (38.6-77.2 MJ) per ha (Helsel, 2006). The application of herbicides by airplane, as large-scale soy farmers commonly do, is more energy-intensive per ha than application by tractor. RR soy sometimes requires fewer herbicide applications than non-GM soybean which thereby reduces energy demand from mechanized application (Qaim & Traxler, 2005). The overall impact of RR soybean on energy costs in weed management is thus likely to vary in place and time.

Soil conservation tillage (see section 2.3.2) requires less energy for soil operations than conventional tillage as less passes with sometimes lighter equipment are made over the land in soil conservation tillage systems. A switch from conventional to no tillage systems in the US has been estimated to save 32.7-53.3 litres of diesel (1262-2057 MJ) per ha (*Fawcett & Towery, 2002*). A switch from conventional tillage to reduced tillage was estimated to save 18.7 litres (722 MJ) per ha. Energy savings associated with the implementation of soil conservation tillage systems may exceed a possibly higher energy use required to produce herbicides applied in RR soybean. However, whereas the energy required to produce herbicides can be directly attributed to the type of soybean cultivated, this is more difficult for the adoption of soil conservation systems, as discussed below in section 2.3.2.

Conclusion

The energy used for weed management in RR crops may be different from that of non-GM crops depending on the amount, the type and the application methods of the herbicides used. The recent trend to use higher amounts of herbicides in RR soybean in some regions (see section 2.3.1.3) will increase energy consumption. Soil conservation tillage practices, associated with RR soybean, can provide substantial energy savings. No comprehensive studies to the total energy use in RR and non-GM soybean have been found and no firm conclusions can be drawn with regard to differences in energy use between GM and non-GM soybean.

2.3.1.5 Water

THEORIZED EFFECTS
The RR trait is not expected to influence water use in soybean. Therefore, it is expected that water use efficiency in RR and non-GM soybean is similar.

Evidence of difference between GM and non-GM production

Early RR soybean lines introduced in Latin America were possibly more sensitive to drought stress than non-GM varieties (*Keller & Fontanetto, 1998*), making these varieties less suitable for cultivation in drier areas. Later varieties of RR soybean did not show this difference with non-GM soybean. In growth chamber studies in the US, nitrogen fixation in early RR soybean varieties was found to be more sensitive to water deficits after glyphosate application (King *et al.*, 2001), which could perhaps also explain the drought sensitivity of RR soybean plants in Argentina.

Indirectly, by promoting the use of soil conservation tillage systems, HT GM soybean can have a positive impact on the crop's water use efficiency. Soil conservation tillage systems often lead to better soil physical properties and a better water retention capacity in drier areas (Buschiazzo *et al.*, 1998).

If a type of GM soybean with an increased drought tolerance will be commercially released in the future, this could substantially improve the water use efficiency of soybean in dry environments.

Conclusion

We found no evidence that water use by RR soybean is somehow structurally different from that of non-GM soybean.

2.3.2 Soil conservation

There is a large body of publications showing that soil conservation tillage can help to improve the sustainability of farming as it assists in reducing soil erosion, improving soil physical, chemical and biological properties and minimizing the environmental costs of ploughing (Bernoux *et al.*, 2006; Boddey *et al.*, 2003; Follett, 2001; Buschiazzo *et al.*, 1998). Especially soil erosion is associated with very high economic and environmental costs, which occur both on-farm and off-farm (Pimentel *et al.*, 1995), Reduced tillage is however not solely associated with positive impacts on the sustainability of farming. Zero tillage could in some circumstances lead to soil compaction, an increased abundance of pests and diseases overwintering in residues, and an increased soil acidity due to less opportunities to incorporate lime into the soil (e.g. for Brazil, see Bolliger *et al.*, 2006). Whether these drawbacks are relevant depends on soil type, climate and the agricultural production system. Moreover, a change from conventional to zero tillage has a large impact on weed abundance due to the change in tillage practices and a change in weed control practices (*i.e*. usually a stronger reliance on herbicides for weed control). This has been well documented in the Pampas of Argentina (Ghersa & Martinez-Ghersa, 2000; De la Fuente *et al.*, 2006). At a different level, zero tillage may allow arable farming on lands that were previously considered unsuitable for cultivation due to tillage and erosion problems, such as erosion-sensitive soils on slopes and wetlands. Apparently, this was the case in some of the wetter parts of the Pampas that are nowadays under arable farming partly because of the availability of zero tillage techniques (*Bindraban* et al.*, 2009*).

THEORIZED EFFECTS
The adoption of RR crops including RR soybean in Northern and Latin America is associated with an increased implementation of soil conservation tillage systems, involving reduced tillage or no tillage at all combined with increased soil coverage with crop and weed residues. Therefore, RR soybean is expected to have a positive impact on soil conservation.

Evidence of difference between GM and non-GM production

The adoption of herbicide-tolerant (HT) crops such as RR soybean in Northern and Latin America coincided with a large increase of the area of arable lands under zero tillage (*Trigo* et al.*, 2009*; Bonny, 2008; Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2007; Cerdeira & Duke, 2006; *Fawcett & Towery, 2002*). This association can be explained by the fact that mechanical weed control conflicts with the aim to minimise tillage operations in soil conservation systems, which usually come with an increased reliance on chemical weed control. HT crops such as RR soybean and other new GM varieties facilitate weed control by allowing the application of a broad-spectrum herbicide after crop emergence. The weed management system associated with HT crops can therefore facilitate the implementation of soil conservation systems. However, the benefits of soil conservation systems also occur in non-GM cropping systems and the adoption of soil conservation systems in soybean and other crops started well before the introduction of HT GM crops (Bolliger *et al.*, 2006). This indicates that the availability of GM crops is not always a pre-condition for the successful implementation of soil conservation tillage systems. It is difficult to assess how the adoption of soil conservation systems would have proceeded without the availability of herbicide-resistant crops.

Conclusion

The availability of RR soybean facilitated the large-scale adoption of soil conservation systems by farmers in Northern and Latin America, thereby contributing to the conservation of arable soils. The use of soil conservation systems is however not uniquely associated with HT GM crops.

2.3.3 Water conservation

THEORIZED EFFECTS
RR soybean is not expected to have a direct impact on water use efficiency of the crop, as explained above in section 2.3.1.5. RR soybean could affect water conservation indirectly through its impact on the use of herbicides and soil conservation tillage. This indirect impact on water conservation is expected to be positive, as glyphosate is a herbicide with a relatively low toxicity while soil conservation tillage helps to reduce erosion and the consequent pollution of water ways with soil particles, nutrients and biocides.

Evidence of difference between GM and non-GM production

We found no studies specifically quantifying the impact of RR soybean adoption on water conservation, probably because the impact is indirect and related to changes in herbicide use and tillage techniques. Glyphosate has a relatively low toxicity (section 2.3.1.3 with Table 2.1) and could therefore help to diminish impacts on the quality of water resources. Also the risk of glyphosate leaching to the groundwater is limited in most soils, in comparison with other herbicides (Duke & Powles, 2008). Glyphosate is easily adsorbed by soil particles and usually has a short half-life in soil due to the degradation by bacteria. In soils with macropores and a pronounced preferential flow, glyphosate can move to the groundwater more readily (Kjær *et al.*, 2005). The main breakdown product of glyphosate, aminophosphonic acid (AMPA), is more mobile in soils and is often found in higher concentrations in groundwater than glyphosate (Kjær *et al.*, 2005), but AMPA is considered a toxicologically irrelevant metabolite in many countries, including the Netherlands. As the risks of water contamination through glyphosate volatilization and subsequent deposition are also small, glyphosate drift depositing in water ways is in most cases the prime source of glyphosate entering water systems. Herbicide spraying techniques applied nearby water ways are an important factor determining the amount of drift deposits ending up in water systems. Herbicide spraying with airplanes usually results in high amounts of drift, relative to the drift occurring when herbicides are sprayed with the help of a tractor. Reducing drift from crop protection agents is of equal importance in non-GM crops and we found no evidence that spraying with airplanes is particularly associated with eihter GM or non-GM soybean cultivation.

Soil conservation tillage which is associated with the use of HT crops as discussed above, reduces erosion and helps to conserve water quality. Erosion has a strong impact on water quality and is associated with high environmental and economic costs worldwide which are often underestimated (Pimentel *et al.*, 1995). Erosion leads to irreversible loss of soils.

Conclusion

RR soybean has the potential to reduce pollution of water from farming activities, as glyphosate is a herbicide with a relatively low toxicity and a low persistence in the soil, but high glyphosate application rates may annihilate this benefit (see also section 2.3.1.3). Soil conservation tillage systems, associated with the use of RR crops, generally give less pollution of water ways than conventional tillage systems. We found no evidence from the field that the adoption of RR crops actually resulted in an improvement of water quality.

2.3.4 Biodiversity

THEORIZED EFFECTS
The effects of RR soybean on agro-biodiversity (i.e. biodiversity in and nearby the field) are expected to be small, as management practices in RR and non-GM soybean are not very different, apart from herbicide use and tillage techniques. The use of the non-selective herbicide glyphosate in RR soybean could be expected to have a larger effect on the biodiversity of field margins than the use of more selective herbicides in non-GM soybean. On the other hand, glyphosate has a relatively low toxicity and could have a lower impact on soil life in the field than herbicides used in non-GM soybean. Soil conservation tillage systems, to some extent associated with RR soybean (see section 2.3.2), are expected to have a positive impact on soil biodiversity, as the soil is less disturbed and the soil surface is better protected by mulch in such systems.

The largest impact from farming on biodiversity usually occurs through the loss of natural areas that can be attributed directly or indirectly to farming activities, rather than through impacts at the field level. RR soybean can be hypothesized to facilitate arable farming on recently cleared lands when weed control is a limiting factor or when soil conservation tillage is a necessity for the expansion of farming. In such a case, RR soybean could help to expand arable farming in areas previously uncultivated and considered unsuitable for arable farming.

Soybean is not expected to survive for prolonged periods in the wild and soybean does not have wild relatives with which it could cross-pollinate in Northern and Latin America. Therefore, the likelihood of GM traits from soybean somehow spreading into natural ecosystems, which could affect biodiversity, is expected to be practically nil in the Americas.

Evidence of difference between GM and non-GM production

Little research has been published on the effects of RR soybean on agro-biodiversity. It was shown that an effective control of weeds with glyphosate in RR soybean can reduce the diversity of weeds (Puricelli & Tuesca, 2005) and the biodiversity dependent on these weeds. If weeds are also controlled effectively in non-GM soybean, as is often the case in the Northern America, this difference will not occur. Soil conservation tillage techniques, to some extent associated with RR crops (see section 2.3.2), are known to contribute to agro-biodiversity as less disturbed soils with higher soil carbon levels tend to carry a higher biodiversity than soil that are regularly ploughed (Holland, 2004).

Northern American countries brought their lands with a good potential for arable farming into cultivation long time ago and currently do not face the risk of great new biodiversity losses due to an expanding agriculture. Latin America on the other hand has recently experienced a rapid expansion of arable lands into previously uncultivated areas. These new lands are often cultivated with soybean. This expansion of soybean lands has primarily occurred in response to the increasing global demand for soybean products. The debate on the impact of expanding soybean production on the loss of natural areas focusses on Latin America, where expanding soybean production has come at the expense of other crops, pastures and natural areas (e.g. see Grau *et al.*, 2005 & 2008 for the Chaco in Argentina). An indirect impact of soybean production on former pastures in Latin America could be that livestock keepers are stimulated to move their activities into previously natural areas. There is some evidence from Argentina that RR soybean helped to expand soybean production in new regions, as the relative area covered by soybean rose after the introduction of RR soybean faster in the new regions than in the traditional soybean production regions of the Pampas (*Bindraban* et al.*, 2009*). There is no evidence from Brazil that RR soybean is planted more frequently in newly cultivated areas than non-GM soybean. In fact, in Mato Grosso, Brazil's main soybean producing State, soybean farmers in the north, which are located close to the Amazon biome with its deforestation problems, primarily cultivate non-GM soybean, as traders in the harbours along the Amazon River from where soybean is exported overseas only accept non-GM soybean. In this region, farmers' choice between GM or non-GM soybean is driven by the available infrastructure and traders' preferences and not by agronomic traits (*Franke* et al.*, 2009*). Zero-tillage techniques, associated with HT crops, may allow arable farming on lands that were previously considered unsuitable for cultivation due to tillage and erosion problems, such as erosion-sensitive soils on slopes and wetlands, which could lead to biodiversity losses (see also section 2.3.2). Apparently some of the wetter parts of the Pampas, previously uncultivated, are nowadays under arable farming partly because of the availability of zero tillage techniques (*Bindraban* et al.*, 2009*).

There are no reports from the Americas that soybean or GM traits in soybean have somehow spread into natural areas.

Conclusion

Evidence suggests that the availability of the RR trait in soybean has had no, or a minor and usually indirect impact on biodiversity.

2.3.5 Climate Change

THEORIZED EFFECTS
The impact of RR soybean on climate change (i.e. greenhouse gases, such as carbon dioxide, dynamics) is expected to come from a change in energy use for the production of soybean, as detailed under section 2.3.1.4 on energy use efficiency. In addition, soil conservation techniques, to some extent associated with RR soybean (see section 2.3.2), are expected to lead to higher soil organic carbon levels, and thus sequestration of carbon in the soil.

Evidence of difference between GM and non-GM production

As mentioned under section 2.3.1.4, RR soybean may be associated with slightly higher energy consumption for the production of herbicides, while the use of soil conservation tillage in RR soybean on the other hand helps to save energy (diesel) required for ploughing. In addition to impacts on climate change, conservation tillage is known to be helpful in maintaining or increasing soil organic matter levels, thus reducing the amount of CO_2 released. It was estimated that the conversion from conventional tillage to zero tillage systems stores on average 300 kg carbon per ha annually, while the conversion from conventional tillage to reduced tillage stores 100 kg carbon per ha annually (*IPCC, 2007*[7]). Some scientists questioned the benefits of conservation tillage for net carbon sequestration when carbon dynamics in the deeper soil layers (> 30 cm) are included in the analysis (Baker *et al.*, 2007; Blanco-Canqui & Lal, 2008). The impact on carbon sequestration is likely to depend on soil properties, climatic conditions and land use. It should be noted that soil carbon levels in arable fields are in most cases well below those in natural areas and grasslands and the gains in soil carbon storage (or reduced losses) made by a conversion from conventional to conservation tillage are rapidly lost when soils are ploughed conventionally again (Follet, 2001).

Conclusion

Increased soil carbon reserves as a result of the implementation of soil conservation tillage, which in its turn is associated with HT crops such as RR soybean, may reduce the amount of greenhouse gasses in the air, but the relevance of this effect is not undisputed in the literature. Besides, the RR trait in soybean can have a direct impact on energy consumption in farming, as explained in section 2.3.1.4. This direct impact on energy use may be positive or negative.

2.4 GM-related sustainability – Profit

2.4.1 Farm income

GM soybean varieties may affect farm income through changes in production costs, revenue, or crop management. Numerous studies have been done to quantify these farm-level impacts, with different results. Whether the net effect is positive or negative for farmers appears to depend on aspects such as region and time. Most research has

[7] International report with an extensive system of peer review.

focussed on soybean production in the US, although reports have been made for other countries as well. In the following, the GM soybean discussed is of the herbicide-tolerant, RR type, as this is the only variant grown in commercial practice until fairly recently.

Effects on farm revenue

In section 2.3.1.1, it was already concluded that RR soybeans do not lead to structurally higher yields than conventional soybeans. Nevertheless, farmers often believe that growing GM soy increases yield – and thus revenue, compared to non-GM soy. In a national survey conducted by the USDA over the period 2001-2003, 63% of the GM-soy growing farmers in the US indicated that they did so because of expected higher yields through improved weed control (*Fernandez-Cornejo & Caswell, 2006*). Other benefits, such as savings on management time (17%) and herbicides (17%) were considered less important. The contradiction between perceived and actual effects on yield and revenue can be explained by distinguishing between yield potential and prevention of yield loss through better weed control (see section 2.3.1.1). The benefit from reducing yield loss has a more incidental character and will be discussed in section 2.4.4.

For countries with a less developed agricultural sector, the situation may be different. In such countries, weed pressure often causes structural yield loss, so GM soy has relatively more impact on yield (see also section 2.3.1.1). A study on GM soybean production in Romania in the period 2002-2003, prior to their entry into the EU, showed that GM crops had a positive effect on yield (Brookes, 2005). Weed control in Romania is still poor because of limited use of herbicides and other control measures.

Both positive and negative price differences between GM and non-GM crops have been observed. In some countries, prices for GM soy are higher than for non-GM soy, because of cleaner harvest. For instance, in Romania, prices in 2002-2003 were 2-3% higher which - together with the positive effect on yield – resulted in a net increase in revenue of approximately 140 EUR per hectare (Brookes, 2005). Also in South American countries, such premiums exist (see *e.g*. Brookes & Barfoot, 2008, Qaim & Traxler, 2005). On the other hand, farmers of conventional soybean may receive a price premium if their crop is certified as 'non-GM' or 'GM-free' (Bonny, 2008; Beckie *et al.*, 2006). These price premiums have been introduced to stimulate non-GM soybean production. Due to legal restrictions on the use of GM-crops in food and feed, there is still considerable demand for non-GM soy in the EU. As Table 2.2 illustrates, the increase in price premiums runs opposite the decreasing trend in supply of non-GM soy (*Aramyan* et al*., 2009*). Although price differences at the farm gate have not been common in the early years of GM crop production, their occurrence is likely to have increased in recent years as a result of developments such as increased legislation regarding coexistence and labelling and traceability, and the (potential) introduction of GM crops for direct human food use (*Gómez-Barbero & Rodríguez-Cerezo, 2006*).

Table 2.2. World non-GM soy production, EU non-GM demand excess supply above EU demand, total EU demand for non-GM and GM soy and additional non-M soy price for 1999-2008.

	'1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
World non-GM soy production (m. ton),	67.5	65.3	54.1	53.0	46.7	48.0	40.1	35.7	29.2	26.8
EU non-GM demand (m. ton),	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Excess supply above EU demand (m. ton)	58.5	56.3	45.1	44.0	37.7	39.0	31.1	26.8	20.2	17.8
Total EU soy demand (m. ton)	29	31	35	34	33	33	34	34	36	33
Price-premium (€/ton)	0.00	0.00	0.00	2.65	4.43	4.02	8.05	7.97	43.86	54.65

Source: Aramyan et al., 2009.

Effects on production costs

In section 2.3.1.3, we concluded that the introduction of RR crops may reduce herbicide use in general, but that this may be compensated by increased use of glyphosate. No matter whether the net effect from glyphosate usage is positive or negative, the reduced demand for herbicides other than glyphosate has led to lower herbicide prices in general (Bonny, 2008). Besides this price effect on herbicides (from which both HT and non-GM soy producers benefit), RR soy basically requires fewer herbicide applications, which will further lower the expenditure on herbicide treatment. Note that there is a difference in *required* and *actual* herbicide use; while there is scientific evidence that the number of treatments can be reduced with RR soy, this hypothetical decrease is less clearly reflected in empirical data. Various side effects (*e.g.* increased low-tillage acreage, lower chemical prices and, more recently, increased herbicide resistance in weeds) may contribute to this difference (Bonny, 2008 and see also section 2.3.1.3). Changes in weed management also result in a reduction of required labour input. Weed management has become easier, as a result of which the farmer frees time for other activities (Bonny, 2008).

Numerous studies have been done that support the above-mentioned effects on crop protection costs. For instance, *Sankula (2006)* calculated total cost savings of 134 million USD for the US in 2005 from reduced herbicide applications in GM soy. Fernandez-Cornejo *et al.* (2005) showed that the adoption of HT soybeans is associated with a significant increase in off-farm household income for U.S. soybean farmers. On-farm household income is not statistically related with the adoption of GM crops but total farm household income is significantly higher for adopters. This suggests that adopters of HT soybeans save managerial time, which they use in off-farm work. *Gardner and Nelson (2007)* modelled the effects of HT soy adoption on labour usage and calculated a reduction of 23 percent relative to conventional soy production. *Acworth* et al. *(2008)* analyzed the economic impacts of change in yield and costs of production arising from the adoption of GM crop technology in Australia. They found that yield benefit from GM crop adoption varies across regions and was determined by agronomic growing conditions. The main contribution to cost reduction in HT canola and soy was reduced herbicide applications and consequently, less herbicide, labour and machinery use. In some regions, application rates may have gone up in recent times, which may also have influenced these cost reductions (see section 2.3.1.3).

Seed prices for HT soybean seed are structurally higher than for conventional soybean seed (Shi *et al.* 2009), which Mascarenhas & Busch (2006) attribute to the near-monopoly position of seed suppliers (see section 2.4.3). Moreover, the purchase of RR soybean seed goes together with a 'no-replant' licence clause. For farmers who grow soy from saved seed, switching to RR soybean production thus increases seed costs. In the US, saving seed had already become less common after the introduction of hybrid varieties. However, in other countries, such as Argentina, the acreage of soybean cultivation with farm-saved seeds was still 25% or more in 1998. For this reason, and because of the poor IP protection in the case of RR soy (see also section 2.4.3), Argentine farmers face much lower seed prices than US farmers (Bonny, 2008, Mascarenhas & Busch, 2006).

Effects on gross margin

Overall, the benefits of saving on weed control costs seem to outweigh the higher costs for seed. *Brookes & Barfoot (2010)* provided an overview of the economic impacts at the farm level for different countries, over the period 1998-2008. A distinction has to be made between technology costs and other costs. Technology costs predominantly exist of seed fees, but in theory also potential adjustments at the firm can be part of technology costs. However, *Brookes & Barfoot (2010)* equal technology costs and seed fees. As shown in Table 2.3, farmers in all countries experience net cost savings on average, although considerable differences between countries exist. Cost savings in most countries were initially higher but dropped in 2008, when the price for glyphosate increased considerably relative to other herbicides. Note that Table 2.3 contains absolute numbers, rather than percentages of average costs or gross margin (not provided by the original source). Therefore, countries should not be compared on the magnitude of effects on farm income. Other sources also found a positive net effect on farm income. For example, *Backus et al. (2008)* come up with a cost disadvantage of 15% if GM soy growers had to switch back to non-GM soy. In 2005, the net cost savings of RR soy growing famers in the US were calculated to be 44.67 USD/ha, resulting in total costs savings of 1.17 billion USD (*Sankula, 2006*).

Table 2.3. Cost savings of HT soybean production and the net effect on gross margin in 2008.

Country	Cost savings, excluding technology costs (USD per ha)	Net cost savings / increase in gross margin including technology costs (USD per ha)
United States	68.6	43.88
Argentina	16.37 [1]	13.87
Brazil	64.07	44.44
Canada	56.59	14.33
South Africa	25.38 [1]	1.77
Romania[2]	64.99	58.79 [3]
Mexico	33.05	54.13 [3]
Bolivia	9.28	80.09 [3]

[1] Cost savings declined in 2008 due to increased glyphosate price.
[2] Data represent the year 2006.
[3] Data include a positive effect on yield (and thus revenue).
Source: Brookes & Barfoot, 2010.

Other effects on farm income

The introduction of RR soy has initiated several changes in farm management. Section 2.3.2 already discussed the relation between introduction of HT soy and an increased acreage of land under conservation tillage. Apart from environmental benefits, the adoption of reduced or no tillage systems reduces the number of passes over the field, which leads to savings in particularly labour and fuel (*Brethour* et al*. 2002*; Brookes & Barfoot, 2009).

Another economic impact of HT soy at farm level comprises the increased opportunity for farmers to grow a second crop of soybeans in the same growing season. This follows from the ease of management of the HT crop and the possibility of low or no-tillage, which allows additional time for growing a second crop (see section 2.3.1.1). In Argentina, the increase in farm income from facilitating additional second cropping was estimated at 1.1 billion USD in 2007, based on gross margin of second crop soybeans times the total acreage of second crop soybeans (Brookes and Barfoot, 2009).

Conclusion on farm income

RR soybeans have a positive effect on farm income through savings in herbicide costs and labour, which generally outweigh increases in seed costs. Thereby, introduction of RR soy leads to a productivity increase for soy growers. Effects on revenue are only significant in countries where soybean yield losses from weed pressure are common. Additional benefits, such as opportunities for a second crop or generating off-farm income, may follow from effects on crop management. Market segmentation of GM and non-GM soybeans may result in (positive) price effects for non-GM soy growers.

2.4.2 National income

THEORIZED EFFECTS
As discussed in Chapter 1, analyzing the impact of the GM crops on income at the sector or national level requires more than aggregating the impact on farm income. Here, we describe the changes that may be expected according to macro-economic theory.

First, the introduction of HT soy is likely to have an impact on producer (output) prices if the introduction has an impact on yield or inputs costs. Because the cropping of RR soy is less costly and thus more profitable than conventional soy (see previous section), farmers may be expected to switch from conventional soy to RR soy, but also from other arable crops to RR soy. As a result, the supply of soy will increase and the price of soy will drop. While for RR soy growers, the income drop is compensated by the savings in chemicals and labour required for weed control, conventional soy growers face a reduction in profits. The unit cost and price decrease may cause major shifts in production and trade patterns away from conventional soy in favour of GM soy.

Second, soybean market changes may lead to major shifts in employment and land use in the economy. Soy requires vast amounts of land in the major soy producing countries. An increase in the amount of land used for soy production may lead to a decrease in the amount of land available for other arable crops, for instance cereals, but also for nature.

Third, in response to changes in production of and trade in soy following introduction of GM soy, changes in the exchange rate and non-soy imports and exports may occur. Such changes are more likely as soy comprises an increasing part of the total exports of a country. Specifically, the introduction of GM soy and the resulting increase in global production and exports of soy could influence the real exchange rate upwards, thereby reducing the country's competitiveness and so exports of non-soy products, potentially worsening its trade balance.

In terms of overall welfare, net importers of GM soy are likely to benefit from lower prices, whereas non-adopting exporters would lose out from the increased competitiveness of GM adopters. If the adverse terms-of-trade effect, *i.e.* rise of prices of imports relative to prices of exports, is strong enough compared to the production and export expansion, net exporters of GM soy may also lose out. Empirical analysis is needed to see how these effects balance out.

Evidence of difference between GM and non-GM production

Macro-economic effects of GM crop adoption have largely been studied through (*ex ante*) modelling studies. The GM crops evaluated in this and other chapters, i.e. soybean, maize, and cotton, are major, internationally traded commodities. Moreover, GM and non-GM crops are in most countries imperfect substitutes for each other, causing market segregation between products that have been produced with GM material and products that have not. For these reasons, general equilibrium models, which account for international trade linkages and linkages with multiple sectors, are of particular relevance in studying effects on national income (*Smale et al., 2009*). Therefore, the review below mainly contains references to studies applying general equilibrium models. One such model, which is widely applied, is GTAP. Concerning the general equilibrium studies, the reader has to bear in mind that presented quantitative figures should be interpretated trend-way, because model studies are based on assumptions and are by definition a simplification of reality.

One of the first and most commonly referred to general equilibrium modelling studies on GM crop adoption was performed by Nielsen & Anderson (2001).The authors simulated the global economic effects of the introduction of GM soy and maize by assuming an increase in factor productivity (through an overall reduction in production costs) by 5% for all coarse grain (cereals excluding wheat and rice) and oilseeds[8]. GM maize and soy are assumed to be widely adopted in the US, Canada, China, India, Argentina, Brazil, Chile, Uruguay, Paraguay and South Africa. Results show that, without import restrictions imposed by any country in the world, the prices of coarse grains and oilseeds (including soy) decrease in the GM-producing countries. This causes a shift in production and exports from the GM-free to the GM-producing countries. The drop in producer prices outweighs the impact on production in adopting countries, causing value added (sector income) in oilseeds to fall slightly in adopting countries. Yet, this is partially compensated for in gains in value added in the vegetable oils and fats sector profiting from cheaper oilseed prices, particularly in South America. Value added in oilseeds is also likely to decrease in non-adopting countries (including Europe), because producer prices are under pressure and production decreases.

A more recent study of Van Meijl & Van Tongeren (2004) focusses on the role of international knowledge spillovers, *i.e.* the degree to which farmers in adopting countries are able to realize the potential productivity gains. Moreover, it takes into account that the introduction of GM crops can have unequal effects on the demand for input factors (called factor-biased technical change). The authors show that as a result of incomplete knowledge spill-overs to countries with smaller average farm sizes or a lower knowledge level, potential productivity growth in these countries as a result of GM crop adoption is lower than in the innovating country (the USA). This suggests that Nielsen & Anderson (2001) overstated the potential productivity shock – and thereby, the impact on national income – in case all countries were to adopt GM maize and soy.

Further updates and extensions of the analysis of Nielsen & Anderson (2001) were performed in 2005 by Anderson & Jackson (2005a, 2005b). In the first study, the authors assume a partial, crop- and country-specific displacement of non-GM crops with GM crops. Different adoption scenarios are evaluated and canola is included as a third crop. However, conclusions have the same direction as Nielsen & Anderson (2001). The second study focusses on adoption of GM crops by Australia and New Zealand. It shows that, if the US, Canada and Argentina adopt but Australia and New Zealand do not, production and net exports of oilseeds (and coarse grains) as well as livestock products fall in Australia and New Zealand due to lower domestic prices. This decrease would be considerably smaller if the two countries were to adopt GM crops.

Brookes *et al.* (2010) estimated the overall effect of GM technology in agricultural crops (maize, canola (oilseed rape), and soybean) on production and price. They used partial equilibrium models, the limitations of which were (partly) overcome by using different models for each sector and linking them to each other. The authors projected what would happen if all GM crops were banned as from 2008, using the actual situation in 2007 as a baseline. They assumed a relatively high productivity increase for some countries: on average 31% in the EU-27, mainly realized through the exceptionally large increase in yield in Romania, and 7.5 and 20% in Paraguay and Argentina, respectively, due to second crop benefits. Simulation results include an increase of 3 to 10% in world prices of maize, soybeans and canola as well as their derivatives and related coarse grains and oilseeds, if GM varieties of these crops were banned. Yields are estimated to fall by 1.5%, 4.3%, and 0.65% for maize, soybeans, and canola, respectively, resulting in a decrease in global trade and usage of soy meal, soy oil and maize. The authors acknowledge that the effect of GM crops on production costs (see section 2.4.1) is not accounted for in this analysis, which may have led to an underestimation of impacts.

[8] While these two categories aggregate maize and soybean with other crops, maize and soybean account – together with canola –for most of the coarse grain and oilseed production in current GM-adopting countries.

Sobolevsky *et al.* (2005) performed a partial equilibrium analysis on HT soy adoption in four regions: the US, Argentina, Brazil, and the rest of the world (ROW). They evaluated the changes relative to the 'pre-innovation' stage (without HT soy), under a no-segregation scenario and scenarios with segregation of HT and conventional soy against different costs. Under the no-segregation scenario, soybean prices would fall in all regions, whereas production would rise in all regions but the US. US soybean production decreases because US farmers experience lower cost savings from HT soy adoption due to higher technology fees. Note that the decrease in US soybean production conflicts with results described above, which are based on equal productivity increase. Yet, part of the difference is due to the fact that Sobolevsky *et al.* (2005) assume that consumers in the ROW are GM-conscious and cut down on the consumption of HT soybeans and soybean products. In a segregation scenario at any costs, conventional soy prices are higher than those of their non-GM equivalent due to a preference for non-GM products in the EU. This gives farmers an incentive to produce conventional soy. Nevertheless, of all four regions, only the US produces conventional soy in addition to non-GM soy, again because US farmers experience the smallest cost reductions from HT soy production. At lower segregation costs, the share of conventional soy production in the US increases, which reduces the HT soy supply and thereby increases prices. At zero segregation costs, Brazil also produces a very small amount of conventional soy.

Several authors studied the effect of regulations on changes in national income due to GM crop adoption. Nielsen & Anderson (2001) show that a Western European import ban of GM cereal grains and oilseeds may cause production and export of oilseeds to drop, particularly in North America, which is highly dependent on the Western European market. This also implies a reduction in land use by this sector. In contrast, non-GM adopters such as Sub-Saharan Africa (SSA) are expected to benefit from increased access to Western European markets. Production and exports of oilseeds in Western Europe also rise dramatically. The downstream vegetable oils and fats sector experiences an increase in competing imports, as a result of more expensive inputs in Western Europe. In the study on GM adoption by Australia and New Zealand (Anderson & Jackson, 2005b), an EU import ban under the non-adoption scenario is shown to have a positive effect for both countries; it reduces the extent of the reduction in production and net exports in these countries. Once Australia and New Zealand adopt GM soy and maize, the effect of the ban becomes negative.

Nielsen & Anderson (2001) also analysed the effect of a shift in Western European preferences against GM coarse grains and oilseeds. The effects of such a scenario are less dramatic than those of a strict import ban: production of oilseeds in GM-adopting countries still increases slightly. Western Europe must still increase its domestic oilseed production somewhat to accommodate the preference shift. And since the preference shift is only partial, consumers and firms benefit from lower import prices. Sub-Saharan Africa experiences a decline in production and exports, since it is not able to benefit from serving European consumers and firms as would be the case with an EU import ban.

Sobolevsky *et al.* (2005), in their partial equilibrium analysis of the soybean complex, evaluate the effect of the US LDP price support program (LDP means: loan deficiency payments). This programme in effect guarantees a US producer price floor for soybeans. Under this support, the US turns out not to produce any conventional soy at all, because it equates producer prices for conventional and HT soy, thereby taking away the producer price benefit of conventional soy production. Brazil (and under the zero cost segregation scenario also Argentina) now produces conventional soy next to HT soy. Total production in the US increases, which depresses prices in all regions.

The increase in crop protection efficiency after the introduction of HT soy has led to an initial reduction in herbicide demand. As a result, herbicide producers decreased their prices in order to limit market losses. In the period between 1996 and 2004, the US market for soybean herbicides declined by 1 billion USD (Bonny 2008; Gianessi 2008). Seed prices, on the other hand, increased. One reason for this is that the decline in use of farm-saved seed led to a higher demand. The increasing market power of the seed industry also contributed to this (Mascarenhas and Busch, 2006). While the cost of herbicides for US soybean growers declined by 27 USD per hectare in the period from 1996 to 2005, in the same period seed costs rose by 32 USD/ha (Gianessi, 2008, based on USDA data).

Conclusions

The model studies reviewed project the introduction of GM crops, including soy, to yield increased global production of these crops at lower prices. Exports are likely to shift from the GM-free to the GM-producing countries, in the case of soy benefitting South America at a cost of Western Europe, which increases its imports. Regulations (*e.g.* import bans, price subsidies) and consumer preferences may have a major effect on the total volume and spatial distribution of GM soy production, as well as prices. Results also depend on assumptions regarding factor productivity increase and technology spill-over under GM adoption. The reviewed modelling studies thus provide evidence for most of the theorized effects. Theorized effects on the interaction with nature (through land use), exchange rates and non-soy imports and exports could neither be supported, nor denied on the basis of the literature review.

2.4.3 Economic welfare distribution

THEORIZED EFFECTS

The macro-economic changes described under 2.4.2 cause changes in the welfare generated through soy production. These changes apply not only to total welfare, but also to the welfare distribution, both vertically (between different stakeholders of the production chain) and horizontally (between different regions or countries in the world). Concerning vertical welfare distribution, the introduction of GM crops has led to changes in farmers' relation vis-à-vis their suppliers and their customers. With respect to horizontal welfare distribution, some adopting countries may benefit more, or experience more disadvantages from adopting GM crops, than others. Examples of factors affecting horizontal and vertical welfare distribution are country-dependent adoption levels, the level of IP protection, GM regulations, and consumer preferences. Below, we will first discuss horizontal welfare distribution, followed by vertical welfare distribution.

Horizontal welfare distribution

Nielsen & Anderson (2001) estimated that under the base case scenario of introducing GM soy and maize, worldwide economic welfare rises by 9.86 billion USD (Table 2.4, 2nd column), two-thirds of which is enjoyed by the adopting regions. However, both GM adopters and non-adopters (except for Sub-Saharan Africa) experience welfare gains. For GM adopters, the benefits of a higher factor productivity outweigh the losses from increased competition on the world market. GM-importing countries benefit from a decline in prices of coarse grains and oilseeds and a more efficient use of resources in domestic production. Sub-Saharan Africa loses because of the assumption that countries in this area are unable to take advantage of the new technology.

The total welfare estimates provided by Nielsen & Anderson (2001) are rather high due to optimistic assumptions on factor productivity increase and adoption levels. In more recent publications, these numbers have been somewhat moderated. For instance, the study of Anderson & Jackson (2005a) (Table 2.4, column 3) presents a global change in economic welfare of just over 4 billion USD, for a scenario in which all countries adopt GM coarse grain and oilseeds. The same study shows that global economic welfare increases with the number of countries adopting the new technologies. Welfare in individual adopting countries decreases as more countries adopt, but remains positive. The authors pay special attention to South Africa (as part of SACU – Southern African Customs Union) and other Sub-Saharan African (SSA) countries. They conclude that for all countries in SSA, adoption by SACU (as is currently partly the case) is beneficial in terms of welfare effects. In a parallel study, the same authors, Anderson and Jackson (2005b), (Table 2.4, column 4) demonstrate the welfare effects of adoption by Australia and New Zealand. Welfare effects for New Zealand are negative; yet, they are not more negative than under a scenario in which the country would not adopt, but other countries do so. In other words, with adoption, New Zealand is not worse off than without adoption.

Table 2.4. Welfare effects of global GM soy and maize (and canola) adoption (million USD).

Regions**	Scenarios		
	Nielsen and Anderson (2001)[1]	Anderson and Jackson (2005a)	Anderson and Jackson (2005b)
North America	2,624		
USA		897	897
Canada		65	65
South America	826		
Argentina		287	287
China + India	839		
India	1,265		
Western Europe / EU-15	2,010	595	595
Sub-Saharan Africa	-9		
SACU		9	
Rest of SADC		18	
Rest of SSA		42	
Australia			2
New Zealand			-5
ROW	2,306	2,204	2,207
Total	*9,859*	*4,047*	*4,047*

[1] Adopting countries: US, Canada, China, India, Argentina, Brazil, Chile, Uruguay, Paraguay and South Africa.

All three studies discussed above analyse the effect of an EU ban on welfare distribution. Nielsen & Anderson (2001) show that in case of a ban, aggregate welfare gains fall by approximately two-thirds. Particularly Western Europe loses, due to a deterioration of allocative efficiency, as it now has to produce oilseeds, whilst it is a less efficient producer of such crops. Welfare results under a change in Western European consumer preferences are comparable with those in absence of an import ban, with the exception of Western Europe, for which the net welfare change drops, although being still positive. Anderson & Jackson (2005a) zoom in at the SSA region. For SACU, adoption of GM coarse grains and oilseeds is only beneficial in absence of an EU ban. Yet, for the SSA as a whole, GM adoption in SACU is beneficial irrespective of an EU ban. Without SACU adopting GM crops, all SSA countries benefit from an EU ban; however, these benefits are very minor compared to the foregone productivity benefits that would occur if all countries in the world adopted GM. Anderson & Jackson (2005b) show that Australia and New Zealand benefit from an EU ban, and that the benefits of GM adoption in both countries occur irrespective of an EU ban.

Sobolevsky *et al.* (2005) present *ex ante* welfare effects of HT soybean adoption in the US, Brazil, Argentina and the rest of the world (ROW), based on partial equilibrium analysis. Without segregation of GM and non-GM soy, global welfare increases with 1.6 billion USD, with the four regions having a share of 66, 12, 6, and 16 percent, respectively. Total welfare increases if GM and non-GM soy are segregated, although this increase diminishes with increasing segregation costs. A US price support programme reduces welfare in all regions except the ROW, because this region is a net importer and thus benefits from the price decline. Global welfare effects are, however, quite similar to those without price support.

Gruère et al. (2007) perform a general equilibrium modelling analysis on adoption of GM soy, maize, and cotton, with special focus on India, Bangladesh, Indonesia, and the Philippines. They assume production of these crops in the countries that had adopted them by 2005. Using initial adoption rates in these countries (*i.e.* the level of GM crop production in the first years after adoption), they come to a global welfare gain of 4.4 billion USD. Of all countries in the world, India experiences the largest relative gains, a welfare increase of 0.07 percent (254 million

USD). Total gains are reduced to 2.7 billion USD when applying a trade filter representing trade restrictions in GM-sensitive countries. These losses come mostly at the stake of GM-sensitive countries. Under a scenario with more countries adopting GM crops at a higher rate, global welfare gain increases to 5.1 billion USD. In this case, the highest relative gains (0.3 percent, 44 million USD) are obtained by Tanzania and Uganda. Of the four countries with a special focus in the study, only India and Indonesia are assumed to adopt – amongst others – GM soybeans.

Vertical welfare distribution

A number of researchers haves studied the distribution of the welfare gains of GM soy (and other GM crops) over the respective stakeholders. *Price* et al*. (2003)* used a spatial (partial) equilibrium model to analyze the worldwide welfare effects of US GM soybean production in 1997, *i.e*. the early stage of GM soybean production. World benefit was valued to be 307.5 million USD. The main actors gaining from GM soybeans were biotechnology companies (in this case Monsanto as the principal holder of the RR trait), seed companies, and US farmers, capturing 28, 40, and 20 percent, respectively. Consumers in the US and the rest of the world had only a minor share, and welfare effects for producers in the rest of the world were even negative.

Trigo and Cap (2006) used a dynamic simulation model to evaluate distribution of national welfare gains in Argentina. Their results are representative for the 1996-2005 period. Argentine farmers turned out to have by far the largest share in total net benefits, namely 78%. This is a result of the weak IP protection of GM soy in Argentina at that time. The national government also had a considerable share, of 13%, due to the tax levied on exports of soybeans. The remaining 9 % was captured by seed and glyphosate suppliers.

Qaim & Traxler (2005) took a partial equilibrium approach to study the economic surplus changes from HT soy adoption in Argentina during the period 1996-2001. They distinguished three regions: Argentina and the US (both having major soy production and thus affecting world market prices), and the rest of the world (ROW). Technology adoption in countries other than the US and Argentina was assumed to be zero. Consumers gained the highest share of overall benefits: 53% on average, but shares differed considerably among the three regions. Soybean producers in countries without GM soy adoption suffered from a decline in world market prices, resulting in welfare loss. Argentine farmers received a relatively large share of the total surplus in that country, because the country mainly exports and has a relatively small domestic consumption of soy. Moreover, in 2001, the relative soy acreage planted with GM soy was larger in Argentina than in the US. Conventional farmers lose, because they experience a price decrease while not having the benefits of GM crop production. Furthermore, in the US, technology suppliers (biotechnology and seed firms) have a large share (57%) in the national surplus. In Argentina, this share is only 8% due to poor IP protection.

Sobolevsky *et al*. (2005) provide a similar analysis, including Brazil as a fourth country. Their conclusions are slightly different, amongst others because in their simulations, GM soy adoption is possible in all regions. They also assume a consumer preference for non-GM soy in the ROW. Under a scenario without segregation between GM and non-GM soy, total welfare gains are 1,6 billion USD, of which 54% comes on the account of technology suppliers. 39% is captured by consumers, and the remaining 8% goes to producers. US farmers experience a net reduction in welfare, because they adopt GM soy at higher costs than farmers in the other regions. Under a zero cost segregation scenario, producers and consumers gain, while technology suppliers lose, resulting in welfare shares of 19, 43, and 38 percent, respectively. Yet, total welfare increases to 1.7 billion USD. Total welfare gains decline as segregation costs increase; yet, they remain higher than without segregation.

Industry concentration may affect the R&D activities of the seed producers. One hypothesis is that dominant firms in consolidated industries conduct more new product research because they have the funds to do so and are able to make profits out of it (*Schumpeter, 1942*). However, it has also been suggested that when competition is less intense due to concentration, seed producers may cut R&D activities. Such situations may occur when R&D results can easily be replicated by competitors without incurring the costs of R&D, when there is considerable uncertainty about the long term private returns from the investments, or when the social marginal costs exceed private marginal benefits, resulting in negetive externalities (*Fernandez-Cornejo, 2004)*. For soybeans, R&D investments have considerably increased during the nineties, probably as a result of better IP protection. However, in the period thereafter, private research investments in soybean and other GM crops seem to have slowed down. The change in number of seed companies over time ran parallel to this trend (*Fernandez-Cornejo & Schimmelpfennig, 2004*, Pray & Naseem, 2007). Schimmelpfennig *et al.* (2004) also found a significant negative correlation between seed industry concentration and R&D investment, particularly for soybeans. Note that this change is relative; total R&D expenditure of a company may have grown over time, but the increase was lower than might be expected on the basis of their increase in size through market consolidation.

Evidence exists for the emergence of black markets for transgenic crops in developing countries (Kostandini *et al*, 2009). Farmers save the seed and plant it during the following season, or they sell it to other farmers. Moreover, IP protection is weak in certain countries. For instance, in Argentina, IP rights were not acknowledged by the government for many years, causing approximately 75% of the HT soybean area to be planted with uncertified or farm-saved seed. Black markets and weak IP protection lower the potential profits to the private sector from R&D expenses, and thus the incentive to undertake R&D. Moreover, they have resulted in price discrimination between farmers of different countries (Bonny, 2008, Mascarenhas and Busch, 2006, see also section 2.4.1).

Conclusions

The model studies reviewed showed that the adoption of GM soy (and other GM crops) has positive net welfare effects. Both GM adopters and non-adopters experienced welfare gains, with few exceptions. GM adoption is generally economically beneficial for a country, and with more countries adopting GM crops, the total welfare increases, although welfare for each individual adopting country may decrease. Restrictions to the adoption or acceptance of GM crops have a negative effect on global welfare, but individual countries may benefit. Vertical welfare distribution in a country depends on the level of IP protection: technology suppliers received a higher share as IP protection gets stronger, at the cost of welfare gains for producers and consumers. In non-adopting countries, producers experience a negative welfare effect.

2.4.4 Financial and other risks

Production risk

For farmers, production risk is one of the major risks as successful crop production is decisive for their income. In this respect, HT soybeans reduce the risk for farmers as yield losses due to weed pressure are reduced. These effects have already been discussed in section 2.4.1. HT soybean production further reduces risks of crop protection, such as injury to the soybean crop and rotational crops as well as timing of crop protection treatments (Gianessi, 2008; Bonny, 2008, see also farm revenues in section 2.4.1 and section 2.2.1, respectively). Brazilian farmers producing GM soy paid less crop insurance (8.00 USD per hectare) than farmers producing conventional crops (9.60 USD per hectare) and less insurance in general (2.75 versus 3.00 USD per hectare) (*Mello, 2004*). The difference in insurance premiums indicate that GM soybean producers less frequently receive an indemnity payment than conventional soybean producers. This suggests that the production risk is lower for GM soybeans than for conventional soybeans. An alternative hypothesis, however, is that farmers producing GM crops are more risk-averse.

While HT soybean reduces short-term production risk, it may bring along another risk in the long run for GM and conventional soybean growers. Weeds could develop resistance against glyphosate (section 2.3.1.3), and become more difficult to control. Moreover, GM volunteer plants which are less easily controlled could affect yield of the next crop (Ervin *et al.*, 2010), but for soybean this risk is low because soybean has no weedy tendencies (Beckie *et al.*, 2006, also see section 2.3.4).

Institutional risk

A major institutional risk associated with GM soybeans is the institutional framework that regulates market access. This framework determines whether farmers have the right to grow GM crops and traders have the right to ship GM crops. Uncertainties regarding market access are closely related to the ethical aspects and social concerns on GM crops (see also section 2.5: People below). An example of institutional uncertainty was the decision of the governor of Paraná (Brazil) to have the state free of GM crops, despite national ruling by Provisional Measure 223, allowing

GM production. This even led to interception of truckloads traveling through Mato Grosso do Sul to Paraná (*Mello, 2004)*. The risk associated with regulatory decisions as well as the financial resources needed to complete the regulatory process slow down the development of GM crops. This is particularly true for the public sector and small businesses (Lemaux, 2009).

Another, related issue comprises the asynchronous approval of cultivation of GM crops by different countries. The EU approves new GM varieties at a lower speed compared to major GM-crop producing countries as the US and Brazil. This may induce key exporters in major GM-crop producing countries to trade in less restrictive markets. Theoretically, this may lead to loss of trade, disruptions in commodity supplies and higher or more volatile prices for feedstuffs in the EU. The magnitudes of such impacts are, however, still largely unclear. *Backus* et al*. (2008)* calculated that a two-year delay in approval for a new soybean GM variety could increase estimated soy prices in the EU to a hypothetical value of over 7,747 Euros per ton. This is an unrealistic scenario, and the outcome should be interpreted as an indication that prices of EU-approved soy could rise to such levels that they undermine the international competitiveness of EU feed and food producers. Another study, performed by DEFRA/FSA in the UK *(DEFRA/FSA, 2009)*, indicated that in a worst-case scenario (with no imports from Argentina and Brazil), feed costs would increase more than 300%, considerably affecting livestock production and meat prices as well.

In the EU, a tolerance threshold of 0.9% for adventitious presence of approved GM is allowed in conventional food and feed; if this level is exceeded, the product is labelled as containing GM. For non-approved GM crops (i.e. GM varieties that have not been approved for cultivation in the EU), a zero tolerance policy applies. Food and feed consignments that do not meet these criteria have to be sent back, relocated, or destroyed. For the exporter this withdrawal brings along considerable economic losses, as well as other costs, such as legal costs, claims, and image damage (*Brookes, 2008*). These potential consequences reduce the willingness of third countries to supply the EU with non-GM raw materials.

Without going into particular crops, Beckmann *et al.* (2006) analyze how different coexistence policies among EU member states affect the adoption of GM crops. The adoption dynamics of GM crops within the EU are likely to be very different across Member States. Apart from the heterogeneity of farms, farm practices and landscape structure, the political willingness to allow GM cultivation and the legal framework for coexistence differ among the EU countries. These aspects reduce the incentives for farmers to grow GM crops, resulting in different adoption rates among EU countries.

Legal risk

Coexistence of GM and conventional crops poses a legal risk to both producers and traders. To maintain the ability of farmers (and consumers; see section 2.5.3) to make a practical choice among conventional, organic and GM crops, commingling/admixture of the first two types of crops with GM material (*e.g.* due to impure sowing seed lots, cross-pollination, volunteer plants) should be avoided. Unintentional commingling during the production stage may induce a lower market price or difficulties in selling the product. Also, production costs may increase, *e.g.* as a result of germination of (GM) volunteers following the production year. Furthermore, organic growers could lose their organic certification (Demont & Devos, 2008, Ervin *et al.* 2010). In soybean cultivation, cross-pollination is unlikely to occur because the crop is 99% autogamous. Therefore, the coexistence risk seems relatively low for soybeans, although negligence in the seed production industry may still lead to commingling of conventional and HT soybean (Bonny 2008).

Financial risk

Little has been reported on financial risks in relation to GM soy. For other crops, financial risks resulting from legal risks have been reported, such as economic losses for farmers due to adventitious presence of GM traces in non-GM harvest (see Chapter 3 on maize). The lack of such evidence for GM soy may have to do with the lower risk of admixture in GM soy from gene flow in the field, as described under 'legal risk'.

Conclusion

GM soybean production may lower production risks for farmers. Uncertainties regarding (future) approval of GM soybeans create considerable institutional risk and can affect the competitive position of soy producers and industry, at EU level as well as in individual EU member states. Moreover, the risk of low level presence of GMOs in non-GM commodities can reduce incentives for third countries to export non-GM commodities to the EU, which further decreases supply in the EU. Also legal risks exist, but seem to be minor for GM soybean production relative to crops with a higher likelihood of gene flow in the field.

2.5 GM-related sustainability – People

This chapter examines the impact of GM soy cultivation most closely in Brazil. Since Brazil produces both GM and non-GM soy, it is a useful country case to make comparisons in, and therefore receives the most attention here. Impacts in the other large soy-producing countries of Argentina and the United States are also discussed when relevant. Although India and China are soybean producers as well, they have not allowed commercial cultivation of GM soy in previous planting seasons, and so are not discussed here.

For this section of the report, there is a great deal of information available from civil society organizations, the International Labour Organization (ILO) and government agencies that has proven useful. Peer-reviewed information is given preference when possible, but relatively few scientific studies are available about the ‘People’ issues.

2.5.1 Labour conditions

Poor labour conditions in the soybean sector are generally not an issue in the United States or Argentina. This is primarily due to the highly mechanized production systems in those countries, which require very low labour inputs, but also the relatively well-established legal systems protecting workers. Information from Argentinean civil society organizations confirmed that poor labour conditions are generally not a problem in soybean cultivation in Argentina (i.e *INTA, 2008; Verner, 2006*).

The NGO organization Repórter Brasil monitors biofuel-related crops to analyze and publicize emerging human rights issues, and is the source of much information related to labour conditions (in the most recent publication of *Gomes* et al*., 2009*). In Brazilian soybean production, they report labour issues caused by low levels of worker organization, the presence of child and forced labour, and generally poor working conditions related to health and safety issues, low wages and long working hours. These issues are treated below under separate headings, ‘child and forced labour’, ‘occupational health and safety’, and ‘employment opportunities’.

<u>Child and forced labour</u>

General situation in soy production

Despite efforts that have been commended by the ILO, there is still child and forced labour in Brazil’s agriculture sector. Based on data provided by the Brazil National Child Labour Survey (*SIMPOC, 2001*[9]*)*, the International Labour Organization reports that 5.5% (900.000) of boys and 2.7% (420.000) of girls in Brazil aged 5-14 years work in agriculture. Forced labour is most common in land clearing stages of production. In 2008, 125 workers clearing land on property where soybeans were planted, were freed from forced labour according to the Catholic Church’s Land Pastoral Commission (*Gomes* et al*., 2009*).

[9] Worldwide authoritative source of information supported by ILO.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
The use of GM or non-GM soybean is not expected to have an impact on the presence of child and/or forced labour in soybean production. If employment in the sector changes (see below), this could have an impact on child and forced labour. However, this is an unpredictable impact; child and forced labour could become less common if more highly-skilled labour is needed, or more common and problematic if low-skilled workers move to more dangerous positions (i.e. in land-clearing activities).

Summary of theorized impacts of GM vs. non-GM soybean
Impact of GM production on child and forced labour is not expected to consistently differ from non-GM production.

Evidence of difference between GM and non-GM production

In terms of labour conditions, the available data from this literature review do not allow firm conclusions to be made about the difference between GM and non-GM production. The available studies about labour conditions in the soy-producing countries examined generally either transformations over time without specifically accounting for GM impacts (i.e. *INTA, 2008, Verner, 2006, Van Gelder & Herder, 2008*) or specific cases and instances of changing employment patterns (i.e. *Gomes* et al*., 2009, CAPOMA, La Soja Mata and Chaya Comunicacción, 2009*). With these types of studies, it is not possible to compare the two production systems while controlling for other factors. Data on forced and child labour are reported at regional levels, which does not provide information that is specific enough to make comparisons. Variation in social and economic situations in each production region hinder attribution of differences to the prevalence of GM or non-GM soy.

Conclusions of impacts from GM soybean versus non-GM soybean

While child and forced labour is present in the soybean sectors of some countries, on the basis of available literature, no differentiation between GM and non-GM production can be observed in this regard.

Occupational health and safety

General situation in soy production

Brazil has a high level of accidents at work; according to the National Institute for Social Security (INSS), the number of employees who suffered accidents during planting soybean increased from 286 cases in 2006 to 485 in 2007 (*Gomes* et al*. 2009*). Herbicide application also affects worker health; according to the National System for Toxic-Pharmacological Information (SINITOX), 6 297 Brazilian farm workers were contaminated in 2006 and 186 died. However, these figures include not only soybean farms, but the entire agricultural sector (*Gomes* et al*. 2009*).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
If larger amounts of herbicide are used in RR soy production, relative to non-GM soy production, worker exposure to herbicides may increase when farmers move from non-GM to RR soy. However, the impact of GM soybean on the total use of herbicides varies (see section 2.3.1.3). Moreover, the frequency of application and the method of application also impact workers' exposure to crop protection agents. Glyphosate's low toxicity to humans (Williams *et al*., 2000), relative to other herbicides used in soybean, suggests that herbicide application in GM RR soybean could result in a smaller impact on farm workers' health as long as the level of exposure to glyphosate is not increased to an extent that it offsets the advantage relative to the herbicides used in non-GM soy (see discussion in section 2.3.1.3, particularly on EIQ).

Summary of theorized impacts of GM vs. non-GM soybean
Increased worker exposure to agrochemicals may occur in countries where few legal protections exist, but as glyphosate is less toxic than the chemicals it replaces, the health impact of the exposure may decrease.

Evidence of difference between GM and non-GM production

In terms of labour conditions, the available data from this literature review do not allow firm conclusions to be made about the difference between GM and non-GM production. The available studies about labour conditions in the soy-producing countries examined generally either transformations over time without specifically accounting for GM impacts (*i.e. INTA, 2008, Verner, 2006, Van Gelder & Herder, 2008*) or specific cases and instances of changing employment patterns (*i.e. Gomes* et al.*, 2009, CAPOMA, La Soja Mata and Chaya Comunicacción, 2009*). With theses types of studies, it is not possible to compare the two production systems while controlling for other factors. Data on agrochemical poisoning are reported at regional levels, which does not provide information that is specific enough to make comparisons. Variation in social and economic situations in each production region hinder attribution of differences to the prevalence of GM or non-GM soy. There is no scientific information indicating that cases of agrochemical poisoning in Brazil differ in frequency between GM soy and non-GM soy. No information is available to establish whether worker exposure to chemicals has changed by the adoption of GM soybean, nor about the potential resulting long-term effects.

Conclusions of impacts from GM soybean versus non-GM soybean

Glyphosate has a lower environmental impact and human health impact than other herbicides. There are not sufficient scientific data or reliable comparisons between GM and non-GM production to conclude whether or not GM production differentially affects workers' exposure to herbicides in Brazil or Argentina.

Employment opportunities

General situation in soy production

Argentina's agricultural sector has transformed over the past two decades as farmers began to adopt a technological model of agricultural intensification. Average farm sizes in the Pampas, where agriculture has always been executed on a large scale, has increased further from 243 to 538 hectares between 1999 and 2005, with increasing numbers of farms growing crops requiring fewer labour inputs (Pengue, 2005). Farm ownership has been concentrated in fewer hands, and land devoted to more labour-intensive production of fruits, dairy, cotton, etc. has decreased significantly. As such, this reduced the number of jobs in the sector. However, the simultaneous processes of crops replacing livestock and the intensification of production due to double cropping reversed this trend and increased the number of jobs in the sector (*Trigo & Cap, 2006*). Although the number of people employed in the Argentinean farming sector has increased due to rapid expansion of planted areas, impacts in some regions have been less positive (*Verner, 2006).*

The Brazilian agricultural output has rapidly grown in recent years. Direct employment benefits of large-scale soy production are limited because large-scale soybean production, as most large-scale agricultural production, needs few on-farm jobs. In Brazil, unlike Argentina, GM soybean was introduced at the same time that large-scale, intensified agriculture started to become the dominant production model. As with the situation in Argentina, the extent to which GM soy production has caused this transformation and the resulting loss of rural employment opportunities is uncertain. For instance, in northern Mato Grosso, where much of the recent Brazilian expansion of the soybean area has occurred, soybean is still largely non-GM (*Bindraban* et al.*, 2009*). It is likely that GM soy facilitated these changes in the agricultural sector, rather than being the main cause behind these changes (see also section 2.3.4).

Soybean production in the United States was already highly mechanized before the introduction of GM soybean. Although casualization of seasonal and migrant labour is a problem in US agriculture, soybean production and harvest generally does not require high seasonal labour inputs because of this mechanization (Nehring *et al.*, 2002).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
With the already existing high level of mechanization in the US, labour requirements for soybean cultivation were already quite low, and are thus unlikely to vary significantly with the adoption of GM varieties. Since it is likely that GM soy facilitated rather than represented the main cause for the changes into more large-scale operations in the Latin-American agricultural sector (see also section 2.3.4), this indirect relationship of GM soybean with employment opportunities will also be uncertain. On the other hand, an intensification of the cropping system (also as a result of the so-called 'second crop benefit' enabled by GM soybean) as well as an expansion of the arable cropping area (at the expense of extensive livestock systems) could increase labour opportunities in the rural sector. As discussed in sections 2.3.2 and 2.4.1, the introduction of GM soybean in Latin America and the US has likely contributed to the implementation of soil conservation tillage systems. This involves reduced tillage or no tillage at all, leading to savings in, amongst others, labour input. In some cases, the labour demand for herbicide application may be reduced as well in GM soybean. A reduced requirement of labour input for the cultivation of GM soy is usually regarded as positive from a farm-level income perspective. With fewer on-farm labour inputs required for GM soy, employment opportunities shift towards fewer but more highly skilled positions (i.e. operating farm machinery, management). It is plausible to predict that less overall labour may be required, with a higher portion of remaining positions being for skilled labourers. Surplus labour could move to any other sector or become unemployed, depending on the economic and social conditions.

Summary of theorized impacts of GM vs. non-GM soybean
Labour demand is expected to be reduced in GM soybean. This may reduce on-farm employment opportunities and there potentially is a shift in labour activities from relatively simple activities to more high-skilled ones.

Evidence of difference between GM and non-GM production

No studies reporting differences in employment opportunities in Brazilian or US GM soy production versus non-GM soy production have been found during this literature review. In Brazil, the available data do not allow firm conclusions to be made because of the inability to separate GM as a variable from other changes in regional production methods such as scale, degree of mechanization, crop intensity, etc. In the United States, a study by Gardner *et al.* (2009) used USDA National Agricultural Statistical Services' to confirm the expectation that no significant difference existed between GM and non-GM cultivation.

On-farm employment opportunities in Argentina may have been affected by GM production, though only if GM soy is responsible for the expansion of the large-scale technological model of agriculture. Although some have claimed that the GM technical package, which includes, for example, the opportunity of direct planting in arid regions by facilitating weed control, one of the advantages of no-tillage systems (see section 2.3.2), enabled this transformation of the sector (e.g. Pengue, 2005, *Delgado, 2007,* or *CAPOMA, La Soja Mata and Chaya Communicación, 2009*), this conclusion is disputable (see also section 2.3.4). Other developments such as the shift to a free market, changes in farm policies, the introduction of external economic actors and strong connections between government and agri-business also impacted the shift towards large-scale farming (*Bindraban* et al.*, 2009;* Laursen, 2010[10]). The Argentinean agricultural sector was also transformed in the 1990s by the end of hyperinflation and the fixation of the Argentinean peso with the U.S. dollar, which increased stability and stimulated investment in agricultural infrastructure. Export tariffs were dramatically reduced (from ~40% to 3.5% on soybeans) during this period as well, but have risen since the economic crisis of 2002 (to 23.5% on soybeans) (Deese & Reeder, 2007). Also the strong devaluation of the Argentinian peso (by more than 60% relative to the US dollar) with the crisis of 2002 greatly stimulated soybean export (Deese & Reeder, 2007). As the introduction of GM soy in Argentina therefore likely facilitated rather than caused the transformation of the agricultural sector to a large-scale, highly mechanized model, the impact of the GM transformation in the agricultural sector on rural labour opportunities is also uncertain. A shift in labour activities from standardized activities such as weed control to other operational and management activities such as quality management, marketing activities, financial management, etcetera, may upgrade the quality of labour input on farms with GM crops. One may expect farmers to be better educated and

[10] News feature in peer-reviewed journal.

skilled and to earn higher incomes (see *Bunte* et al*., 2009*). Fernandez-Cornejo *et al.* (2005) found that farmers and their relatives in the US spend their extra time on off-farm economic activities.

Conclusions of impacts from GM soybean versus non-GM soybean

No significant difference was found in the United States with respect to employment opportunities when GM soy was introduced in an already highly mechanized agricultural production system. For Brazil, no data are available that effectively control for other factors such as simultaneous changes in scale, mechanization, intensity of production, etc. Similarly in Argentina, it is the transformation of the agricultural sector into a larger scale of operation that may have changed employment opportunities; the introduction of GM soy in Argentina likely facilitated rather than caused this transformation. In the US, farmers spend their extra time on off-farm economic activities.

2.5.2 Land rights, community rights and rights of indigenous people

General situation in soy production

According to Repórter Brasil, land conflicts in Brazil are common and indigenous and local peoples often face the risk of eviction. Land register is weak in Brazil, creating uncertainty around land ownership. As a demonstration of the insufficient legal protections that may be given to local communities, there is the case of the Bordolândia Settlement Project, in which the Federal Attorney's Office requested the eviction of 1,200 families for allegedly deforesting the area without a license. Repórter Brasil argues that the conflict is based on land speculation caused by the paving of a nearby road (BR-158, *Brianezi, 2009*)). Road development forces up land prices by making agricultural production more economically viable, as transportation costs to crushers and traders are a large part of soybean producers' expenses.

In Argentina, *CAPOMA, La Soja Mata and Chaya Comunicacción (2009)* reported that there has been repeated encroachment of soy production into indigenous territories. For example, according to these organizations, between 2004 and 2007 the production estates La Hercilia, Guamache and El Álamo received permits to deforest a total of 66,951 ha of lands occupied by Wichí communities in San Martín. In some cases, hearings on land use decisions have been held without prior notification and in remote locations. In 2008, the Secretary of Environmental Policy facilitated an agreement between the community of El Traslado and El Álamo that offered 1,900 ha of land in a flood zone as compensation for the displacement. According to these organizations, other land conflicts between indigenous communities and soybean producers in Argentina involve a Wichí community in Misión Chaqueña, Creole families along the Dorado River, and Guaraníes communities in the province of Jujuy, who through violence and intimidation have lost 7,000 of the 11,000 ha of land that they were promised by the provincial government in 1996 (*CAPOMA, La Soja Mata and Chaya Comunicacción, 2009)*.

Land conflicts are generally not an issue in the United States soybean sector. This is primarily due to the well-established legal system protecting land owners and land users in the US.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

GM production itself does not have a direct connection with land rights issues, except inasmuch as GM might facilitate larger-scale production when this leads to occupation of additional lands and consequent conflicts with local communities. The perceptions and attitudes of local communities and NGOs that oppose GM production can potentially exacerbate existing conflicts by making GM an additional point of conflict.

Summary of theorized impacts of GM vs. non-GM soy

GM production might facilitate the expansion of large-scale cultivation. This expansion, combined with a poorly functioning land register system, is one of the primary causes of land conflicts.

Evidence of difference between GM and non-GM production

Some cases of land conflict have been reported that are directly related to GM crop testing and/or planting. For instance, in Brazil some civil society organizations, including Amnesty International, claimed that in 2007 in Paraná, Syngenta occupied farm land to test GM crops, whereas the land had been suggested for use to produce seeds for small-holder farmers (based on environmental zoning law). NGOs highlighted the connection to GM production to rally opposition to Syngenta's project. Human rights groups reported violent and illegal methods to forcibly evict, threaten and attack land activists. A court case on the killings of a security guard and a leader of the Landless Workers Movement in October 2007 started in November 2008, and Syngenta has since returned the land to the state government (*Amnesty International, 2008*).

Land conflicts are more likely to occur as a consequence of the large-scale expansion of soybean production. In Argentina, claims and studies about land rights issues often link the expansion of soybean cultivation regions with the availability of GM soybean. However, as discussed in section 2.5.1, the introduction of GM soy in Argentina likely facilitated rather than caused the transformation of the agricultural sector. In Brazil, the frequency of land conflicts is not different between northern Mato Grosso, where much of the recent expansion of the soybean area has occurred, but soybean is still largely non-GM, and areas where GM soy cultivation is expanding. However, in conflicts where GM soybean is involved, GM may be used by critics as an additional reason to oppose the soy cultivation (see *Gomes* et al*., 2009*, for examples).

Conclusions of impact from GM vs. non-GM soybean

There are claims from many civil society organizations that GM production has been a strong driver of large-scale agricultural expansion in Argentina, which would not have been possible without GM varieties. However, the introduction of GM soy in Argentina likely facilitated rather than caused the transformation of the agricultural sector. No general link between land rights conflicts and GM production can be observed across different regions in Brazil; large-scale expansion activities, rather than the choice for GM, appear to be the primary cause of land rights conflicts.

2.5.3 Freedom of choice

General situation in soy production and theorized impacts of GM vs non-GM production

This section of the report focuses on Brazil. Brazil still has a sizeable non-GM soybean production (30-40% of the total production) and is therefore an interesting case to study with respect to freedom of choice. We can contrast this to the situation in Argentina and the US, where most soy is GM.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

The possibility to cultivate GM soy crops in a sense widened the farmer's options for soybean cropping. As all non-subsistence, commercial farmers depend on prices and availability of farm inputs and outputs, and often on financiers with particular demands, commercial farmers are always rather limited in their freedom of choice for particular crops or varieties, if they want their farm to remain economically viable. This is also true for farmers' freedom to choose between GM and non-GM soybean. While farmers in the Americas are in essence free to choose between the cultivation of GM or non-GM soybean, external factors such as the availability of seed, market demands and marketing opportunities strongly influence their choice.

Summary of theorized impacts of GM vs. non-GM soy

Farmers in the Americas are in essence free to choose between the cultivation of GM or non-GM soybean. However, external factors such as the availability of GM and/or non-GM seed, market demands and marketing opportunities strongly influence their choice between GM and non-GM production.

Evidence of difference between GM and non-GM production

Although commercial and government banks are available in some cases, the majority of soybean farmer financing in Brazil is provided by processors and traders. Farmers' seed choices may be influenced by the financier. As part of a pre-financing agreement, financiers have the ability to require farmers to use specific inputs and/or methods that have been proven effective in some sense. Only anecdotal evidence is available that these demands include the cultivation of specific GM or non-GM varieties.

Brazilian farmers are often also limited in their choice of market outlets due to the infrastructure and the vast distances between production fields and markets or export harbours. For instance, Brazilian farmers in northern Mato Grosso primarily deliver soybeans to the traders that operate from two harbours in the Amazon river basin, as transport costs to deliver to traders in the south are very high. These traders only accept non-GM soybean to satisfy the demand for non-GM soybean in foreign markets such as the EU and Japan, thereby strongly stimulating farmers in northern Mato Grosso to grow non-GM soybean (*Franke* et al*., 2009*). In other areas of Brazil, a segregation system preventing admixture of GM and non-GM soybean is required throughout the chain if farmers, processors and traders want to capitalize on the demand for non-GM soybean and the possible premiums paid for non-GM soybean. Brazil currently has segregation systems for non-GM soybean that are mostly maintained by private parties in the chain and that function fairly well. Brazil is therefore capable of exporting substantial amounts of non-GM soybean. However, market actors have identified a developing challenge to this system. Insufficient transport and storage space, combined with potential impurities in non-GM seed itself, have been recognized as threats to the current segregation system (*Franke* et al*., 2009*).

The availability of soybean seed of well-adapted GM or non-GM varieties may also strongly influence farmers' choice to grow GM or non-GM soy. Breeding companies may prefer the release of GM varieties, due to the economic benefits they receive from royalty payments. Transgenes are protected by patents and farmers must pay royalty (technology) fees included in the seed prizes for their use. *Franke et al. (2009)* reported that in Brazil some seed companies devote most of their research investments to breeding GM varieties. However, the public research institute Embrapa in Brazil regards maintaining a non-GM soybean breeding program and helping to maintain the availability of good varieties of non-GM seed to farmers as a strategic priority (*Franke* et al*., 2009*).

In Argentina, the IPR on the RR trait in soybean is not recognized and farmers pay no or only a minimal additional price for RR soybean seed, providing Argentinian exporters with a slight advantage in international markets. This situation will, however, be changed by the amended Seed Law (Laursen, 2010). The absence of a technology fee on RR soybean seed improved the net benefits that farmers obtained from the cultivation of RR soy, resulting in a very high adoption rate of RR soy (99%). Seed companies have not released any new non-GM soybean varieties since 2005 (*Co-Extra, 2009)*, presumably because of a lack of demand among farmers for non-GM seed. As a result, the still available non-GM seeds in Argentina may be outdated, as between 2005 and now progress in breeding will have been made, unrelated to the availability of GM traits. In the particular case of Argentina, the absence of royalties on RR seed implied that royalties were not an incentive for breeding companies to produce RR soy seed.

In the United States, in 2009, farmers had difficulties acquiring non-GM seeds as well. However, this was caused by short-term supply problems rather than persistent unavailability. The public sector in the United States – with a primary role for State universities – has been able to maintain seed availability from non-GM variety breeding. According to *Co-Extra* (*2009*), funding for these activities is expected to diminish in the near future.

The high adoption rates of GM soybean in Argentina and the US, as well as the characteristics of their infrastructure, resulted in most areas in the absence of segregated chains for processing and transporting GM and non-GM soy. Therefore, the incentive that Brazilian farmers may receive for the production of non-GM soybean by a price premium for their produce is absent for soybean farmers in Argentina and the US for lack of a separate non-GM market outlet.

Conclusions of impacts on freedom of choice

While farmers in the Americas are in essence free to choose between the cultivation of GM or non-GM soybean, external factors often influence their choice. These external factors include: obligations from financiers, the availability of market outlets, market demands, the availability of segregated systems for handling GM and non-GM soybean, and the availability of GM or non-GM seed. There is evidence that these factors indeed influenced farmers' choice for GM or non-GM soy through their impact on the profitability of GM or non-GM soybean production. In Brazil, Argentina and the US, particular characteristics, e.g. with regard to arrangements for royalty payments (technology fees) for GM seed, infrastructure for handling GM soy, non-GM soy, or both, seed companies and the involvement of public institutes in GM or non-GM variety breeding, affected the economic attractiveness of cultivating GM or non-GM soybean differently, explaining to a large extent the different adoption rates of GM and non-GM soy among regions in these three countries.

2.5.4 Competition with food production

General situation in soy production

The choice to grow crops for export rather than, or next to crops for local markets, is influenced by many different factors, which may include the availability of GM crops and biofuel production opportunities. Soybean cultivation contributes to food production in Argentina, Brazil and the US, mostly in the form of providing feed for domestic livestock production. The use of soybean as a livestock feed in these countries serves the (increasing) national demand for livestock products. Expanding soybean cultivation could in theory be considered a threat to food security given the fact that a hectare of a predominantly feed crop cannot feed as many people as a hectare of a food crop. However, the area of arable land not devoted to soybean production is sufficient to produce food crops, as is evident from the fact that Brazil, Argentina and the US are currently also major producers and exporters of cereals such as maize and wheat and other products. In Argentina, maize and wheat for export have partly been replaced by soybean for export. Argentina and Brazil indeed have vast areas of arable land available, relative to the number of inhabitants, and logically, their arable farming sector is and has been for long export-oriented. This export orientation does not need to threaten food production for national consumption. The economic crisis in Argentina around the turn of the century (see section 2.5.1) has reduced food security among poor people in Argentina due to a lack of purchasing power.

The soybean oil (20% of the bean) that becomes available during the production of soybean meal is also used as biofuel. As the demand for biofuel production is on the rise, the United States import soybean-based biodiesel from Latin American countries including Argentina. The Food and Agricultural Organization of the United Nations (FAO), in its report on biofuel of April 2008, reaffirmed its position of considering biofuel a potential threat to food security for the people of Latin America and the Caribbean (*FAO, 2008*). However, soybean is never solely produced for biodiesel production. The meal (80% of the bean) is always used in the food chain, mostly as livestock feed. Some local organizations in Brazil and Argentina, however, are worried about the use of soybean oil as biodiesel. In Mato Grosso (Brazil), biofuel companies have been making contracts with farmers so that they produce soybean, but there are no conclusive studies in Brazil indicating that biofuel production drives up prices of daily food products such as rice and beans. Concerns have been expressed by organizations such as Landless Workers Movement (MST) and Via Campesina, as according to them there is a great risk to people's freedom for food choices if soybean is used in biofuel production and large companies control the sector (*Gomes* et al*., 2009)*.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
It is unlikely that the presence of GM soybean played a role in food security of poor people in Latin America, e.g. in Argentina after the economic crisis around the turn of the century. Nor is it likely that GM soybean plays a role in shifts toward using soybean in biofuel production. In both cases, this is conditional upon there not being a GM-specific incentive for expansion of soybean cultivation, as already discussed in section 2.5.1.

Summary of theorized impacts of GM vs. non-GM soy
There is no expected difference between GM and non-GM production on food security in soybean producing countries, since both types of soybean are export-oriented and not for direct human consumption.

Evidence of difference between GM and non-GM production

While export-oriented large-scale agricultural production in general can have an impact on food security and local food prices/availability, it is unlikely that there is a difference in impact between GM and non-GM soybean cultivation. Both GM and non-GM soybean are produced primarily for export markets and on large scales, and compete with food production in the same way. Food production and availability can be negatively impacted if GM soybean makes soybean production more attractive relative to other food crops than non-GM soybean, as it would stimulate farmers to increase the area of soybean at the expense of other crops.

In Brazil, no evidence has been found that the above mentioned production trends and subsequent possible threats to food security are driven by GM cultivation. GM production in Argentina has contributed to the transformation of the agricultural sector that has affected domestic food production. Nevertheless, other factors have also played important roles in this process, and the relative contributions are difficult to assess (*Bindraban* et al*., 2009*, see more extensive discussion in section 2.5.1).

Conclusions of impact from GM vs non-GM soybean

No interaction between GM soybean production and food security has been observed from the available scientific literature.

2.5.5 Contribution to livelihoods of producers and local communities

This section considers the economic impacts of GM soy cultivation, as discussed in Chapter 2.4.1, on income security and the distribution of benefits to livelihoods of farmers and local communities, and impacts of GM soy cultivation on community health and safety under separate headings.

Income security and the distribution of benefits

General situation in soybean production

The cultivation of GM soy has a positive effect on farm income through savings in herbicide costs and labour, which generally outweigh seed costs (see section 2.4.1). Also the savings in crop management (reduced or no tillage system), which offers an increased opportunity for farmers to grow a second crop in the same year and/or generate income from off-farm activities, has a positive effect on farm income, even if the on-farm economic impact of the soybean cultivation itself is neutral. Many US farmers earn a substantial part of their income from off-farm activities and employment (see section 2.5.1).

The *UNDP's Country Programme Document for Brazil 2007-2011 (2006)* reports that, while the country as a whole may be able to meet Millennium Development Goals, regional inequalities are large and the poorest regions are in the expanding agricultural frontier. The Argentinian export-oriented farming model also has mixed impacts on producer and community livelihoods and distribution of direct benefits in rural areas is unequal. However, large-scale agriculture in Argentina contributed to government revenues through export taxes. In 2008/2009, taxes on soybean product exports contributed revenue worth ~3.5 billion euros to Argentina's federal government – approximately 10% of its total budget (*Credit & Finance Risk Analysis, 2010*).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
Income security of farmers and distribution of benefits of increased efficiency of GM cultivation to farmers may depend on whether they are able to afford new technologies and to become or remain competitive. It is theorized that large-scale production for export may be facilitated by GM production (see also section 2.5.1). While this likely has positive macro-economic benefits, distribution of direct benefits in rural areas is unequal. Indirectly, the Argentinian Government revenues could contribute to communities in poorer regions of the country by well-planned and implemented development programs, public works investments and infrastructure development.

Conclusions of impact from GM vs non-GM soybean
There are likely to be positive impacts for farmers who are able to adopt GM soybean.

Evidence of difference between GM and non-GM production

Section 2.4.3 showed that part of the global welfare created by the availability of GM soybean went to farmers. The actual share that farmers received from the additional welfare, relative to the share that seed producers or consumers for instance obtained, varied a lot between countries, depending for instance on national intellectual property rights arrangements for GM seed. Thus, in general soybean farmers received financial benefits from the adopion of RR soy, explaining to a large extent the high adoption rate of GM soybean varieties. To assess how these benefits of GM soybean impacted livelihoods of farmers, it is, among others, necessary to determine how the benefits have been distributed among farmers and among other members of rural communities.

For a country with its particular level of per capita income, Brazil has historically had a particularly uneven income distribution: in 2001, about 30% of Brazilians were poor, while the global average for countries with similar per capita incomes was only 8% (*De Barros* et al*., 2001*). Since 2001, regional income inequality has decreased significantly due to federal income transfer payments and the Bolsa Familia program (*De Souza Ferreira Filho & Horridge, 2009*). This level of income inequality and the rapid changes brought about by short-term public policies makes that regional comparisons of income and opportunities cannot adequately isolate the impact of GM or non-GM production. Moreover, widespread GM soy production in Brazil is relatively new, the long-term data on its contributions to producer and community livelihoods that would be needed to establish a connection to this issue do not exist.

According to Argentina's 2008 agricultural census, more than 60,000 farms shut down between 2002 and 2008, while the average size of farms increased (*Trigona, 2009*). The National Indigenous Campesino Movement of Argentina (MNCI) reported that 82% of farmers made their livelihood from 13% of the nation's land used for agriculture, while 4% of large land holders or financial investors in the agriculture sector owned more than 65% (*Trigona, 2009*). It is thus likely that farm-level benefits from growing soybean have been rather unequally distributed among rural people in Argentina. The high profitability of soybean production has led to a rise in tenant farming and absentee landlords in Argentina (Tomei & Upham, 2009). Farmers who are unwilling or unable to take the production risk rent out their land to others who manage production from year to year. As a result, the value of land has increased five times in the past decade (*Monti, 2008*), and in 2007 some 60% of farms were managed by tenants. Rising land values have benefited many farmers, but could be harmful for poorer farmers without secure land titles. The link with GM production depends, as with many other impacts, on the extent to which GM soybean has enabled this transformation in the agricultural sector, In this regard, GM soybean has been most likely more facilitating than being a causative factor (see section 2.5.1). No information was found whether the Argentinian Government's revenues from taxes on soybean product exports indeed contribute to communities in poorer regions of the country by well-planned and implemented development programmes, public works investments or infrastructure development.

In the United States, Fernandez-Cornejo *et al.* (2005) found a positive relationship between GM soybean adoption and off-farm income. Their result suggested that adopting GM soybeans can free up resources for alternative uses without decreasing on-farm income due to simplified weed management. Gardner *et al.* (2009) confirmed these results, showing that complete adoption of GM soybeans will reduce the quantity of household labour applied by 14.5%, for a total of 94.5 hours, or about ten 9.5-hour days throughout the growing season. A part-time farmer can use this time to work at his/her off-farm job or for leisure.

Conclusions of impact from GM vs non-GM soybean

Farmers in general benefitted from the adoption of GM soybean, caused by reduced labour demands, an increased flexibility of the timing of spraying operations, opportunities to include additional crops in the rotation and/or increased net benefits from soy production. While the distribution of benefits from GM soybean among farmers appeared to be relatively equal in the US, the picture is less clear for Brazil and Argentina due to a lack of data.

Community health

General situation in soybean production

Negative community health impacts have been reported in the context of agrochemical poisoning caused by aerial spraying in Brazil and Argentina. Even when the toxicity of glyphosate that is used with RR soybean is relatively low, this remains a major and controversial social impact. There have been isolated incidents of this kind in the United States as well, but legal and regulatory processes have protected community rights there.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
In Brazil, where the share of non-GM soy is still relatively large, GM soybean production is not particularly associated with large-scale farming and in Argentina, GM soy may have facilitated the ongoing enlargement of the scale of farming (see section 2.5.1). As aerial spraying is mostly used on large-scale farms in general, the use of aerial spraying is basically not expected to differ between GM crops and non-GM crops.

Summary of theorized impacts of GM vs. non-GM soy:
More exposure to crop protection agents is expected in jurisdictions where rural communities are not well-protected by law or law enforcement is limited. More exposure is anticipated in areas where soybean farming is large-scale and aerial crop spraying is practiced. Both are not expected to be directly related to whether the soybean grown is GM or non-GM.

Evidence of difference between GM and non-GM production

Aerial crop spraying may impact local communities if regulations are not adhered to or not enforced. Civil society organizations have reported examples of such impacts: Repórter Brasil mentions complaints from the Sangradouro Indigenous Land (IL) reserve of low-flying planes spraying agrochemicals on or near villages (*Gomes* et al*., 2009*). The Argentinian Santa Fe court stated in a recent case that farmers 'have been indiscriminately using agrochemicals such as glyphosate, applied in open violation of existing laws [causing] severe damage to the environment and to the health and quality of life of the residents' (quoted in *Romig, 2010*). Aerial spraying is more common in large-scale crop production in general. GM soy may have facilitated the ongoing enlargement of the scale of farming that took place in the Argentinean agricultural sector, but in Brazil, there is no evidence that this trend towards larger scale agriculture is attributable to GM production (see section 2.5.1).

Conclusions of impact from GM vs non-GM soybean

There were examples of communities exposed to herbicides from soybean production in Brazil and Argentina. No studies are available indicating that aerial spraying of herbicides – leading to the exposure of communities - is more common in GM production than in non-GM production, although civil society organizations stated that it is.

3. Maize

3.1 General characterization of cultivation and trade

Maize (or corn as it is often called in the USA, *Zea mays* L.) is one of the main cereal crops and it is cultivated in a wide variety of cropping systems across continents. Table 3.1 gives an overview of grain maize cultivation in 2006 and 2007 for the twenty most important producers worldwide. The world acreage of grain maize is about 150 million ha, with a total grain production of about 700 million tonnes. Apart from grain production, there is also a large acreage of forage maize, which is mostly used locally as feed. The US is one of the largest exporters of grain maize, together with China and a few other countries in the Americas. In Europe, France is the largest producer (1.7% of world production in 2007), followed by Italy and a few Eastern European countries. The twenty most important grain maize growing countries (Table 3.1) together produced 89.5% of world production on 77.7% of the world acreage in 2007. The US alone produced 42.3% of the world production on only 22.2% of the world acreage. China had considerably lower yields and so, produced 19.4% of the world production on an acreage that is not much smaller than that of the US. Together, the US and China make up for more than 60% of the worldwide production of grain maize.

Grain yield is about 3,700 kg per ha on average across all countries. As was already apparent from the example of the two largest producers, the US and China, yields vary a lot among the various countries. Next to the US and North-western Europe, high yields are found in Southern Europe (Spain, Italy and Greece), in the Middle East (Egypt, Israel, Kuwait and Iran) and elsewhere, in Tajikistan, Chile and New Zealand. This is mostly in line with the general level of crop productivity in these countries, but maize is also well adapted to the their climatic conditions. The relatively large yields in the Middle East and Southern Europe are related to the use of irrigation.

Maize is an important crop to the Netherlands; however, it is almost entirely grown as forage maize. Grain maize is grown on just about 2,000 ha, with yields in line with the high-productivity countries mentioned before (*FAOSTAT, 2010*). This grain production represents only a very small part of the total grain maize consumption in the Netherlands.

The grains are used for food and feed, as well as for industrial products. Processing basically starts with two types of milling, 'wet milling' or 'dry milling' (*Kok* et al.*, 2006*). Wet milling is used with starch production, the result is processed further through fermentation or refining for use in a wide array of products in e.g. the chemical and food industry. Worldwide, starch production is covered for 80% by maize (Scott & Pollak, 2005). Apart from starch, oil, gluten, fibres and maize germs are produced that are mainly used for feed production. Dry milling leads to products, such as gluten, semolina and maize germs that for the great part are directly used for food or feed (*Kok* et al*. 2006*).

Table 3.1. Grain maize: acreage, yield and production in the 20 countries with the largest production in 2006 en 2007 (FAOStat, 2010*).*

Country	Acreage (Mha)		Yield (kg/ha)		Production (Mton)	
	2006	2007	2006	2007	2006	2007
USA	28.6	35.0	9360	9482	267.6	332.1
China	27.1	28.1	5378	5413	145.6	152.0
Brazil	12.6	13.8	3382	3731	42.7	51.6
Mexico	7.3	7.8	3001	2885	21.9	22.5
Argentina	2.4	2.8	5903	7666	14.4	21.8
India	7.9	7.8	1907	2160	15.0	16.8
France	1.5	1.5	8586	8850	12.9	13.1
Indonesia	3.3	3.5	3470	3588	11.6	12.4
Canada	1.1	1.4	8474	7754	9.0	10.6
Italy	1.1	1.1	8729	9144	9.7	9.9
Hungary	1.2	1.3	6816	6716	8.3	8.4
Nigeria	3.9	4.7	1818	1660	7.1	7.8
South Africa	2.0	2.6	3412	2876	6.9	7.3
Egypt	0.8	0.9	8264	8116	6.9	7.0
Philippines	2.6	2.7	2366	2474	6.1	6.7
Ukraine	1.7	2.0	3735	3350	6.4	6.7
Vietnam	1.0	1.2	3702	3750	3.8	4.3
Ethiopia	1.8	1.5	2248	2725	4.0	4.0
Russia	1.0	1.6	3629	2520	3.7	4.0
Serbia	1.2	1.2	5143	3249	6.0	3.9
World	146.7	157.9	3768	3656	699.3	784.8

Maize is an important product for the Dutch economy and trade. There is not only trade in the raw material, but also in all sorts of processed products. The maize imported into the Netherlands in 2008 originated almost all from 13 countries in total and for almost a quarter from four countries outside of Europe (Table 3.2). Within the EU, most of the maize came from France and Germany. There are quite some changes over the years; for instance, Brazil was ranking seventh in 2006, but since then almost doubled its export to the Netherlands. Interestingly, relatively little is imported from the US, which is one of the largest maize producers in the world. The US processing industry probably takes a large part of the production themselves; for instance, ethanol production for biofuel has increased enormously recently. An indication for this extensive local processing is the large amount of by-products from the maize-processing industry that was imported from the USA. Problems with ship loads commingled with unapproved GM varieties might have played a role as well in the low amount of maize imported from the US. This situation may change as recently more GM variants have been allowed in the EU, but new GM assessments are still lagging behind countries in the Americas (asynchronous approval, see below under Institutional risks, 3.4.4).

*Table 3.2. Origin of maize imported into the Netherlands in 2008 (*CBS, 2009*).*

Countries	Import (Mton)
France	1.548
Brazil	0.785
Germany	0.678
Belgium	0.504
Hungary	0.223
Argentina	0.142
Slovakia	0.036
United Kingdom	0.011
Italy	0.011
Russia	0.006
China	0.006
United States of America	0.002
Turkey	0.002
Other countries	0.015
Total	3.970

3.2 Genetic modification

3.2.1 Current events

Maize was one of the first crops in which genetically modified varieties became available (in 1997) and these have become important in cultivation since then. Worldwide, the GM maize acreage was 25.2 Mha in 2006, 35.2 Mha in 2007, 37.7 Mha in 2008 and 41.7 Mha in 2009; the total grain maize acreage was about 150 Mha (*James, 2009*). Thus, within the little more than ten years since the introduction of the first transgenic varieties, cultivation of GM maize has increased to about 28% of the total maize acreage. Outside of Europe, GM maize was grown in ten countries in 2009: the US, Canada, Honduras, Brazil, Uruguay, Chile, Argentina, the Philippines, South Africa and Egypt (*James, 2009*). In the US, Canada and Argentina, GM varieties occupied 80-85% of the total maize acreage. According to *James (2009)*, six EU countries grew GM maize (containing the Bt MON810 event, the only maize event allowed for cultivation in the EU) in 2009 (in order of decreasing acreage): Spain, Czech Republic, Portugal, Romania, Poland and Slovakia. As of 2010, six EU countries, France, Germany, Austria, Greece, Hungary and Luxembourg, have banned the cultivation of Bt MON810 maize temporarily on the basis of a precautionary clause. Other GM maize varieties are not allowed for cultivation in the EU, but several variants of Bt and HT (herbicide tolerance, e.g. events GA21 and NK603, both encoding glyphosate tolerance) have been allowed for import. The total acreage of GM maize has remained relatively limited in the EU up till now (more details in the review by Devos *et al.*, 2009 and *GMO Compass, 2010*).

The GM varieties presently cultivated contain transgenes encoding herbicide tolerances (HT) or insect resistances (IR) (*James, 2009*; Scott & Pollak, 2005). In the US, adoption of glyphosate-tolerant maize was initially low because of good alternative conventional herbicide schemes, but steadily increased and reached 60% in 2008 (Duke & Powles, 2009). In the present commercial cultivars, the insect resistances are based on the Bt protein (originating from the bacterium *Bacillus thuringiensis*), variants of which have a toxic effect on members of the Lepidoptera (moths etc., for instance, Cry1Ab (e.g. MON810) against European corn borer, *Ostrinia nubilalis*, or Cry1Ac against African stem borers, *Busseola fusca* and *Chilo partellus*) or Coleoptera (beetles, e.g. Cry3Bb against the Western corn rootworm *Diabrotica virgifera virgifera*).The two types of transgenes (HT and Bt) are becoming more and more stacked in new varieties; for instance in the US, 75% of the GM hybrids had stacked traits in 2009 (*James, 2009*).

3.2.2 Events in the commercial and regulatory pipeline

GMO Compass, AGBIOS and EFSA give overviews of transgenes being tested for maize[11]. As mentioned in the previous section, existing transgenes, i.e. HT and Bt variants, are being stacked in new varieties (*GMO Compass, 2009, James 2009*). As with soybean (see section 2.2.2), Pioneer has a herbicide-tolerant Optimum® GAT® version of maize in the regulatory pipeline. The Optimum trait is for tolerance to herbicides of the ALS inhibitor class; GAT has a different mode of action for glyphosate tolerance than Monsanto's EPSPS version, i.e. by inactivating the herbicide instead of having a resistant version of the EPSPS enzyme targeted by glyphosate. Monsanto's first drought-tolerant GM maize is expected to be commercially released in the US in 2012. The drought-tolerance is based on a bacterial *CspB* gene encoding a chaperone protein (Castiglioni *et al.*, 2008). GM varieties with an increased level of lysine are developed for poultry feed in both the US and China. Other GM varieties with altered compositions in the pipeline have changed oil contents and phytase (*Stein & Rodríguez-Cerezo, 2009*). China recently approved its phytase GM maize line.

3.3 GM-related sustainability – Planet

3.3.1 Production efficiencies

3.3.1.1 Land

The presently cultivated GM maize varieties have traits aimed at improving harvest reliability (by Bt transgenes) and/or growing efficiency (by HT genes), which should also optimize yields and thus land use efficiency.

Bt maize

Gómez-Barbero *et al.* (2008) studied the effects of Bt maize in Spain, which is the most important area in the EU where Bt maize has been grown at a commercial scale already for several years. Bt maize was compared to the non-GM varieties at present in cultivation, by means of questionnaires with growers. Growers of Bt maize had on average higher yields, but the difference with non-GM growers was statistically significant in only one of the three regions studied (Zaragoza). This may be related to the infestation level of the European corn borer (ECB) in Zaragoza, but there were no good figures for these borer populations available to test this hypothesis. There is also the possibility that the genetic background of the Bt varieties was not optimal in the years of the study (2002-2004), as just two hybrid varieties containing the MON810 Bt event were available at the time, whereas this number had risen to 53 in 2007 (Devos *et al.*, 2009). Brookes & Barfoot (2008) reported yield improvements for Bt maize in Spain of 6.3% on average between 1998 and 2003, and later on, of about 10%. In the earlier period, Bt event Bt176 was the only one available; later on, the already mentioned MON810 event became available for growers. For the US and Canada, Brookes & Barfoot (2008) reported an average yield improvement of 5%. Yield developments are not easily assessable with Bt maize, because in practice, effects on yield naturally depend on the occurrence of the relevant pest insects. For instance, the occurrence of the ECB, which is an important pest in both Europe and North America, is highly irregular, with for example exceptionally high infestation levels being observed once every 4 to 8 years in the Middle West of the US. Also, use of pesticides as alternative method to control borers varies between growers, since effective application is complicated by the borers' occurrence inside stems protecting them from pesticide sprays. Taking into account such limitations, *Gurian-Sherman (2009)* described several scenarios in which average yield improvements for all Bt variants taken together ranged from 1.3 to 5.5%. These figures are of the same order as Brookes & Barfoot's (2008) 5%, but the average scenario is clearly below the latter number. According to Brookes & Barfoot (2008), yield improvements were higher in the early years (1998-2004) in Argentina, where no pesticides were applied against corn borers. In later years, yield improvements were 5-6%. The same authors also reported higher yield improvements for South Africa and the Philippines: on average 15% and 24%, respectively. For South Africa, Gouse *et al.* (2005b) reported yield increases in Bt maize of 11% in both irrigated and dry land large-scale farming; the differences with non-GM maize were significant only for the averages

[11] AGBIOS: http://www.agbios.com/main.php; EFSA: http://www.efsa.europa.eu/EFSA/efsa_locale-1178620753812_home.htm.

for the total irrigated land and total dryland, respectively, taken together across all regions studied. These results were obtained in a season where no high infestation levels of African stem borers were reported.

HT maize

With GM HT maize, there does not appear to be any clear improvement in yields compared to conventional varieties in the US according to *Gurian-Sherman (2009)*. Brookes & Barfoot (2008) also did not report yield improvements for the US; the main advantage of HT varieties lies in better cultivation efficiency (see further under 'Profit', section 3.4.1) and in the control of some problematic weeds, such as Johnsongrass, bindweed and pigweed (*Sankula, 2006*). However, according to Brookes & Barfoot (2008), the use of GM HT maize did lead to yield improvements in Argentina, an average of 3% in the 'corn belt', rising to 22% in marginal areas, and the Philippines, 15% based on sources with the sowing seed industry. Apparently, yields can be improved by HT varieties in marginal areas where weed control was less optimal before, provided the farmers can afford the accompanying herbicide.

Conclusions

GM HT maize generally does not lead to significant yield increases, except in situations where weed control was suboptimal before. GM Bt maize shows improvements in yield, but the extent of this as compared to conventional maize is highly dependent on infestation levels of the targeted pest insect and on the level of control attained using insecticides.

3.3.1.2 Fertilizers

THEORIZED EFFECTS
The presently cultivated GM maize varieties have transgenes encoding HT or Bt and therefore, their primary goal does not lie in improved nutrient use efficiency. When applicable, a side-effect of increased yields could be an improved nutrient use per unit harvested product.

Evidence of differences between GM and non-GM maize

Mungai *et al.* (2005) did not find differences in the influence of plant residues on soil nitrogen dynamics between Bt and non-Bt maize. On the other hand, changes observed in GM HT soybean rhizospheres that might affect micronutrient uptake (e.g. manganese, see 2.3.1.2), have also been found in maize, which is often grown in rotation with soybean in the US (Kremer & Means 2009). Effects on yield of maize have not been reported. In so far GM maize varieties are effective in improving yields (see above), they could result in better use of the normal inputs of their respective cultivation.

Conclusions

The traits of presently cultivated GM HT or Bt maize varieties are not directly related to nutrient use and practically no effects on fertilizer use have been reported for maize.

3.3.1.3 Biocides

Bt maize

Head & Ward (2009) gave an extensive review of the impact of Bt varieties on the use of crop protection agents. They concluded that Bt maize led to a substantial decrease in insecticide use against the corn rootworm in the US and on Lepidopterans in Argentina and the Philippines. Brookes & Barfoot (2008) reported an environmental impact decrease in EIQ terms of 5% for the US in the period of 1996-2006. So, there can be a substantial impact of Bt varieties on biocide use, but this will depend on local conditions. In addition, not all farmers apply insecticide against corn borers as this is complicated due to the difficulties in reaching the larvae once they are inside maize plants (*Sankula, 2006*). This was for instance apparent from the study on the impact of Bt maize in Spain by Gómez-Barbero *et al.* (2008) where the decrease in insecticide application was strongly regionally dependent. However, in all three regions studied, the average number of treatments was lower with Bt maize, i.e. 0.32 times per year compared to 0.86 with conventional varieties; 70% of Bt maize growers did not apply insecticides as compared to 42% of conventional growers. On the other hand, Gouse *et al.* (2005b) indicated that in South Africa substantial amounts of insecticide are used against African stem borers. Thus, insecticide usage was found to be cut by roughly half in terms of costs with the cultivation of Bt maize by large-scale farmers.

Pest insects may adapt to disease resistances (including internal biocides, such as Bt) in crops. Therefore, Bt crops need to be grown under insect resistance management plans. In this regard, mostly the so-called high dose/refuge model of cultivation is followed, which means that for instance, in the case of the high dose Bt event MON810, 20% of non-Bt maize is sown with Bt maize cultivation. Up till now, cases of resistance development against Bt in pest insects in the field have been extremely rare (Tabashnik *et al.*, 2009; Naranjo, 2009). Two reported examples are Bt resistance in the stem borer *Busseola fusca* in South Africa (Kruger *et al.*, 2009) and in *Spodoptera frugiperda* in Puerto Rico (Storer *et al.*, 2010).

HT maize

The introduction of HT varieties was considered to have the additional advantage of a lower environmental impact of the herbicides used in their cultivation (Dewar *et al.*, 2003; Kleter *et al.*, 2007; *Sankula, 2006*). Thus, Kleter et al. (2007) estimated EIQ values 39% lower for GM HT maize in the US in 2004; Brookes & Barfoot (2008) estimated a 5% lower EIQ for the whole period 1996-2006.

In the EU, there has not been any large-scale cultivation of GM HT maize and rather few field trials. Therefore, for Europe, practically the only source of data gathered in large scale agronomical trials is available from the Farm Scale Evaluations (FSE) performed in the UK. In the FSE, GM HT (Liberty Link, LL, active ingredient glufosinate-ammonium) and conventional maize were compared in trials following a split-field design across the whole country (Firbank *et al.* 2003). Herbicide usage in LL maize was on average 57% lower than in conventional varieties in terms of the amount of active ingredients (Champion *et al.*, 2003). The manner of herbicide treatments hardly differed between GM and non-GM maize: 1-2 times post-emergence of the crop with GM versus 2 times with conventional (Champion *et al.*, 2003). No calculations in terms of EIQ were presented in the reports from the FSE. The main aim of the FSE was the assessment of effects on biodiversity. Biodiversity is discussed in section 3.3.4.

Weeds may adapt to herbicide applications with crops. For GM HT cultivation, there is not yet a clear regime to delay evolution of herbicide-resistant weeds. Cerdeira & Duke (2006) mentioned three weed species for which herbicide resistance most likely developed under GM HT cultivation (*Conyza canadensis*, *Ambrosia artemisiifolia en Amaranthus palmeri*). Powles (2008) reported glyphosate resistance for *Ambrosia artemisiifolia*, *Ambrosia trifida*, *Amarathus palmeri*, *Amaranthus rudis*, *Amaranthus tuberculatus*, *Conyza* spp. and *Lolium* spp. in the GM HT growing regions of the US. Options for counteracting resistance development are the introduction of new types of HT transgenes, the application of higher doses of herbicide and adaptations in crop rotation in combination with the application of different types of herbicides, in the US for example, alternation of maize with soybean and/or winter wheat as cover crop (e.g. Davis *et al.*, 2009). In a survey in the US, Johnson *et al.* (2009) showed that only 30% of growers perceived herbicide resistance in weeds as a problem; however, these authors also showed that the likelihood of resistance development was often underestimated. In this regard, *Benbrook (2009)* observed an increase over the years of glyphosate use in US maize, like with soybean (see section 2.3.1.3) but to a lesser extent (39% vs. a doubling), particularly in recent years, and related this to the emergence of glyphosate-resistent weeds. However, in a comment on Benbrook's report, Sheridan, (2010[12]) indicated that over the last few years, no reliable data on herbicide use have become available yet.

Conclusion

GM Bt maize has led to reductions in insecticide use, but the extent to which depends on previous usage, as for instance, not all growers apply insecticides against borers. This is due to complexities in achieving effective application, *i.e.* leading to significantly bringing down borer presence. GM HT maize was shown, among others, in the US and in the FSE in the UK to enable decreases in environmental impact of herbicide usage, but over the years

[12] News item in peer-reviewed journal.

glyphosate application has increased in the US, as with soybean though to a lesser extent. This increase may be related to the rise in glyphosate-resistent weeds.

3.3.1.4 Energy

THEORIZED EFFECTS
As with soybean, energy use may have increased with the increased production of glyphosate coming with GM HT maize cultivation, but this may have been compensated by increases in no-till practices. The decrease in insecticide use in GM Bt maize will have led to a concomitant decrease in energy use for its production.

Evidence of differences between GM and non-GM maize

Brookes & Barfoot (2009) calculated reduced energy use due to no-tillage practices. However, they did not take into account energy use in herbicide production. No further literature specifically on maize was found for this aspect (see further soybean section 2.3.1.4 for a general discussion and section 3.3.2 on soil conservation below).

Conclusion

Energy use may have decreased through no-till practices with HT varieties, but the trade-off with possibly increased energy use in herbicide production is not clear for maize.

3.3.1.5 Water

THEORIZED EFFECTS
The presently cultivated GM maize varieties have transgenes encoding HT or Bt and therefore, their primary goal does not lie in water use efficiency.

Evidence of differences between GM and non-GM maize

No effects of HT cultivation on drought sensitivity were reported for maize. No-till practices that may be facilitated by GM HT cultivation were shown to improve the soil's water status (Buschiazzo *et al.*, 1998). Bt varieties effective against rootworm show relatively better growth under combined rootworm and water stress, as a side effect of the root system not being damaged by rootworm. In addition, there are GM lines in the pipeline having transgenes that should improve drought tolerance. Monsanto is expecting to commercially introduce the first transgenic drought-tolerant maize within the next few years, in the US possibly already in 2012.

Conclusion

No direct effects of HT or Bt varieties on water use efficiency have been reported. There may be positive effects from increased no-till practices with HT maize and less root damage by rootworm with Bt maize.

3.3.2 Soil conservation

THEORIZED EFFECTS
GM HT varieties may facilitate no-till practices by offering a more reliable weed control option and this in turn will lead to improved soil conservation.

Evidence of differences between GM and non-GM maize

The relative amount of no-till was 20% higher in the US in 2004 than before the introduction of GM HT maize (*Sankula, 2006*). However, with the increase in glyphosate-resistant weeds, also tillage before planting is reported to return in order to overcome weed problems by Duke & Powles (2009). Supplemental tillage is not popular, though, probably because of the higher costs (Frisvold *et al.*, 2009). In addition to advantages in water management and controlling erosion, no-till leads to an increase in carbon sequestration in the soil, which results in more optimal levels of organic matter (e.g. for maize, Locke *et al.*, 2008). For a more extensive discussion of benefits and drawbacks of no-till, see under soybean, 2.3.2.

Conclusion

There has been an increase of no-till practices, which generally improve soil conservation, since the introduction of HT maize. The strength of the relationship with HT varieties is not completely clear (see further under soybean, 2.3.2, which is usually grown in the same crop rotation in the US).

3.3.3 Water conservation

THEORIZED EFFECTS
GM HT maize has the potential to reduce pollution of water from farming activities, as glyphosate is an herbicide with a relatively low toxicity and a low persistence.

Evidence of differences between GM and non-GM maize

In addition to being broken down relatively quickly, glyphosate absorbs strongly to soil particles so generally will give less pollution of water ways by run-off than conventional herbicide systems in the US using e.g. atrazine or alachlor (Cerdeira & Duke, 2006). Atrazine has been banned in the EU as of 2004 (see below under Biodiversity, section 3.3.4). See for a more extensive discussion under soybean, section 2.3.3. Likewise, reduced insecticide use (see biocides section 3.3.1.3) will also lead to less leakage towards surface and ground water.

Conclusion

Less water pollution can be expected from the use of glyphosate with HT crops and decreased insecticide use with Bt varieties.

3.3.4 Biodiversity

Bt maize

With Bt maize, meta-analyses by Marvier *et al.* (2007) and Wolfenbarger *et al.* (2008) showed that non-target organisms, such as predators and herbivores, are more abundant in Bt maize than in maize treated with insecticides. In comparisons with a maize crop without insecticide treatment, this was not always the case, particularly with insects that are specifically sensitive to the Bt protein (members of the Lepidoptera and Coleoptera). Parasitoids of target pest insects occur less frequently on Bt maize, but this is a logical indirect effect of the decrease in occurrence and/or the poor growth of the pest insect itself. In soils, Prihoda & Coats (2008) hardly found any effects on important decomposers, such as earthworms, isopods or springtails. In a field study over four years, Icoz *et al.* (2008) also did not find any consistent effect of Bt maize on soil microorganisms as compared to the effects of location, season and the genetic background of the maize varieties tested. In general, no accumulation of Bt was found in soils, even though the Bt protein can stay intact for at least 234 days when adsorbed to clay particles.

HT maize

With GM HT maize, the Farm Scale Evaluations (FSE, see also under biocides of section 3.3.1.3) in the UK showed a strikingly different result from the other crops tested, oilseed rape and sugar beet. Weed control turned out to be less effective with the herbicide regime in GM HT maize (LL, glufosinate) than in conventional varieties (Champion *et al.*, 2003). In line with this observation, weed and invertebrate diversity were significantly higher in HT maize (Heard *et al.*, 2003a & b; Haughton *et al.*, 2003). Accumulated over all field sites, 33% more weed species were found in the GMHT maize (Squire *et al.*, 2009). The more effective weed control in conventional maize was related to the use of triazine herbicides, a type of herbicide that was later (2004) banned in the EU. Field margins were also more strongly affected by the herbicide treatment used with conventional maize, although these were only small percentual differences (Roy *et al.*, 2003). On the other hand, vegetation damage in verges was higher in the GM crop, like also was shown in oilseed rape and beet (Roy *et al.*, 2003). Based on the BRIGHT programme (*Sweet* et al.*, 2004*), Sweet & Lutman (2006) proposed that the more flexible weed control offered by GM HT crops makes it possible to leave parts of the field untreated so as to sustain weed diversity without too much risk of upsetting weed control.

Hart *et al.* (2009) did not find significant effects of the cultivation of RR maize (which comes with glyphosate) in Ontario (Canada) on the abundance and community structure of denitrifying bacteria and fungi; seasonal effects were shown to be much larger. Powell *et al.* (2009) also found no consistent differences across treatments and years in Ontario between HT (glyphosate) and non-GM maize on detritivorous soil biota and decomposition. More frequently, a higher fungi to bacteria ratio was observed under HT maize and a lower decomposition rate but in the latter case, there was interaction with precipitation level. See however the effects of glyphosate use on rhizospere microorganisms discussed in section 3.3.1.2.

Gene flow

Maize is a strong outbreeder and thus, (trans)gene flow is possible through wind pollination. However, there are no compatible wild relatives occurring in Europe and the large-scale cultivation areas in the US and Canada. In Mexico and Guatemala, wild relatives are found, the teosintes. As of 1998, there was a ban on GM maize cultivation in Mexico, but after some controversy about the scientific firmness of the first report on the occurrence of transgenes in maize landraces by Quist & Chapela in 2001, follow-up studies have provided better evidence for transgene occurrence in landraces at several places in Mexico, including those where Quist and Chapela (2001) sampled (e.g. Serratos-Hernández *et al.* 2007, Piñeyro-Nelson *et al.* 2009 and Dyer *et al.* 2009). There are no reports yet on any presence of transgenes in maize's wild relative, teosinte, but gene flow between the conventional crop and the teosinte, *Zea mays* ssp. *parviglumis* (Iltis & Doebley), which co-occurs with maize cultivation, has been found by Baltazar *et al.* (2005). As of 2009, field trials of GM maize were allowed again in Mexico. Pollen-mediated gene flow between fields is furthermore of interest to coexistence of GM and conventional or organic cultivations. This subject is further treated under 'Profit', 3.4 and 'People', 3.5.

Conclusions

Only minor effects of the herbicide regimes associated with GM HT maize cultivation on agrobiodiversity have been reported. The positive effect found in the FSE in the UK was in comparison to conventional maize treated with atrazine, which has been banned in the EU (but not in America) in the mean time. GM Bt maize generally has a lower impact on agrobiodiversity than insecticide treatment. No consistent effects of Bt maize were found on soil organisms.

3.3.5 Climate Change

THEORIZED EFFECTS
Increased soil carbon reserves as a result of the implementation of soil conservation tillage, which in its turn is associated with GM HT crops such as HT maize, reduce the amount of greenhouse gasses in the atmosphere. Besides, the GM HT glyphosate trait in maize can have an impact on energy consumption and thus CO_2 emission in farming.

Evidence of differences between GM and non-GM maize

Evidence for facilitation of no-till practices and concomitant lower energy usage with the introduction of HT maize is explained in section 3.3.1.4 above. For a more extensive discussion see under soybean, section 2.3.5.

Conclusion

Soil carbon storage probably increased and energy use may have decreased through no-till practices with HT varieties, but the trade-off with possibly increased energy use in herbicide production is not clear for maize.

3.4 GM-related sustainability – Profit

3.4.1 Farm income

HT and Bt maize varieties affect farm income in different ways. Moreover, different Bt maize varieties have been developed, aiming at different pests and having different impacts on farm income, depending on crop management under conventional maize production. To maintain transparency, the effects of HT and Bt are discussed separately. In this section, effects on farm income due to changes related to GM maize at the farm level are discussed. Indirect effects on farm income, caused by changes at a national level (e.g. price effects) are discussed in section 3.4.2.

3.4.1.1 Bt maize

According to the conclusion of section 3.3.1.3, Bt maize has led to reductions in insecticide use. To what extent this is the case depends on infestation levels and the level of pest control under conventional maize production. Different Bt transgenes have been introduced into maize to reduce damage from corn borers and Western corn rootworms (WCR), respectively (see section 3.2.1 for details). Most literature on Bt maize refers to the first category because varieties of the last category have been introduced only more recently. Corn borer control by using insecticides is difficult to achieve due to the need of precise timing of application, and therefore the investment is not always profitable. As a result, farmers often accept yield losses (see section 3.3.1.1) rather than incurring costs of insecticides. About 32% of the European acreage of maize threatened by corn borers is treated with insecticides (*Gianessi* et al*., 2003*). Knowing this, Bt maize can affect farm income by increasing the farm revenue or by decreasing production costs, depending on the reference situation.

In contrast to the corn borer, corn rootworm pests are commonly controlled using chemical insecticides. Bt maize providing resistance against the WCR may therefore provide substantial insecticide savings (*Fernandez-Cornejo & Caswell, 2006*).

Effects on revenue

The European Corn Borer (ECB) is an economically important pest, causing severe crop losses particularly in North-America and countries around the Mediterranean Sea (Demont & Tollens, 2004). Yield losses of between 5 (temperate growing areas) and 10% (tropical areas) have been reported, which are consistent with the information in section 3.3.1.1. As a consequence, adoption of transgenic corn borer resistant maize in areas that are highly susceptible to corn borer infestations may lead to higher revenues even if insecticides were applied. However, as already concluded in section 3.3.1.1, actual yield losses – and thus potential benefits of corn borer-resistant transgenic maize regarding farm revenue – greatly depend on infestation levels.

Brookes & Barfoot (2010) provided a review of farm-level economic impacts of GM crops in countries where these crops are grown. They presented average yield effects in the range of 4 to 12.5%, causing increases in crop revenue varying from 28 USD/ha in Argentina to over 200 USD/ha in Spain and Slovakia (see Table 3.4). *Sankula (2006)* distinguished between low and high infestation years in an *ex ante* evaluation study on impact of GM crops on US agriculture. He calculated that for US growers of YieldGard Corn Borer maize (one of the corn borer-resistant varieties), the average increase in revenue relative to conventional maize production without insecticide treatment is 22.4 USD/ha in a low infestation year and 72 USD/ha in a high infestation year. Even in the case that insecticides are applied under conventional maize production, the production value of Bt maize is 14 USD/ha higher in high infestation years, since conventional maize yield under pest control is still assumed to decline by 20% in such years. In low infestation years, no yield losses are expected under appropriate pest control.

Sankula (2006) also provided data on the impact of YieldGard Root Worm maize, a WCR-resistant transgenic variety. Assuming a 5% yield increase compared to conventional maize production, the average gain in crop value for US farmers in 2005 was 36 USD/hectare.

Few effects on prices have been reported. In the Philippines, farmers growing Bt maize receive a price premium due to better quality and less impurities (Yorobe & Quicoy, 2006). In Spain, no differences were found in crop price paid to Bt and conventional maize farmers in the period 2002-2004 (*Gómez-Barbero* et al*., 2008*).

Effects on production costs

For Bt maize, cost savings could be realized by applying less insecticides compared to conventional varieties. For corn borer-resistant varieties, this effect is rather small as conventional maize is often only partly treated with insecticides against the corn borer, if treated at all. *Brookes & Barfoot* (2010) estimated reductions in costs of pesticide use in 2008 of around 25 USD/ha in the US and Canada, 12 USD/ha in South Africa, 42 USD/ha in Brazil, around 60 and 70 USD/ha in Spain and Germany, respectively, and no reductions at all in several other EU countries (see Table 3.4). On the other hand, farmers have to pay higher prices for GM maize seeds compared to conventional maize seeds. The difference in prices is indicated by the term 'technology fee'. Technology fees also vary among countries and are often even higher than the cost savings from reduced pesticide use (*Brookes & Barfoot, 2010*), resulting in a negative impact on production costs.

In Spain, which is the EU member state with the highest adoption rate of Bt maize in agriculture, a farm survey in the period 2002-2004 revealed that 70% of the Bt maize growing farmers use no insecticides for maize borers, as opposed to 42% of the conventional maize growing farmers. The resulting decline in pesticide costs among Bt maize growers varied between 3 and 20 euros per hectare. Technology costs of Bt maize were much higher, ranging from 3.5 to 48 euro per hectare and varying both between regions and between years. Technology costs were found to increase with yield effects, suggesting that price premiums reflect performance of the technology (*Gómez-Barbero* et al*., 2008*).

In the study of *Sankula* (2006) for the US, pesticide costs under corn borer Bt maize production are reduced by 35 USD/ha in years with high infestation levels; in low infestation years, no differences are expected. When including a technology fee of 7 USD/ha, growing corn borer Bt maize in a 'typical' year (weighted average of low and high infestation years) would lead to an increase in production costs of 1.5 USD/ha. For WCR Bt maize, adoption costs were on average 35 USD/ha and the reduction in insecticide costs was 37 USD/ha, resulting in net cost savings of 2 USD/ha. The authors noted that the actual reduction in insecticide costs may be smaller, because insecticides may still be necessary to control secondary pests that emerge when omitting WCR control.

Effects on gross margins

Tables 3.3 and 3.4 summarize reported average effects of Bt maize at the farm level, for the US in 2005 (*Sankula, 2006*) and for various countries in 2008 (*Brookes & Barfoot, 2010*). These data suggest that the overall impact of

Bt maize on farm income is positive, both for corn borer and WCR resistant varieties. Net benefits are particularly high in East European countries and Spain, even though most of these countries experience relatively high costs of the technology (Table 3.4). According to US data, benefits of WCR-resistant maize are higher than those of corn borer resistant varieties, mainly as a result of the large difference in technology fee, see Table 3.3. Moreover, benefits from WCR-resistant maize result from both an increase in revenue and a reduction in pesticide costs, whereas the benefits from corn borer resistant maize follow largely from the increase in revenue. It should be kept in mind that results are highly sensitive to pest pressure and pest control in conventional maize production.

In the Spanish survey, gross margins varied considerably among the three regions studied, from less than 10 euro per hectare in two of the three regions to more than 100 euro per hectare in one region (*Gómez-Barbero* et al*., 2008*). This last and highest regional value is consistent with the calculations of *Brookes & Barfoot* (2010) for Spain for the same period. However, the concerned region represented roughly 15% of the total Bt maize acreage in Spain at that time, as compared to approximately 30% for the other two survey regions. Dillen *et al.* (2010) performed a modelling study on the cost-effectiveness of various strategies to control WCR, including Bt maize, in seven countries in Central and East Europe. Results show that in most countries, Bt maize offers the highest average benefit. In the Czech Republic, however, crop rotation yields a higher net benefit. The simulated average net benefit of IR maize as control strategy is 98 USD/ha (similar to data in Table 3.4), as compared to 184 USD/ha for crop rotation. The study also stresses the heterogeneity among farmers – and consequently in net benefit of Bt maize. For instance, in Serbia, Bt maize gives a higher average net benefit than crop rotation, but for most farmers, crop rotation is the most cost-effective alternative. Furthermore, the simulated net benefits for Slovakia (64 USD/ha) and Poland (41 USD/ha) are much lower than the numbers in Table 3.4. These results suggest that data in Tables 3.3 and 3.4 may be computed from an optimistic perspective and stress the importance of considering regional conditions and farming practices when evaluating the cost-effectiveness of GM maize adoption. Nevertheless, the general conclusion remains that Bt maize usually has a positive effect on gross margins.

An analysis among Bt maize growing farmers in the Philippines showed that in 2003-2004, a benefit-cost ratio of 2.0 was achieved compared to conventional maize. This financial performance was mainly realized due to an increase in total revenue; cost savings from pesticide applications were also obtained but were considerably smaller than the higher seed costs of Bt maize (Yorobe & Quicoy, 2008). Gouse *et al.* (2005b) found that in South Africa, economic effects differ among farm types. In the 2001/02 growing season, large commercial farmers experienced yield, pesticide and income advantages, while smallholders only experienced higher yields but still a positive net effect. According to the authors, Bt maize adoption among smallholders is constrained by the relatively high seed prices. In Spain, benefits were not found to be statistically related to farm size. This might change if farmers are legally obliged to take technical measures to enable coexistence (see section 3.4.4), as larger farms are expected to cope better with such measures, and to implement them at lower costs (*Gómez-Barbero* et al*., 2008*).

Table 3.3. Average impact of GM maize varieties with different traits on farm income of US maize growers based on 2005 production data, in USD/hectare. Source: Sankula, 2006.

GM maize variety	Increase in revenue	Technology fee	Reduction in insecticide costs	Net effect on farm income
YieldGard Corn Borer[1] (Bt)	19	-7	5.5	17.4
YieldGard RW (Bt)	36	-35	37	38.7
Roundup-Ready (HT)	0	-17	41	
Liberty Link (HT)	0	0	26	

[1] Assuming insecticide treatment and representing a typical year, i.e. weighted average of low and high infestation years.

Table 3.4. Summarized data on farm level impact of corn borer Bt maize, provided by Brookes & Barfoot (2010). Numbers are representative for 2008.

Country	Cost savings (USD/ha)	Net cost savings including cost of technology (USD/ha)	Yield increase (%)	Net increase in gross margins (USD/ha)
US	24.71	-8.83	5	67.51
Canada	(similar to US)	(similar to US)	(similar to US)	(similar to US)
Argentina	(data not available)	-20-22	5.5	(data not available)
Brazil	42	20.4	4.66	48.12
South Africa	11.74	-4.55	10 (range: 5-32)	87.07
Spain	61.49	10.25	10	225.36
Germany	73.21	14.64	4	78.64
Portugal	0	-51.24	12.5	75.60
Czech Republic	26.35	-51.24	10	101.95
Slovakia	0	-51.24	12.3	228.31
Poland	0	-51.24	12.5	133.08
Romania	0	-46.85	7.1	26.59

Other effects on farm income

Brookes & Barfoot (2009) reported labour and cost savings due to less monitoring time (now only for possible resistance development in the pest insect), reduced pesticide application and energy use. Also, they mentioned that Bt maize could in some countries, notably India, allow for a second crop. However, they did not empirically prove these effects.

Ervin *et al.* (2010) suggested that farmers of non-GM crops may benefit from GM crops produced nearby their fields, because of lower pest pressure. In line with this, a recent publication of Hutchison *et al.* (2010) provides statistical evidence of a negative correlation between acreage of Bt maize and regional ECB density. The authors calculated that cumulative benefits from Bt maize adoption in five major maize-growing states of the US over the past 14 years were almost 6.9 billion USD, of which 4.3 billion USD followed from benefits of general suppression of ECB populations to non-Bt maize growers.

Conclusion

Bt maize has a positive effect on farm income. Higher seed costs are more than offset by the reduction in pesticide costs (corn rootworm-resistant varieties) and increase in revenue (corn rootworm- and corn borer-resistant varieties). It should be kept in mind that in comparison, results are highly sensitive to pest pressure and pest control and cropping practices in conventional maize production.

3.4.1.2 HT maize

Effects on revenue

Section 3.3.1.1. already concluded that HT maize has no significant effect on yield, except in cases with high weed infestations. This implies that revenue of HT maize in countries with generally effective weed control is similar to that of conventional maize, unless prices are different. In agreement with this, *Gianessi* et al. *(2003)* used results of a study on impact of biotech crops in the US to predict potential economic benefits for countries in the EU. For HT maize, they did not expect any effect on revenue. Neither did *Sankula (2006)* in his case study on HT maize production in the US. No price differences related to the ‘GM’ status of HT maize were found in literature. For GM soy, positive price differences were reported as a result of cleaner harvest. For HT maize, such effects have not been reported.

Effects on production costs

While effective weed control in HT soybean production can be realized completely by post-emergence application of glyphosate, HT maize requires the use of additional pre-emergence herbicides. Therefore, total cost savings (benefits from reduced herbicides use minus increase in seed costs) are lower than in soybean. The National Center for Food and Agricultural Policy (NCFAP) has quantified the impact of GM crops on US agriculture in a number of case studies (*Sankula, 2006*). In 2005, glyphosate-tolerant (Roundup-Ready, RR) and glufosinate-tolerant (Liberty Link, LL) maize production resulted in an average herbicide cost reduction of 41 and 26 USD/ha, respectively. Savings were smaller for the LL type of HT maize because prices of glufosinate were higher than those of glyphosate at the time of the study. For glyphosate-tolerant maize, a technology fee of 17 USD/ha was charged in that year, reducing the net cost savings to 23 USD/ha. Estimated average cost savings for US HT maize growing farmers in 2005 were 23.73 USD/ha, as opposed to 44.67 USD/ha for HT soybeans.

Gianessi et al*. (2003)* performed case studies to assess the potential impact of plant biotechnology on pest management, including two studies on HT maize. Their work was funded by the biotechnology industry. Consistently with *Sankula (2006)*, they report herbicide cost savings of approximately 24 USD/ha in the US from adoption of HT maize. However, they noted that in the US, farmers still used the broad-spectrum and low-cost herbicide atrazine. In the EU, this herbicide was banned in 2003, resulting in substitution by other herbicides at higher costs. As a consequence, they expected a herbicide cost reduction of about 90 Euros per hectare for EU maize growers who adopt HT maize (assuming a 55% herbicide reduction).

Effects on gross margins

Since the effect on revenue is negligible (provided that weed control is optimal), the profitability of HT maize is determined by the balance between increased costs of technology and reduced herbicide (application) costs. For HT maize production in the US, a positive net effect of 20-25 USD/ha was observed in the early years of the 21st century. However, the net effect reduced to about 18 USD/ha in 2008 due to the price increase of glyphosate. Results are thus sensitive to herbicide prices. Canada shows a similar pattern with slightly lower net benefits (*Sankula, 2006*, *Brookes & Barfoot, 2010*). In some other countries, neutral or negative effects of HT maize production have been observed. In Argentina, cost savings from reduced herbicide use more or less equal the costs of the technology, which are very high as opposed to the technology fee for soy (see sections 2.4.1 and 2.4.3). Nevertheless, in marginal maize-growing areas, which have high weed infestation levels. a yield impact of about 22 percent was reported, causing considerable net benefits in those areas. Argentinean growers experienced lower additional returns from adopting HT maize than from Bt maize, resulting in a lag in adoption of HT maize until varieties with combined HT and Bt traits became available in 2007. Other data presented in this section support the suggestion that HT maize offers lower benefits to farmers than Bt maize does. In South Africa, the net effect on farm income in 2008 was negative, due to the increased price of glyphosate. In the years before, however, farmers experienced small net savings (*Brookes & Barfoot, 2010*).

On a global scale, the farm-level economic impact of HT maize was estimated at 433.5 million USD in 2005, 82% of this was in the US. Of this total amount, 92% was associated with cost savings, the remaining 8% comprised yield gains (*Brookes & Barfoot, 2010*). The source did not mention in which countries these yield gains were obtained. *Gianessi* et al*. (2003)* estimated that production of HT maize in the EU (France, Germany, Italy and Spain) could potentially result in an increase of the net EU grower income by 23.5 million Euro. This increase is based on the assumption that 40% of the EU maize acreage (1.5 million hectares) is planted with HT varieties, predominantly in France.

Other effects on farm income

As HT soybean, HT maize may facilitate the use of no- or low-tillage systems (see section 3.3.2), although it is unclear to which extent this is true in practice. Provided a causal relationship, the use of HT maize reduces labour and fuel costs associated with tillage. Furthermore, HT crops in general increase management flexibility, as herbicide applications become less time-consuming (Brookes & Barfoot, 2009), enabling the manager to undertake other farm or off-farm activities.

Conclusion

HT maize generally has a positive effect on farm income due to cost savings from reduced herbicide use. However, the effect is sensitive to herbicide use in conventional maize production and herbicide prices, and may be neutral or negative for farmers in particular years and countries. HT maize offers more flexibility in farm management, which may enable farmers to generate additional (off-farm) income.

3.4.2 National income

THEORIZED EFFECTS
As discussed in Chapter 1 and in Chapter 2 on soybean, analyzing the impact of the GM crops on income at the sector or national level requires more than aggregating the impact on farm income. Here, we describe the changes that may be expected according to macro-economic theory.

First, the introduction of GM maize is likely to have an impact on producer (output) prices if the introduction has an impact on yield or inputs costs. Farmers may in this case be expected to switch from conventional maize to GM maize, but also from other arable crops to GM maize. As a result, the supply of maize will increase and the price of maize will fall. While for GM maize growers, the income fall is compensated by the savings in inputs, conventional maize growers face a reduction in profits. The unit cost and price decrease may cause major shifts in production and trade patterns away from conventional maize in favour of GM maize.

Second, maize market changes may lead to major shifts in employment and land use in the economy. An increase in the amount of land used for maize production may go at the cost of the amount of land available for other arable crops, but also for nature.

Third, in response to changes in production of and trade in maize following introduction of GM maize, changes in the exchange rate and non-maize imports and exports may occur. In terms of overall welfare, net importers of GM maize are likely to benefit from lower prices, whereas non-adopting exporters would lose out from the increased competitiveness. If the adverse terms of trade effect, *i.e.* rise of prices of imports relative to prices of exports, is strong enough compared to the production and export expansion, net exporters of GM maize may also lose out.

Summary
In terms of overall welfare, net importers of GM maize are likely to benefit from lower prices, whereas non-adopting exporters would lose out from the increased competitiveness. If the adverse terms of trade effect is strong enough compared to the production and export expansion, net exporters of GM maize may also lose out. Empirical analysis is needed to see how these effects balance out.

Evidence of difference between GM and non-GM production

Macro-economic effects of GM crop adoption have largely been studied through (*ex ante*) modelling studies. The GM crops evaluated in this and other chapters, i.*e*. soybean, maize, and cotton, are major, internationally traded commodities. Moreover, GM and non-GM crops are in most countries imperfect substitutes for each other, causing market segregation between products that have been produced with GM material and products that have not. For these reasons, general equilibrium models, which account for international trade linkages and linkages with multiple sectors, are of particular relevance in studying effects on national income (*Smale* et al.*, 2009*). Therefore, the review below mainly contains references to studies applying general equilibrium models. One such model, which is widely applied, is GTAP. Concerning the general equilibrium studies, the reader has to bear in mind that presented quantitative figures should be interpretated trend-way, because model studies are based on assumptions and are by definition a simplification of reality. Moreover, model studies often deal with several crops simultaneously, which inevitably causes some overlap with the previous chapter 2 on soybean. Yet, specific results highlighted may be different.

One of the first and most commonly referred to general equilibrium modelling studies on GM crop adoption was performed by Nielsen & Anderson (2001). The authors simulated the global economic effects of the introduction of GM maize and soy by assuming an increase in factor productivity (through an overall reduction in production costs) by 5% for all coarse grain (cereals excluding wheat and rice) and oilseeds[13]. GM maize and soy are assumed to be widely adopted in the US, Canada, China, India, Argentina, Brazil, Chile, Uruguay, Paraguay and South Africa. Results show that, without import restrictions imposed by any country in the world, the prices of coarse grains (including maize) and oilseeds (including soy) decrease with approximately 5% in the GM-producing countries. This causes a shift in production and exports from the GM-free to the GM-producing countries. The EU production of cereal grains falls by 4.5%, and is partially replaced by imports (+0.1%). In general, production responses for cereal grains are not so pronounced as for oilseeds, as cereal grains are exported less and therefore more limited by domestic demand. Production of GM maize increases in the Americas. Yet, the fall in producer prices outweighs the impact on production, causing value added (sector income) in cereals to fall slightly in the Americas. This may be partially compensated for in gains in value added in the livestock- and meat-processing sectors profiting from cheaper cereal grains, which is most pronounced in North America. Value added in cereal grains is also likely to fall in Europe, because producer prices are under pressure and production decreases.

A more recent study of Van Meijl & Van Tongeren (2004) focusses on the role of international knowledge spillovers, i.e. the degree to which farmers in adopting countries are able to realize the potential productivity gains. Moreover, it takes into account that the introduction of GM crops can have unequal effects on the demand for input factors (called factor-biased technical change). The authors show that as a result of incomplete knowledge spill-overs to countries with smaller average farm sizes or a lower knowledge level, potential productivity growth in these countries as a result of GM crop adoption is lower than in the innovating country (the USA). This suggests that Nielsen & Anderson (2001) overstated the potential productivity shock – and thereby, the impact on national income – in case all countries were to adopt GM maize and soy.

Further updates and extensions of the analysis of Nielsen & Anderson (2001) were performed by Anderson & Jackson (2005a, 2005b). In the first study, the authors assume a partial, crop- and country-specific displacement of non-GM crops with GM crops. Different adoption scenarios are evaluated and canola (oilseed rape) is included as a third crop. However, conclusions have the same direction. The second study focusses on adoption of GM crops by Australia and New Zealand. It shows that, if the US, Canada and Argentina adopt but Australia and New Zealand do not, production and net exports of oilseeds (and coarse grains) as well as livestock products fall in both latter countries due to lower domestic prices. This decrease would be considerably smaller if Australia and New Zealand were to adopt GM crops.

Brookes *et al.* (2010) estimated the overall effect of GM technology in agricultural crops (maize, canola and soybean) on production and price. Unlike Nielsen & Anderson (2001), they used partial equilibrium models, which are based on the assumption that changes in the market of one good do not affect markets of substitute or complementary goods. This limitation was (partly) overcome in the analysis by using different models for each sector and linking them to each other. Nevertheless, interactions between markets can be dealt with only to a limited degree. Moreover, the study does not add to the results of above-mentioned studies in the sense that again, the macroeconomic impacts of three GM crops are simulated simultaneously. The authors projected what would happen if all GM crops were banned as from 2008, using the actual situation in 2007 as a baseline. Compared to Nielsen & Anderson (2001), assumptions regarding productivity increase were higher for some countries, particularly for soybean (see further section 2.4.2). Simulation results include an increase of 3 to 10% in world prices of maize, soybeans and canola as well as their derivatives and related cereals and oilseeds, if GM varieties of these crops were banned. Global yields are estimated to fall by 1.5%, 4.3%, and 0.65% for maize, soybeans, and canola, respectively, resulting in a decrease in global trade and usage of soymeal, soy oil and maize. The authors acknowledge that the effect of GM crops on production costs (see section 2.4.1) is not accounted for in this analysis, which may have led to an underestimation of impacts.

[13] While these two categories aggregate maize and soybean with other crops, maize and soybean – together with canola – account for most of the coarse grain and oilseed production in current GM-adopting countries.

Several authors studied the effect of regulations on changes in national income due to GM crop adoption. Nielsen & Anderson (2001) show that a Western European import ban considerably affects production and prices of cereals, although not as pronounced as for oil seeds (see further section 2.4.2), since only 18% of North American cereal grains are exported and only 8% of those exports go to Western Europe. Nevertheless, the lower demand leads to lower world price, which significantly reduces the positive production effect of GM maize in adopting regions. Western European cereal grain production increases by 5.3%, not as much as for oilseeds because of a high initial degree of self-sufficiency. The shift from imports to domestically produced cereal grains has implications for the downstream livestock and other food processing sectors in Western Europe, which experience more expensive inputs (more costly domestically produced non-GM grain) and an increase in competing imports of meat and other processed foods. In the study on GM adoption by Australia and New Zealand (Anderson & Jackson, 2005b), an EU import ban under the non-adoption scenario is shown to have a positive effect for both countries; it reduces the extent of the reduction in production and net exports in these countries. Once Australia and New Zealand adopt GM maize and soy, the effect of the ban becomes negative. Nielsen & Anderson (2001) also analysed the effect of a shift in Western European preferences against GM coarse grains and oilseeds. The effects are comparable to those of an import ban, but much less severe: cereal production and exports in GM producing countries slightly slightly decrease compared to absence of a preference. EU cereal production still decreases compared to absence of GM crop production, but less than in absence of non-GM preferences.

Van Meijl & Van Tongeren (2004) investigated the role of the Common Agricultural Policy (CAP). This is a system of European subsidies and programs. The article shows that given a GM innovation in the USA the traditional CAP has a positive impact on EU production and farm income as EU farmers are isolated from price changes on world markets and still obtain the positive knowledge spillovers from innovations in the USA. The welfare effect for the EU is negative as the CAP leads to lower imports of innovative USA products and therefore to less knowledge spillovers and lower productivity gains in the EU. Due to the current CAP reforms (Agenda 2000, Mid Term Review 2003 and the Health Check Reform 2008), the price insulation of the CAP is much lower for cereals and most cereal prices are close to world market prices. Therefore, the effects of the CAP is much less dramatic than in the results of Van Meijl & Van Tongeren (2004).

Conclusions

The introduction of GM crops, including maize, is projected to yield increased production of these crops at lower prices. Exports are likely to shift from the GM-free to the GM-producing countries, benefitting South America at a cost of Western Europe. Regulations (e.g. import bans, price subsidies) and consumer preferences can have a major effect on the total volume and spatial distribution of GM maize production, as well as on prices. Results also depend on assumptions regarding factor productivity increase and technology spillover under GM adoption.

3.4.3 Economic welfare distribution

THEORIZED EFFECTS

In terms of overall welfare, net importers of GM maize are likely to benefit from lower prices, whereas non-adopting exporters would lose out from the increased competitiveness. If the adverse terms of trade effect is strong enough compared to the production and export expansion, net exporters of GM maize may also lose out. Empirical analysis is needed to see how these effects balance out.

In addition to a change in overall welfare, GM maize production is likely to affect welfare distribution, both vertically and horizontally. Concerning vertical welfare distribution, the introduction of GM crops has led to changes in farmers' relation vis-à-vis their suppliers and their customers. With respect to horizontal welfare distribution, some adopting countries may benefit more, or experience more disadvantages from adopting GM crops, than others. Examples of factors affecting horizontal and vertical welfare distribution are country-dependent adoption levels, the level of IP protection, GM regulations, and consumer preferences. Below, we will first discuss horizontal welfare distribution, followed by vertical welfare distribution.

Horizontal welfare distribution

Nielsen & Anderson (2001) estimated that under the base case scenario of introducing GM maize and soy, worldwide economic welfare rises by 9.86 billion USD (Chapter 2, Table 2.4, 2nd column), two-thirds of which is enjoyed by the adopting regions. However, both GM adopters and non-adopters (except for Sub-Saharan Africa) experience welfare gains. For GM adopters, the benefits of a higher factor productivity outweigh the losses from increased competition on the world market. GM-importing countries benefit from a decline in prices of coarse grains and oilseeds and a more efficient use of resources in domestic production. Sub-Saharan Africa loses because of the assumption that countries in this area are unable to take advantage of the new technology. The total welfare estimates provided by Nielsen & Anderson (2001) are rather high due to optimistic assumptions on factor productivity increase and adoption levels. In more recent publications, these numbers have been somewhat moderated. For instance, the study of Anderson & Jackson (2005a) (Chapter 2, Table 2.4, column 3) presents a global change in economic welfare of just over 4 billion USD, for a scenario in which all countries adopt GM coarse grain and oilseeds. The same study shows that global economic welfare increases with the number of countries adopting the new technologies. Welfare in individual adopting countries decreases as more countries adopt, but remains positive. The authors pay special attention to South Africa (as part of SACU – Southern African Customs Union) and other Sub-Saharan African (SSA) countries. They conclude that for all countries in SSA, adoption by SACU (as is currently partly the case) is beneficial in terms of welfare effects. In a parallel study, the same authors, Anderson & Jackson (2005b) (Chapter 2, Table 2.4, column 4), demonstrate the welfare effects of adoption by Australia and New Zealand. Welfare effects for New Zealand are negative; yet, they are not more negative than under a scenario in which the country would not adopt, but other countries do so. In other words, with adoption, New Zealand is not worse off than without adoption.

All three studies discussed above analyze the effect of an EU ban on welfare distribution. Nielsen and Anderson (2001) show that in case of a ban, aggregate welfare gains fall by approximately two-thirds. Particularly Western Europe loses, due to a deterioration of allocative efficiency, as it now has to produce oilseeds, whilst it is a less efficient producer of such crops. Welfare results under a change in Western European consumer preferences are comparable with those in absence of an import ban, with the exception of Western Europe, for which the net welfare change drops, although being still positive. Anderson & Jackson (2005a) zoom in at the SSA region. For SACU, adoption of GM coarse grains and oilseeds is only beneficial in absence of an EU ban. Yet, for the SSA as a whole, adoption in SACU is beneficial irrespective of an EU ban. Without SACU adopting GM crops, all SSA countries benefit from an EU ban; however, these benefits are very minor compared to the foregone productivity benefits that would occur if all countries in the world adopted GM. Anderson & Jackson (2005b) show that Australia and New Zealand benefit from an EU ban, and that the benefits of adoption in both countries occur irrespective of an EU ban.

In the study of Van Meijl & Van Tongeren (2004), the CAP is projected to reduce the welfare gains in the EU (and in total), because it shifts resources into the distorted coarse grains sector and reduces the benefits of lower world prices. Alternatively, under an EU ban, the negative welfare effect for the EU is much lower than projected originally by Nielsen & Anderson (2001), because of the CAP protection. Yet, it should be kept in mind that the welfare effects of the CAP have become much less pronounced since 2004 because of the recent CAP reforms (see section 3.4.2).

Gruère et al. (2007) perform a general equilibrium modelling analysis on adoption of GM soy, maize, and cotton, with special focus on India, Bangladesh, Indonesia, and the Philippines. They assume production of these crops in the countries that had adopted them by 2005. Using initial adoption rates in these countries (i.e. the level of GM crop production in the first years after adoption), they come to a global welfare gain of 4.4 billion USD. Of all countries in the world, India experiences the largest relative gains, a welfare increase of 0.07 percent (254 million USD). Total gains are reduced to 2.7 billion USD when applying a trade filter representing trade restrictions in GM-sensitive countries. These losses come mostly at the stake of GM-sensitive countries. Under a scenario with more countries adopting GM crops at a higher rate, global welfare gain increases to 5.1 billion USD. In this case, the highest relative gains (0.3 percent, 44 million USD) are obtained by Tanzania and Uganda. Of the four countries with a special focus in the study, only India and Indonesia are assumed to adopt – amongst others – GM soybeans.

Vertical welfare distribution

Demont & Tollens (2004) performed a partial equilibrium analysis for Bt maize adoption in Spain. They calculated an average yearly welfare gain of 1.8 million USD over the period 1998-2003. This value is relatively low, but note that the adoption rate of Bt maize in 2003 was very low in Spain. Over 60% of the total welfare went to the farmers; the remaining part went to the seed companies. Consumers did not experience welfare gains, because the authors assumed a small open economy with an infinitely elastic demand. The motivation for this is the price protection Spanish farmers received from the EU (*i.e.* the CAP), causing prices not to drop with increasing supply.

Trigo & Cap (2006) used a dynamic simulation model to evaluate distribution of national welfare gains of Bt maize adoption in Argentina. Their results are representative for the 1996-2005 period. Total accumulated benefits over this period were calculated at 480 million USD, in which farmers, technology suppliers, and the government had a share of 43, 41, and 16%, respectively. The share of technology suppliers in this period is much higher for maize than for soy (see Chapter 2), due to better IP protection. The share of the national government follows from tax levies on exports of maize.

Demont *et al.* (2008) model (hypothetical) welfare effects of – amongst others – Bt and HT maize adoption in the Czech Republic and Hungary. Adoption rates are determined by the model as well. They conclude that, in spite of the considerable market power of upstream actors in the production chain, farmers in both countries substantially gain from introduction of GM crops (Table 3.5). The taxpayers' savings refer to the benefits of having no government expenditure for farmers' subsidy of *Trichogramma* capsules (a biological insect-control method) when producing Bt maize.

Table 3.5. Potential welfare gains and distribution of Bt and HT maize production in Czech Republic and Hungary. Source: Demont et al. (2008).

	Adoption rate (%)	Total welfare gains (million euros)	Welfare distribution (%)		
			Producers	Industry	Taxpayers' savings
Bt maize					
Czech Republic	1.4	0.09	46	51	4
Hungary	10	3.6	77	23	-
HT maize					
Czech Republic	38	1.5	66	34	-
Hungary	58	42.5	75	25	

Industry concentration may affect the R&D activities of the seed producers. One hypothesis is that dominant firms in consolidated industries conduct more new product research because they have the funds to do so and are able to make profits out of it (*Schumpeter, 1942*). However, it has also been suggested that when competition is less intense due to concentration, seed producers may cut R&D activities. Such situations may occur when R&D results can easily be replicated by competitors without incurring the costs of R&D, when there is considerable uncertainty about the long term private returns from the investments, or when the social marginal costs exceed private marginal benefits, resulting in negetive externalities (*Fernandez-Cornejo, 2004)*. R&D investments by the seed industry have considerably increased during the nineties, probably as a result of better IP protection. However, in the period thereafter, private research investments in maize and other GM crops seem to have slowed down. The change in number of seed companies over time ran parallel to this trend (*Fernandez-Cornejo & Schimmelpfennig, 2004*, Pray & Naseem, 2007). Schimmelpfennig *et al.* (2004) also found a significant negative correlation between seed industry concentration and R&D investment in maize, although not as large as for soybeans. Note that this change is relative; total R&D expenditure of a company may have grown over time, but the increase was lower than might be expected on the basis of their increase in size through market consolidation.

Conclusions

The adoption of Bt and HT maize has positive net welfare effects. Both GM adopters and non-adopters experience welfare gains, with few exceptions. GM adoption is generally economically beneficial for a country, and with more countries adopting GM crops, the total welfare increases, although welfare for each individual adopting country may decrease. Restrictions to the adoption or acceptance of GM crops have a negative effect on global welfare, but individual countries may benefit. Vertical welfare distribution in a country depends on the level of IP protection; irrespectively, farmers have a reasonable share in welfare gains in the countries for which case studies have been described in this section.

3.4.4 Financial and other risks

Production risk

Bt maize reduces the risk of crop losses due to insect damage. Dillen *et al.* (2010) show that, in Central and East European countries, variation in farm income is lower under Bt maize cultivation than under any other WCR control strategy. The drawback of risk reduction is that potential increases in revenue and/or production costs only occur in years when pest pressure is high. Farmers must decide whether to use Bt maize before they know what the pest pressure will be in that year, and may incorrectly forecast infestation levels and maize prices, resulting in overadoption. In such years, farmers growing conventional maize may actually be better off financially (*Fernandez-Cornejo & Caswell, 2006*). Results of most empirical studies show large differences in yield effects of Bt maize between different regions within countries (see, e.g. *Gómez-Barbero et al., 2008*; *Sankula, 2006*, Yorobe & Quicoy, 2006), emphasizing the strong relation of farm level impact with pest pressure. Moreover, in the first years after introduction, Bt maize varieties did not always give optimal yields compared to the yield potential of alternative non-GM varieties, because they were less well adapted to the local circumstances. In such cases, farmers experience a trade-off between reducing the risk of severe yield losses and accepting a lower potential yield. *Carpenter et al. (2002)* mentioned that farmers may plant Bt maize as an insurance policy knowing that ECB populations are unpredictable but may have devastating effects. Moreover, differences in yield between Bt maize varieties and non-GM varieties have largely disappeared recently (*Gómez-Barbero et al., 2008*, see section 3.3.1.1).

Institutional risk

As was already described for GM soybean in the previous chapter (section 2.4.4), discrepancies in approval of GM products between countries and continents comprise an institutional risk to GMO adopters as well as non-adopters: This comprises several issues:

1. Non-adopters face the risk of reduced supply, resulting in higher prices. Because a growing number of GM events may be expected in crops as soybean and maize (*Stein & Rodríguez-Cerezo, 2009*), the import supply of maize is at stake in regions with a slower approval rates, such as the EU. Although the EU is largely self-sufficient when it comes to maize production, a reduced import supply may still cause an increase in maize prices (see section 3.4.3). This implies a cost for the European livestock sector. To illustrate this: incidents with GM maize in the 2007/08 season were reported to have cost the EU livestock sector more than 1.5 billion USD (*Backus et al., 2008*).
2. Adopters run the risk of adventitious presence of GMOs in their (non-GM) products, thereby affecting the profitability of trade. A major concern is the low level presence (LLP) of EU unauthorized GMOs in imported food and feedstuff. According to EU legislation, food and feed consignments arriving to an EU harbour containing unauthorized GMOs – even at extremely low levels – have to be sent back, relocated, or destroyed. The same applies to non-GM commodities containing more than the maximum allowed level (generally 0.9%, sometimes even lower) of approved GMOs. Thus exporters and importers face serious failure risks, i.e. risks of adventitious presence of GMOs in their product. Costs from such a product failure would likely be manageable as long as the failure occurs within the borders of the exporting country (see financial risk section below). If the product failure occurs at the point of import or beyond, however, product failure costs can be considerable (*Brookes, 2008*). This reduces the willingness of third countries to supply the EU with non-GM raw materials.

The uncertainties regarding approval of GM products in the EU affect adoption among farmers in countries exporting to the EU. In the US, the HT maize adoption rate among famers was rather low, amongst others due to its pending approval status in the EU. After NK603 (RR) maize had been approved in 2004 for import, processing and use in animal feed in the EU, its adoption increased considerably (*Sankula, 2006*; *Carpenter et al., 2002*). Paarlberg (2006) analyzed the risk from restrictions on trade of GM crops to the EU for farmers in 12 African countries. He concluded that for these countries, the risk is small, because only a small share of exported commodities that might be replaced by GM alternatives are destined for the EU or other countries with GMO import restrictions. Moreover, these 'potential GM-exports' would comprise only a small share of total exports of agricultural commodities from these countries. Note that Paarlberg (2006) analyzes risks at the national level; for individual maize producers, the risk may be considerable.

Legal risk

The coexistence of GM and conventional maize poses a legal risk for farmers in maize production areas where both types of maize are produced. The EU has provided guidelines for coexistence, specifying that farmers who introduce a new trait (e.g. an HT or Bt maize variety) should bear responsibility for implementing the farm management measures necessary to limit gene flow and other ways leading to unintended admixture (*Commission of the European Communities, 2003*). *Messéan et al. (2006)* calculated the potential economic consequences of such measures for farmers in the Poitou-Charentes region in France (Table 3.6). Note that the numbers are theoretical calculations and have not been empirically validated. Moreover, the authors assume an economic advantage of Bt maize of 58 USD/ha, which is rather low compared to data in Table 3.4 (but see reflections on this table in the respective section). Therefore, the data in Table 3.6 should be interpreted qualitatively.

Demont & Devos (2008) warn for a 'domino effect' if rigid minimum distance rules are implemented as coexistence measure. If farmers decide to plant fields within isolation distances of deliberately non-GM crops also with deliberately GM-free variants of the same crop species in order to also gain the price premium, the GM-free cropping area will increase in size more and more as each consecutive neigbouring field will follow the same strategy, and as a consequence, costs of coexistence management for GM crops will go up. The authors plead for less rigid, flexible segregation such as buffer zones (i.e. zones filled with non-GM maize, which is more effective than 'empty' isolation distances, cf. Van de Wiel & Lotz, 2006; Devos *et al.*, 2009).

Table 3.6. Economic consequences of implementing coexistence measures at farm level, calculated for the Poitou-Charentes region in France. Source: Messéan et al. (2006).

Additional measure	Costs or gross margin losses
Clean the machines	Costs of shared machinery[1]:
- single seed driller	- €38.38/cleaning
- combine harvester	- €56.84/cleaning
- transport – trailer or truck	- €1.48 /cleaning
Time isolation	Change from very late to late (30°days): €201/ha Change from late to mid-early (60°days): €46/ha
Discard width on the non-GM-field - extra harvest	6 m discard width: €1.27 – €2.85/ha[2] 12 m discard width: €2.55 – €5.70/ha[2] 24 m discard width: €5.10 – €11.40/ha[2]
Non-GM buffer zones around the GM field	€60.54/ha - €78.07/ha [3]

[1] Renting fees for collectively used machinery were used for calculating the costs of shared machinery.

[2] The first figure is for a neighbouring non-GM field of 5 ha, and the second for a non-GM field of 1 ha.

[3] The first figure is for a 50% GM adoption rate in a region with clustered fields, while the second is for a 10% GM adoption rate with dispersed fields. Harvest from the buffer zones is assumed to be kept separate from GM harvest; if the two harvests were mixed (as is the experience in Spain), buffer costs would be much lower.

As already mentioned in section 2.4.4, variation among coexistence policies in EU member states may affect the adoption of GM crops in individual member states (Beckmann *et al.*, 2006). The political willingness to allow GM cultivation and the legal framework for coexistence differ among the EU countries, causing different incentives for farmers to grow GM crops or not.

Financial risk

Little has been reported on financial risks in relation to GM maize. Aerni (2005) found for South Africa that GM crops are not expected to improve farm liquidity and solvability (or rather indebtedness) because prices of GM crop seeds are expected to be so high that they will be discouraging farmers to adopt GM maize. Nevertheless, presently significant proportion of farmers adopted GM maize in the mean time (78% of maize acreage in 2009, *James, 2009*).

Van Asseldonk & Huirne (2006) assessed the financial risks of co-existence of GM and non-GM crops in the Netherlands, including maize. The analysis was based on published data on probabilities of outcrossing, empirical data on the likelihood of a non-GM maize field bordering a GM maize field, and the assumption that tests for adventitious presence of GMOs are 100% effective. This latter assumption implies that any contamination of a conventional or organic maize consignment will be detected before it is traded (see also discussion under Institutional risk). The authors found that at a tolerance threshold level of 0.9%, the economic damage of crossing is minimal for maize as well as the other crops investigated (potato and sugar beet), amongst others because there are other, yet less profitable markets for crops commingled with GM. At a tolerance threshold level of 0.1%, the damage is higher, particularly when the number of GM-maize producers increases. Nevertheless, in all scenarios, the economic losses at the national level are rather low.

Conclusion

GM maize – Bt maize in particular – decreases production risks for farmers, although a risk of overadoption exist in years with low pest pressure. Extra costs may need to be made to manage the risks of coexistence. Within the EU, coexistence policies may in effect slow down the adoption rate of GM crops, including maize. If cross-fertilization despite coexistence measures occurs, economic damage tends to be low as long as it is detected right after harvest. Post-import detection, on the other hand, can lead to major economic consequences. Risks related to asynchronous approval and low level presence of GMOs in non-GM commodities reduce the supply of non-GM commodities to the EU, which may imply higher production costs for sectors dependent on these commodities in the EU, such as the livestock sector.

3.5 GM-related sustainability – People

Maize is grown by millions of farmers worldwide for subsistence and local consumption as well as export purposes. We studied ‘People’ aspects in the entire distribution range where maize is cultivated. We highlight here studies from Spain, South Africa, Mexico, Colombia, and Brazil. Spain is the only EU country in which GM cultivation of some importance has taken place for a longer period of time. The Spanish experiences therefore provide information about the impact of GM (Bt) crops within the European Union, which may also be representative for cultivation in industrialized countries in general. In South Africa, Mexico, Colombia and Brazil, many of the social impacts addressed in this report appear to be playing a role. Moreover, in Mexico and Colombia, maize cultivation is not just for food production but also regarded as part of the ‘way of life’ of indigenous and local people. As very little maize is imported into or exported from the EU also in these countries, there is no direct relationship to sustainabilty of GM maize usage in the EU. However, in Mexico and Colombia, maize is increasingly cultivated for the production of ethanol. Particularly in relation to Mexico, which currently exports maize for ethanol production mainly to the US but intends to increase its own maize-based ethanol production, sustainability issues such as impact on food security may arise in the future.

In Brazil, which is the origin of approximately 20% of the maize imported in the Netherlands (see section 3.1), farmers increasingly grow Bt maize. This development may be indirectly driven by the demand for ethanol production worldwide, which leads to a decreasing cultivation of maize for consumption in for instance the US and consequently, a growth in cultivation of maize in export countries like Brazil (*James, 2009*; *OECD-FAO, 2006*). As Bt maize was officially released in Brazil only in 2008, no scientifically based information on the impact of Bt maize cultivation is available yet.

3.5.1 Labour conditions

Poor labour conditions in the maize sector are generally not an issue in the United States or Spain. This is primarily due to the well-established legal systems protecting workers. Labour rights are largely enforced by these Governments as reported in the Country Reports on Human Rights Practices, US Department of State, 2009. Some countries outside the European Union and the US have less comprehensive legal requirements in relation to working conditions and the enforcement of laws and policies may be less strict. The possible impact of GM maize cultivation on labour conditions, the factors wage levels, occupational health and safety, employment opportunities and the existence of child labour will be considered under separate headings in the following.

Wage levels

General situation in maize production

Low wages, which may be in line with national minimum wages but do not constitute a decent standard of living for a worker and his or her family, are common in the agricultural sectors of countries like Brazil, Mexico, Colombia and South Africa (*US Department of State, 2009*). Due to the informal nature of the agricultural sector and due to limited financial and human resources, governments also face difficulties in enforcing minimum wages in these countries.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
As reported in sections 3.4.1.1 and 2, the cultivation of GM maize generally has a positive effect on farm income due to cost savings from reduced pesticide use, depending on the local circumstances. While it is expected that an increased farm income will benefit farmers in developed and developing countries, this does not necessarily benefit farmworkers, especially in developing countries, as even minimum wages do not necessarily constitute a living wage there.

Evidence of difference between GM and non-GM production

The cultivation of GM maize generally has a positive effect on farm income due to cost savings from reduced pesticide use, depending on the local circumstances. However, it could not be established on the basis of scientific literature that wage levels of farmworkers in developed and/or developing countries increased.

Conclusions on impact from GM vs. non-GM maize

While the cultivation of GM maize generally has a positive income effect on-farm, it could not be established on the basis of scientific literature that GM-maize cultivation had an impact on wage levels of farmworkers in both developed and developing countries.

Occupational health and safety

General situation in maize production

Maize production often involves the use of relatively toxic insecticides, such as organophosphates, that have a large impact on human health and the environment in comparison with other crop protection agents. According to (Gouse *et al.*, 2005b), large-scale non-GM maize farmers in South Africa spray substantial amounts of insecticide to control corn (stem) borers (the dominant insect problem in maize production in South Africa), particularly in the irrigated areas. On the other hand, many farmers in the Americas and Europe do not apply insecticides against corn borers, since their effective application is complicated, but they will do so against corn rootworms (see sections 3.3.1.3, and 3.4.1.1 and 2). Also, in these regions, personal protective equipment is widely used with insecticide application and therefore the application of insecticides is likely to have less health impacts for the applicators.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
The primary effect of cultivating Bt maize is that the need for monitoring of corn (stem) borer infestations is reduced and the level of application of insecticides becomes lower, even though insecticides may be still necessary to control emerging secondary pests. Considering that the overall effect of Bt maize is a decrease in application rates of pesticides, it is plausible to assume that some improvements in worker health and safety may arise from its cultivation. Thus, there may be reduced risks of accidents, spillage, and exposure to insecticides. The effect on worker exposure will be smaller in countries where personal protective equipment is widely used during insecticide application.

Evidence of difference between GM and non-GM production

Studies about GM maize production in the US, Spain and South Africa indicate reductions in pesticide use (Brookes & Barfoot, 2009, Gómez-Barbero *et al.*, 2008, Kleter *et al.*, 2007 and *Sankula, 2006*). In the United States, the National Center for Food and Agricultural Policy estimated a reduction in insecticide use ranging from 0.19 kg ha^{-1} to 0.43 kg ha^{-1} through the specific use of corn-borer resistant GM maize (reported in Kleter *et al.*, 2007).

As mentioned above in section 3.3.1.3, Gómez-Barbero *et al.* (2008) reported that the decrease in insecticide application in Spain resulting from the use of Bt maize is strongly regionally dependent. However, in all three regions studied, the average number of treatments was lower with Bt maize, *i.e.* 0.32 times per year compared to 0.86 with non-GM varieties; 70% of Bt maize growers did not apply insecticides as compared to 42% of non-GM maize growers. The reduced use of pesticides does not necessarily mean that there is a significant gain in worker's health and safety in this case. Agrochemical poisoning in maize production in Spain is already infrequent. With proper protective equipment, health impact from the application of the chlorpyrifos used is minor. Accordingly, no measurable impact on worker health and safety has been observed since the introduction of Bt maize in Spain.

While in less developed countries there is a potential health and safety benefit due to a reduction of pesticide use in Bt maize, this could not be substantiated by scientific literature. Possible health and safety impacts of insecticides that may have become (again) necessary to control secondary pests that emerged due to release from insecticides previously used for corn borer control, could not be established either.

Conclusions on impact from GM vs. non-GM maize

Pesticide use decreased in Bt maize, but there is no evidence of positive impact on worker health in countries where risks are already low. There is a potential safety benefit in developing countries, but no studies show direct evidence of this. Impacts of insecticides that may have become necessary to control secondary pests, on workers' health and safety could not be established either.

Employment opportunities

General situation in maize production

As reported in sections 3.4.1.1 and 2, GM maize cultivation requires less labour input due to reduced insecticide application (Bt maize) and likely due to the use of no- or low-tillage systems (HT maize). The impact of GM cultivation on labour intensity and employment opportunities can be considered either positive or negative, depending on the perspective chosen. From the farm-level profit perspective, a reduction of required labour inputs is a positive impact of GM crops. However, the unequal distribution of this economic benefit could also be considered as a possible negative impact, e.g. farmworkers losing employment opportunities. A determinant factor in this respect is the possibility for labourers to shift to other positions, which is related to both the social conditions of individual farm workers (such as level of education, family situation, available resources for education, moving) and the availability of suitable positions locally and nationally, which might be influenced by agricultural transformation processes.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
Since treatment of ECB (European corn borer) infestations must be performed in a narrow time period and farm sizes are relatively small, reduced pesticide application will not likely lead to a reduction in labour opportunities in industrialized countries, such as Spain. In other countries, where pesticide application is labour-intensive, reductions in labour opportunities are more likely. However the impact may still be minor, as corn borers can only be targeted during a narrow time period and so pesticide spraying is not a frequent activity.

Evidence of difference between GM and non-GM production

Generally speaking, GM maize cultivation is expected to reduce labour input (Brookes & Barfoot, 2009). According to Gouse *et al.* (2006), Bt technology is neutral or slightly positive with regard to labour use (input) on small-holder farms (usually subsistence farmers) in South Africa. In their results of a survey conducted in rural South Africa, Gouse *et al.*, (2009) mentioned that relative to non-GM seed, GM maize cultivation (both Bt and RR) actually does not seem to cause very large reductions in family labour on small-holder farms. Whether the slightly reduced labour on small-holder farms will lead to diversion of labour to other tasks (part-time jobs in other sectors, schooling, household chores) or to expansion of planted areas is uncertain (Gouse *et al.*, 2009). Brookes & Barfoot (2009) reported that GM maize cultivation (on smaller and larger farms) may allow for the cultivation of a second crop or increase management flexibility, but they did not empirically prove these effects. However, it could not be established on the basis of scientific literature, whether and to what extent the reduction in labour input has led to reduced labour opportunities of farmworkers or movement of workers to other jobs and regions in both developed and developing countries.

Conclusions on impact from GM vs. non-GM maize

GM maize cultivation is likely to require less labour input, also on small-scale farms. Whether this has led to reduced labour opportunities of farmworkers or movement of workers to other jobs and regions in either developed or developing countries could not be established.

Child labour

General situation in maize production

Although child labour is prohibited by law in most countries, child labour is prevalent in the agricultural sector, including the maize production sector, of Brazil, Mexico, Colombia and South Africa. Many of those children do not receive a wage and the hidden and informal nature of child labour makes children especially vulnerable to workplace accidents. Child labour especially occurs on small-scale family farms, but also on large-scale commercial farms. *Doran* (*2006*) reported that in maize cultivation in Mexico, most working children are employed by a parent's side and they perform similar tasks as their parent(s). In Mexico, child labour is common amongst migrant and indigenous communities. In South Africa, some forms of child labour do occur on maize farms. However, the extent to which this contravenes ILO standards is unknown. Much of the child labour is in the form of children working on family farms and they do not necessarily miss educational opportunities in doing so (Gouse *et al.*, 2009).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
If the cultivation of GM maize requires less labour and increases wages, the amount of child labour might be reduced as well, for instance benefiting higher school attendance. However, decreasing employment opportunities and rising unemployment might lead to more children working on family farms in order to contribute to the family income.

Evidence of difference between GM and non-GM production

Child labour is not common in countries with strict laws and a well-established legal system. In the results of a survey conducted in rural South Africa, Gouse *et al.*, 2009 indicated that relative to non-GM maize, Bt maize cultivation actually seemed to increase the child-labour input for all tasks (land preparation, weeding, harvesting). A further analysis of the causes of the increase in child-labour has not been provided. Even though the conclusions of Gouse *et al.* (2009) were based on a limited number of cases, and could not be extrapolated, this study did show that reduced labour requirements of Bt maize cultivation do not necessarily lead to reduced levels of child labour.

Conclusions on impact from GM vs. non-GM maize

Child labour occurs in both GM and non-GM maize production in South Africa. Reduced labour use on Bt maize small-holder farms does not necessarily reduce the use of child labour.

3.5.2 Land rights, community rights and rights of indigenous people

General situation in maize production

Land conflicts and community conflicts are generally not an issue in countries with a well-established legal system. This is primarily due to a comprehensive legal system protecting land owners and land users. No land conflicts are known in relation to GM maize. In Spain, Bt maize cultivation also has generally not altered or expanded cultivation areas. The introduction of GM maize did have implications for community rights and rights of indigenous people. Cases from Mexico and Colombia will be described in detail.

In Mexico, many campesinos (local farmers) are indigenous people and over two-thirds of the campesinos are small-holders. Much diversity of maize is maintained in landraces by these local and indigenous farming communities. Long before the development of GM traits, small-holders (mainly subsistence farmers) consciously and unconsciously introduced traits from modern varieties into their landraces, by growing them side to side or by crossing them (Louette *et al.*, 1997). Introduced seed that is perceived as valuable diffuses rapidly, although the introduction of non-local seed in central and South-eastern Mexico is rarer than previously thought, possibly because it is not suitable for local preferences and agro-ecological conditions (Dyer & Taylor, 2008).

There are, as elsewhere in the world, socio-economic incentives for farmers to replace varieties that evolved within their own agrosystem with improved varieties from modern breeding practice. On the other hand, there are also incentives to maintain traditional landraces, not only for reasons of expected yield stability under low-input conditions, but also of market demand, e.g. superior culinary qualities. In addition, maize is so important to the cultures and the 'way of life' of indigenous peoples in the Americas that it is part of how they call themselves (*Greenpeace, 2004*). For instance, the Embera people in Colombia are literally 'the people of maize,' and the Zenú people refer to themselves as 'the children of maize' (*Grupo Semillas, 2010*).

In 1998, maize varieties with GM traits were introduced in Mexico through officially legalized and sanctionized imports from the USA, but cultivation of GM maize was not allowed at that time. Nevertheless, since then, transgenes have been shown to occur at a low level in landraces (see section 3.3.4). Statutory provisions for the regulation of genetically modified crops, allowing for amongst others the planting of Bt maize, were enacted in Mexico in 2009.

In Colombia in 2005, the State issued a Decree (4525) that regulates the approval of GMOs. So far, three varieties of GM maize have been approved for commercial planting in Colombia. Consultation and information provision are, according to ILO Convention 169 (ratified by the Netherlands, Mexico and Colombia: *ILO, 1989*) and the 2007 UN Declaration on the Rights of Indigenous People (*UNPFII, 2007*), important components of indigenous rights, both prior to the development of GMO regulations and policies and prior to the release of any GM seed.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
In countries with traditional maize cultivation, many smallholders may adjust to or benefit from GM traits as they have done previously through their practice of combining non-GM modern varieties with local landraces, while still perceiving these as traditional landraces. Thus, many local small-holders are used to combining useful traits from modern varieties with their landraces and this could also apply to GM traits (Bellon & Berthaud, 2006). However, with regard to the cultural importance of landraces, GM maize production may be conceived by local and indigenous people and others as a potential risk to the rights of indigenous peoples to preservation of their culture and traditional farming practices, when introgression of GM traits into these landraces would be perceived as decreasing the intrinsic cultural value of the landraces. Even though maize varieties with GM traits were initially meant for import and not for cultivation in Mexico, the latter requiring different types of consultation and information procedures, this might not change the perceptions of local and indigenous people and others.

Summary of theorized impacts from GM vs. non-GM maize
In countries with traditional maize cultivation, many smallholders may adjust to or benefit from GM traits as they have done previously with traits from non-GM modern varieties. However, with regard to the cultural importance of landraces and preservation of traditional farming practices, GM maize production may be conceived by local and indigenous people and others as a potential risk to the rights of indigenous peoples. Consultation and information are an important component of indigenous rights, both prior to the development of GMO regulations and policies and prior to the releasing of any GM seed.

Evidence of difference between GM and non-GM production

According to surveys by the Commission for Environmental Cooperation of North America, published in the 'Maize and Biodiversity' report (*CEC, 2004*[14]) and as evidenced by a petition of Oaxacan community members (*Greenpeace, 2004*), there are a number of Oaxacans, especially campesinos, who consider the presence of any transgenes in maize as an unacceptable risk to their traditional farming practices and their cultural, symbolic, and spiritual value of maize. These opinions were held regardless of scientifically studied potential or actual impact upon human health, genetic diversity, and the environment (*CEC, 2004*). When assessing this issue, the question is not so much whether adoption of improved modern varieties has been part of traditional farming practices for a long time, but the perspective of the indigenous people, who value these traditional practices as cultural traditions, is the most important consideration (d'Engelbronner-Kolff, 2001, see also Soleri *et al.* 2005 and Soleri *et al.* 2008).

A general distrust of campesinos and community organizations of governments and institutions entrusted with biosafety as well as the absence of information to and lack of consultation with the local rural communities during the introduction of GM traits in Mexico may play an influential factor in these perceptions (*CEC, 2004*). However, many Mexican smallholders (farms smaller than 5 ha) are not opposed to GM as such, but fear that GM varieties will be forced on them, as has happened in the past with modern non-GM varieties, and impact their traditional practices, through, for example, a dependency on seed companies (Soleri *et al.*, 2005) or limited or no official consultation and information processes. Such fears of inroads into the freedom of choice, which will be further discussed in section 3.5.3, are also apparent from the above mentioned petition of Oaxacan community members (*Greenpeace, 2004*). Nevertheless, as mentioned above, it is important to note that the initial introduction of GM traits in Mexico was through imports not meant for cultivation. As cultivation was not allowed at that time, the Mexican authorities did not organize a consultation period (*CEC, 2004*).

In Colombia, the granting of licenses for GMOs took place in accordance with Decree 4525 of 2005. The Decree, although asking for public participation, did not lay down specific measures to engage with citizens and indigenous people, even though the State is obliged to do so by the mandates of the Colombian Constitution, ILO Convention 169 (*ILO 1989*), and national laws. Subsequently, local organisations (*Grupo Semillas*, 2010) emphasized that indigenous, Afro-Colombian and peasant communities have not been consulted, and they filed lawsuits seeking the

[14] This report was subjected to a thorough scientific and public review process. However, not all of its findings were endorsed by the government parties involved, as some of the recommendations were regarded to do not reflect the report's scientific findings, but to rather reflect cultural and social perspectives of the Advisory Group and other entities.

nullification of GMO permits authorized by the Colombian Agricultural Institute in regard of Monsanto's YieldGard Bt maize and Dupont's Herculex I maize in May 2007. Several organisations and institutions submitted a petition to the UN Special Rapporteur on the Situation of Human Rights and Fundamental Freedoms of Indigenous People insisting on the obligation of Colombia to consult with indigenous peoples prior to issuing any policy concerning GMOs and prior to releasing any GM seed that might affect indigenous peoples (*ACIN et al., 2009*). Subsequently, the UN Special Rapporteur emphasized that despite the significant level of attention from the State of Colombia to indigenous issues, there are still big challenges facing the Government to meet its obligations to effectively protect and promote human rights and fundamental freedoms of indigenous people, including in the areas of rights to land and to natural resources, and in relation to prior consultation with indigenous peoples in decisions affecting them (*Anaya, 2010*). In March 2010, Grupo Semillas has submitted a report to the UN Committee on Economic, Social and Cultural Rights to study this issue as it concerns the realization of the rights to health and food in Colombia as well as the lack of prior consultation of indigenous people (*Grupo Semillas, 2010*).

The above emphasizes the importance of comprehensive national biosafety laws and regulations, which include provisions of public consultation and prior information and risk management procedures based on the participation of farmers (see also Soleri *et al.*, 2005). It requires broadbased awareness campaigns and participative consultation processes which include local communities and indigenous people both prior to the introduction of GMOs and prior to the issueing of licenses for GM seeds. Public awareness campaigns, capacity building and monitoring activities, such as carried out by the International Maize and Wheat Improvement Center (CIMMYT) in eastern and southern Africa in the IRMA programme (Insect-Resistant Maize for Africa) might improve the consultation with and information to farmers and community members (Hoisington & Ortiz, 2008). According to *De Groote et al. (2005)*, first 'participatory rural appraisals' were held with more than 900 farmers to assess constraints in maize cultivation. As one of the most serious pest problems reported were stem borers, a potential interest in Bt varieties was concluded. Bt material was then tested in local trials enabling assessment by farmers. These aroused interest from local seed firms provided costs of these varieties would be reasonable, a
nd local farmers generally judged Bt maize favourably and expressed interest in introgression into their local varieties in annual stakeholders meetings. However, Soleri *et al.* (2008) criticized the IRMA approach for still retaining elements of a top-down approach: the farmers were not directly asked whether they preferred using GM varieties or other types of solutions.

Regulations and guidelines employed within the EU and US in order to ensure coexistence of non-GM (including organic) farming and GM farming systems could be effective measures to manage differences between cultivation systems based on ethical and/or socio-economic reasons (see section 3.5.3.). In countries where large-scale farmers and small-scale farmers, including indigenous people, are in each other's neighbourhood, designing rules for coexistence, based on freedom of choice and respecting indigenous people rights including principles of participation, could also be helpful despite the fact that the cultivation systems in this situation are more different from each other in scale and methods than in the EU. Since within traditional farming systems gene flow is welcomed for maintaining diversity, only limitation of gene flow between traditional and more industrial cultivations could be acceptable. Farmers have been able to maintain their landraces in the presence of modern conventional varieties before. There is also an example of such a system in the EU: the maize landraces used in Italy for local culinary purposes ('polenta') were also shown to be maintained even though traces of admixture with modern varieties were found in a study by Bitocchi *et al.* (2009).

Conclusions on impact from GM vs. non-GM maize

Land rights, community rights and rights of indigenous people are not impacted in Spain and other industrialized countries, as land use has not changed and rights are protected by e.g. Spanish and European law and regulation.

Generally speaking, smallholders (smaller than 5 ha) can adjust to and even sometimes benefit from newly introduced varieties by crossing them with their landraces, which could also be the case if the new varieties contain GM traits. Nevertheless, the rights of indigenous people and local communities in Mexico and Columbia may have been impacted by the introduction of GM maize, as information and consultation were lacking during introduction and prior to releasing GM seed, despite the fact that the initial introduction of GM traits in Mexico was through imports not meant for cultivation, and so no consultation period was thought to be necessary at the time. The consideration of possible impacts of GM maize on traditional farming practices and the cultural, symbolic, and spiritual value of maize, as assessed by indigenous people themselves, is most important, as laid down in ILO convention 169 on indigenous peoples' rights (*ILO, 1989*).

There are now examples of consultation programs with introduction of GM varieties into developing countries, such as IRMA (Bt maize in Africa) by CIMMYT, even though these may still leave room for improvement, e.g. by considering a wider variety of options and employing a more participatory bottom-up approach. Coexistence rules and guidelines, which are applied within the EU and US in relation to organic and/or non-GM, and GM farming systems, could possibly be adapted to situations with traditional agriculture.

3.5.3 Freedom of choice

General situation in maize production

This section of the report focuses on Spain, South Africa, Kenya, Mexico and the United States, which all produce GM maize alongside non-GM maize (including organic maize). The possibility of admixture of non-GM maize with GM maize is high due to the outcrossing, wind-pollinated nature of the crop (see section 3.3.4).

In the US, 85% of the total maize produced is GM maize (*GMO Compass, 2010*). The coexistence of GM, non-GM and organic crops in the US is not regulated by government, but based on a common set of practical guidelines (Ramessar *et al.*, 2010[15]).

While the EU has officially approved Bt maize to be grown by European farmers, cultivation of this crop is not possible in several member states (e.g. in France, Germany and Hungary) due to national bans or other measures such as co-existence regulations and monitoring requirements that limit GM crop cultivation (Devos *et al.*, 2009).

GM maize cultivation in Spain is primarily located in regions that are threatened by ECB (European corn borer) infestation in the provinces of Huesca, Zaragosa and Lleida. *Brookes & Barfoot (2009)* reported that in 2007, 21% of the country's maize crop had an insect-resistance (Bt) trait. All GM maize is sold through normal marketing channels to users in the animal feed sector and no segregation of GM from non-GM maize was required. While the EU has proposed coexistence of GM, non-GM and organic cultivation by the introduction of segregation measures, the implementation of specific measures adapted to local circumstances was left to the individual member states. Differently from several other EU states, Spain has not yet enacted their proposed segregation measures. This has not been regarded as necessary as the Spanish market does not require the segregation of GM and non-GM maize for feed use (*Commission of the European Communities, 2006*).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
While the possibility to cultivate GM maize widens the farmer's options, at the same time different factors may limit the farmer's freedom of choice for cultivating non-GM maize. It is expected that the freedom to choose between GM and non-GM maize cultivation in the countries selected may be limited by several factors including regional and national regulations and measures, cross-pollination, a decreasing availability of non-GM seed, limited access to information and consultation as well as changing priorities of seed companies, in part due to the economic benefits that they receive from royalty payments.

Evidence of difference between GM and non-GM production

Several examples of regional differences in Spain show that large-scale and small-scale farmers are able to afford GM or non-GM seed and acquire the necessary financing and technical support to plant what they choose. Although land concentration is ongoing, average farm sizes are still relatively small: Catalonia: 5.5 ha; Aragon 7 ha for grain and 30 ha for forage maize, respectively, and farmland is highly fragmented. The attractiveness of Bt maize is limited to regions with threats of ECB infestations and total cultivation area is still relatively small (~20%) in this

[15]Commentary in peer-reviewed journal.

country (Binimelis, 2008). This is different in countries, such as the US, where non-GM maize constitutes only a small portion of total maize production and seed companies prioritize GM maize seeds, in part also due to the economic benefits they receive from royalty payments. Transgenes are protected by patents and farmers must pay royalty (technology) fees included in the sowing seed prizes for their use. In this way, GM seed prices are higher than they would be in a perfectly competitive market (*i.e.* without patents and/or market power), despite competition from chemical alternatives (Demont & Devos, 2008). On the basis of available literature, however, it could not be established whether and to what extent the intellectual property rights systems of the US and other countries impacted on the availability of non-GM maize.

According to Ramessar *et al.* (2010), the US system of practical guidelines for coexistence places emphasis on the balance between GM and non-GM crops, the isolation distances for avoiding cross-pollination above a certain threshold are based on scientific principles and both GM and non-GM farmers (including organic) have cultivated crops for years without government involvement. In Boulder County, protocols were developed in 2002 to encourage coexistence of GM and non-GM maize on public-owned farmland, i.e. to achieve shared responsibility for the preservation of non-GM crops by organic, GM and non-GM farmers (Byrne & Fromherz, 2003).

The difficulties of coexistence between organic and GM maize production systems are due to a clash of rationale not only at the technical but also at the conceptual level, which describes organic farming as a sustainable development model associated with a specific notion of a desirable naturalness of methods and materials used (e.g. Binimelis, 2008). EC regulations have set a threshold of 0.9% adventitious GM presence above which labelling as GM is required (1829/2003). The latest EC recommendation (2010/C 200/01) of 13 July 2010 adds that Member States may define measures aiming at lower thresholds in cases where the potential loss for organic and some conventional producers may already accrue at values lower than 0.9% GM. This depends on national standards for organic production and remains subject to the principle of proportionality, *i.e.* there should not be any unnecessary burden to agricultural producers. This is relevant with regard to an economic difference between conventional and organic cultivation, namely the price of organically produced maize. While there is no price difference between GM and non-GM maize, organic maize can be sold at a premium, amounting to approximately 50% (*i.e.* 0.21 €/kg instead of 0.14€/kg) in Spain in 2007 (Binimelis, 2008). David Olmo of the Aragon Organic Agriculture Committee stated in 2006 that GM admixture was a serious concern and could lead to farmers losing their premium for organic produce. Olmo claimed that, in 2005, 40% of Aragon's organic maize crop tested positive for the presence of GM, though details of how this was assessed were not available *(Hayley, 2006)*. In fact, between 2004 and 2007, the area planted with organic maize in Aragon declined by 75%. According to Bimimelis (2008), this was because organic farmers wished to avoid conflicts with neighbours that grew GM maize.

Levidow & Boschert (2008) mentioned that the mixture of GM maize with non-GM or organic maize is not tracked to the farmers responsible in Spain, and any cost accrues to those whose crops are admixed. There have been no cases of litigation linked to GM admixture amongst farmers, in part because determining liability would depend on identification of the specific farm that GM pollen came from, which could be impossible in many regions. Although there is a legal requirement to state where GM crops are sown, this information is not publicly available to, for example, other community members, according to Binimelis (2008). Binimelis (2008) also states that particularly small farmers in Spain may face social pressure in the adoption and acceptance of GM seeds, not only from companies but also to achieve a status of being up to date with the most modern farming technology. Binimelis' (2008) study concluded that farmers felt that the Spanish regulation did not sufficiently cover this aspect, while the problems farmers may face in proving causation and legal liability and the lack of reliable dispute-resolution mechanisms have resulted in the promotion of genetically modified over organic production in some regions in Spain. In the Netherlands, it will be possible for farmers to receive compensation from special funds (per crop) in the proposed coexistence regulation measures, if damage from specific levels of admixture can be established (*Commission van Dijk, 2004*).

On the other hand, according to several recent surveys conducted across Europe, farmers from Romania, Portugal, Spain, and other EU countries, claim that coexistence measures and long procedures for admitting GM varieties to the EU restrict their freedom of choice to grow GM maize and put them at a competitive disadvantage compared with producers outside the EU (e.g. *EuropaBio, 2010*).

While there are some similarities with the differences between organic and GM maize production as far as the clash of rationales at the conceptual level and the emphasis of cultural context concerned (Binimelis, 2008), the objections of traditional farmers against admixture with GM traits, are based on their indigenous people rights to preserve culture and traditional systems, which may be hampered by a lack of information and consultation. The right to know is a necessary pre-condition to make choices about cultivation systems. Inadequate information and consultation processes could limit a farmers' freedom of choice and are more common in countries with less established legal systems (see previous section 3.5.2, the cases of GM maize admixture in landraces of local and indigenous communities in Mexico and the introduction of GM into Colombia without prior consultation the same groups).

Similarly, the South African GMO Act (no. 15 of 1997), the Regulations promulgated under it and the National Environmental Management Act, No 107 of 1998 (NEMA) contain requirements of access to information and public participation in relation to GMOs, necessary for the enjoyment of the freedom of choice. In the court decision entitled 'Biowatch vs the Registrar: Genetic Resources *et al.* of February 2005, the Pretoria High Court affirmed 'the duties of public bodies to provide access to information in the public interest, specifically risk assessments of Bt maize.[16] The High Court also clarified the role of the Registrar of Genetic Resources in providing parties who have an interest in, or are affected by, GM crops with access to documents, which are important for better understanding how GM crops are regulated in South Africa.

Finally in Kenya, most farmers in agro-ecological zones plant local varieties of maize. According to Mwangi & Ely (2001), Bt genes could quickly spread to the fields and saved seed stores of farmers who never purchased the GM maize. They argued that cross-pollination could bring benefits of Bt maize to wide numbers of farmers. These benefits, however, might come at the expense of individual choice on the side of farmers if they are not aware of the presence of the Bt gene and/or not able to detect it. At the time of this outlook, there was no Bt maize cultivation in Kenya yet, but introduction has taken place in the mean time in the context of the IRMA programme (see section 3.5.2).

Conclusions on impact from GM vs. non-GM maize

Several examples of regional differences in Spain show that large-scale and small-scale farmers are able to afford GM or non-GM seed and acquire the necessary financing and technical support to plant what they choose.

While the possibility to cultivate GM maize crops has widened the farmer's options, different factors may have at the same time limited the farmer's freedom of choice for cultivating either GM or non-GM maize in some countries or regions. Risk of cross-pollination and lack of timely and reliable information and proper consultation procedures may pose limitations to a farmers' freedom of choice.

Most countries, in which inroads into the freedom of choice are found, either have not promulgated adequate regulations or measures to prevent cross-pollination and to guarantee proper and meaningful participation, or lack effective means of enforcement.

3.5.4 Competition with food production

General situation in maize production and theorized impacts of GM vs non-GM production

The choice to grow cash crops rather than, or next to subsistence crops, is influenced by many different factors, which in maize may include the availability of GM crops and biofuel production opportunities. Determining the impact

[16] Biowatch vs the Registrar: Genetic Resources et al. (Biowatch Trust vs the Registrar: Genetic Resources, the Executive Council for GMO's, the Ministry for Agriculture, Monsanto SA, Stoneville Pedigreed Seed Company, and D& PL SA South Africa, High Court South Africa (transvaal provincial Division), Feburary 2005, case no 23005/ 2002),' The Court ordered that Biowatch South Africa be granted access to almost all the information it had requested. Monsanto South Africa (Pty) Ltd and two other companies joined the court proceedings as co-respondents, on the grounds that they have a direct and substantial interest in the subject matter of the proceedings.

of GM maize cultivation requires looking not only at the impact on local food production, but also the resulting impact on food prices and food availability, since other sources may compensate for reduced local or regional food production.

The introduction of GM maize in Spain has not led to an expansion or shifting of cultivated areas, and there are no observable impacts of GM cultivation on land use patterns. The vast majority of maize in the country (>80%) continues to be used for animal feed production, and GM technology has not affected this.

South Africa is one of the few developing countries in which GM varieties of maize are grown for human consumption.

In Mexico, the cultivation of maize for ethanol production is increasing. In 2007, rising prices for maize and tortillas stimulated by this increase in production for ethanol and limited availability of maize in Mexico, led to a food crisis and social unrest. An amendment was made to the Mexican Bioenergy Promotion and Development Law that clearly states in art. 11 that 'Maize will only be used for making ethanol as long as there is a national production surplus (*Kim, 2008*)

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
In Spain, no impact of Bt maize on food production is expected. There is no expected link between impacts from using maize for biofuel production and the cultivation of GM maize in Mexico, unless it can be established that the qualities of GM maize make it more suitable for ethanol production than non-GM maize. With higher yields, the cultivation of Bt maize in South Africa might increase the production of the basic staple food.

Evidence of difference between GM and non-GM production

GM crops are frequently reported to improve food security, because of better yield potential or lowering of some production risks. Some studies from South Africa suggest that food production can be improved through GM maize cultivation, if effective extension services and financial support can be provided (Gouse *et al.*, 2005b; Aerni & Bernauer, 2006). According to Gouse *et al.*, 2005b) the cultivation of GM maize for human consumption in South Africa will increase production of staple food, also for poor consumers, thereby alleviating pressures on food scarcity as well as increasing income for small-scale farmers, who are usually subsistence farmers. Similarly, stakeholders in South-Africa indicated that the cultivation of GM maize may contribute to food security (Aerni & Bernauer, 2006; Aerni, 2005). However, although many stakeholders in his survey supported the notion of GM maize's advantage to food security, Aerni (2005) was not convinced that large scale, capital-intensive production fosters food security and lowers food prices in South Africa. Food may very well be abundant in one region, but not find its way to neighbouring regions with food scarcity due to ranging regional food prices, high transaction costs and lack of purchasing power of consumers. Rather, there should be a focus on local food self-sufficiency according to Aerni (2005).

The studies reviewed for this report (amongst others Gouse *et al.*, 2005b; Gómez-Barbero *et al.*,2008) gave no indication that GM maize cultivation in Spain and South Africa has displaced other food production or indirectly caused food prices to rise. This literature review has not found evidence that the availability of GM maize has led farmers to adopt maize for feed rather than for human consumption in those countries.

Maize for human consumption does compete with maize for ethanol production. No evidence could, however, be found indicating that specifically the GM variants of maize cultivation had an impact on the rising food prices and limited availability of maize in Mexico in 2007. Regulated GM maize cultivation is only allowed since 2009 in Mexico. These developments may rather be the effect of a higher demand for maize, particularly for ethanol production or consumption in the US (*GMO compass, 2010*).

Conclusions on impact from GM vs. non-GM maize

The cultivation of Bt maize in South Africa will increase the production of the basic staple food, thereby contributing to food security. However, it is indecisive from the literature reviewed whether this will be equally valid country-wide, as availability of sufficient food might differ from region to region (due to ranging regional food prices, high transaction costs and lack of purchasing power of consumers).

In the literature reviewed in this study, competition with food production is not identified as an issue in Spain and South Africa, primarily because land use patterns and choice of crops have not changed with the introduction of Bt maize.

The rising food prices and limited availability of maize in Mexico rather is the effect of a higher demand for maize in general, particularly for ethanol production or consumption in the United States of America, than of the cultivation of the GM variants of maize.

3.5.5 Contribution to livelihoods of producers and local communities

General situation in maize production

According to *Brookes (2002),* the ECB (European corn borer) is estimated to cause an average of 15% yield loss in some regions of high annual corn borer pest pressure where no insecticides are used and an average yield loss of 10% in some regions if insecticides are used but applied at sub-optimal times. The main target of Bt maize in South Africa is the African maize stem borer (*Busseola fusca*) and the Chilo borer (*Chilo partellus*). The stem borers are estimated to be annually responsible for more than 10% maize yield loss even though chemicals are used to control them. A 10% yield loss means an average annual loss of just under a million tonnes with an approximate value of 116 million USD (Gouse *et al.*, 2005b).

The cultivation of GM maize has a positive effect on farm income through savings in pesticide costs and labour inputs (see section 3.4.1). GM maize cultivation also leads to lower prices (see section 3.4.3), which, amongst others, is advantageous to maize importers. In 2006, Mexico produced only 22 million tonnes of maize of the 30 million that it needs. The limited supply of maize has led to the import of maize for consumption from the United States, largely GM.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

Income security of and distribution of benefits to all farmers may depend on whether farmers are able to afford new technologies and to become or remain competitive. The major consideration of GM cultivation relevant to this issue is whether or not access to the technology provides benefits that are distributed to small farmers as well as large ones. In countries with poorer small-scale farmers (usually subsistence farmers), it is a possibility that they do not have the financial means to acquire GM seed. If producing GM maize eventually is more profitable than producing non-GM, this can widen existing income inequalities.

In countries that adopt GM crops the production costs go down (see section 3.4.3). Local communities could benefit from lower prices following a larger supply of maize. Net importing countries are likely to benefit from lower prices of GM maize, but their farmers may face more competition. For instance, small-scale farmers in Mexico may face an increasing competition from the US agricultural sector, potentially driving small holders out of the local market.

Evidence of difference between GM and non-GM production

Gómez-Barbero *et al.* (2008) reported that access to Bt maize in Spain is well distributed and average users are relatively small (<50 ha farm size). Moreover, they measure no significant differences in adoption rates based on farm size. Farmers who would otherwise have applied insecticides saved ~€3-20/hectare on costs and paid +€6-40/hectare for the Bt seed. However, farmers will not necessarily need to use insecticides each season, and so cost savings can vary widely. Additional revenues from yield increases, taking into account crop failures when infestations occur, ranged widely from +€7 to +€144/hectare (see section 3.4.1).

Brookes (2002) reported similar factual data, but calculated the effect of catastrophic yield failures differently. This methodology led to the conclusion that, overall, farmers paid an additional +€18.5/hectare for the Bt seed, but save +€24-102/hectare on pesticide applications. *Brookes (2002)* accounted for potential yield increases in the cost of pesticide applications by assuming that pesticides will always be successfully applied and will prevent yield damage. The wide range of potential pesticide costs reflects the fact that it is difficult to guarantee that pesticide applications reach the target insects before they begin boring into the maize stalks, after which they are protected from further pesticide applications (see section 3.3.1.3).

The overall economic benefits to small producers in Spain reported by Gómez-Barbero *et al.* (2008) ranged between less than € 10/hectare for Bt maize adopters in two of the three regions studied to more than €100/hectare in the third region. *Brookes* (2002) reported that many farmers saw the financial impact of using Bt maize as neutral, but considered it to be an important risk reduction tool that takes away the worry of significant ECB damage occurring. Gómez-Barbero *et al.* (2008) confirmed that the most common reason given for the adoption of Bt maize was to control the risk of corn borer damage and the associated uncertainty in regions where borer damage from time to time occurs. The reduction of this high level of uncertainty, even when infestation levels do not necessitate the use of Bt, benefits small-scale farmers in particular because of their relative inability to absorb the costs of such losses.

According to Gouse *et al.* (2005b), large-scale (commercial) farmers who planted Bt maize in South Africa experienced a yield increase of between 7-11%, depending on land conditions. While farmers have to pay for a technology fee along with the purchase of seeds, costs are lower due to reduced application of pesticides, reduced labour costs and lower costs for fuel during the application process. The survey indicated an increase in net income ranging from 24 USD per ha in rain-fed land areas to over 143 USD per ha in irrigated areas.

Keetch *et al.* (2005) reported that Bt maize in South Africa may be even more beneficial for small-scale farmers, as they do not regularly control stalk borers with chemicals (due to difficulty detecting pests early), and can frequently lose large parts of their crops. Demonstration and trial plots have successfully introduced small-scale farmers to Bt maize, but new extension services and financial support mechanisms will be required if small-scale farmers are to be able to access the benefits of GM maize on a larger scale (Keetch *et al.*, 2005).

No science-based evidence could be found as to whether the livelihood of small farmers in Mexico have been directly impacted by the import specifically of GM maize for consumption from the United States of America. *Fitting (2006)* described the impact of competition from cheap maize imported for the supply of city communities on rural livelihoods. This led to temporary migration of younger people to cities in Mexico and mostly the US, but rather paradoxically, the remittances from this labour migration were often used by older people to sustain or even extend traditional maize production, which also still had some market value because of superior culinary qualities. So, these effects on rural livelihoods can only be indirectly related to GM production in the US, that is, in so far US farmers are able to lower their production costs and thus export prizes by implementation of GM maize. However, differences in agricultural subsidies structure between these two countries may also play a role *(Wise, 2007)*.

Conclusions on impact from GM vs. non-GM maize

There is a positive impact, especially on smaller farms, from reduced risks and (potentially) increased income as benefits (reduced costs for pesticides and labour) seem to outweigh the costs (the technology fee on GM sowing seeds), as long as agricultural extension and financial services sufficiently enable access by small-scale farmers.

No science-based evidence could be found as to whether the livelihood of small farmers in Mexico have directly been impacted by the import of GM-maize for consumption from the US. The sustainance or even extension of traditional maize production can only be indirectly related to GM production in the US, that is, in so far US farmers are able to lower their production costs and thus export prizes and competitiveness by implementation of GM maize.

4. Cotton

4.1 General characteristics of cultivation and trade

Cotton is the world's most important fibre crop in terms of production volume and cropping area. The cotton yield from the field consists for 35-40% of fibres (*Cotton Australia, 2009*). The protein and oil rich seeds, providing cotton oil for various applications and proteins for the animal feed industry, represent 55% of the cotton yield. Unprocessed cotton seed contains gossypol which can poison livestock if seeds are used as feed. The remaining 5-10% of the cotton yield exists of stems and leaves, though this figure may be lower when cotton is hand-picked. Several different cotton species are grown worldwide, but *Gossypium hirsutum* (L.) is commercially the most important species being cultivated on about 90% of the total cotton area.

The world's largest cotton producers are China, India, the US, Pakistan, Brazil and Uzbekistan (Table 4.1). Cotton cultivation in the EU is limited to Southern Europe. Average cotton yields strongly fluctuate between countries with a world average in 2007/2008 of 793 kg fibres per ha. Cotton yields are relatively high (>1000 kg fibres per ha) in Brazil, Mexico, Australia, Syria, Turkey and China. In sub-Saharan Africa on the other hand, national yield averages varied between 230 and 470 kg fibres per ha. Also the use of inputs such as fertilizers and crop protection agents strongly vary between countries (*IFA, 2002*). The chains processing raw cotton into end products are often complex due to the involvement of many actors in several countries. Especially China, India and Pakistan are important processors of cotton and exporters of cotton products.

Most cotton in the Netherlands is imported as processed products such as textile and is not registered as cotton. Data on the total cotton trade and consumption in the Netherlands are therefore difficult to retrieve. In the US, the average cotton consumption (fibres) in 2004 was 15.5 kg per capita (*US Cotton Board, 2009*). The Dutch consumption per capita will probably be somewhere in that order as well, giving an estimated total national consumption in the Netherlands of 256,000 tonnes per annum.

Cotton production is associated with a number of sustainability issues (*BCI, 2010*). Cotton production often involves the use of relatively toxic insecticides such as organophosphates and pyrethroids that have a large impact on human health and the environment, in comparison with other crop protection agents. Moreover, the cultivation and processing of cotton demands relatively large amounts of water (Chapagain *et al.*, 2006), while cotton production areas are often located in areas with water shortages. Also several problems exist with regard to the People dimension of cotton production. Cotton production, as well as cotton seed production, has frequently been associated with child labour and the exposure of farmers and field labourers to harmful crop protection agents and other chemicals used during processing (*Tripp, 2009*[17]). Moreover, many cotton farmers in developing countries such as India are trapped into spiralling debts.

[17] 'Biotechnology and agricultural development: transgenic cotton, rural institutions and resource-poor farmers' (ed. R. Tripp) was the outcome of an Oxfam-America research project in which many experts in the field and an advisory committee were involved. It has been frequently used in this review, particularly in the 'People' part.

Table 4.1. Cotton production (fibres), the average yield per ha and the area of cotton in 2007/2008 per country and worldwide (Source: USDA, 2009*).*

Land	Production (1,000 tonnes)	Yield (kg/ha)	Area (1,000 ha)
China	8,056	1,299	6,200
India	5,356	567	9,440
US	4,182	985	4,250
Pakistan	1,938	646	3,000
Brazil	1,602	1,488	1,080
Uzbekistan	1,197	826	1,450
Turkey	675	1,298	520
Greece	288	916	320
Turkmenistan	283	472	600
Syria	250	1,252	200
Egypt	218	907	240
Argentina	153	494	310
Burkina Faso	147	367	400
Kazakstan	136	680	200
Australia	135	2,077	70
Mexico	135	1,227	110
Other countries *	1,496		4,320
World	26,247	793	33,090

** including Tajikistan, Benin, Peru, Nigeria, Tanzania, Cameroon, Myanmar, Iran, Mali, Tsjad, Columbia and Ivory Coast.*

4.2 Genetic modifications

4.2.1 Current events

In 2008, worldwide 15.5 million ha of GM cotton was cultivated, which encompassed almost half of the total cotton area (*James, 2009*). Most GM cotton was cultivated in China, India and the US with smaller areas in Argentina, South Africa, Australia, Brazil, Mexico, Burkina Faso, Pakistan and Columbia (Table 4.2). In 2009, GM cotton with traits that lead to insect resistance (Bt) and herbicide tolerance (HT) were commercially cultivated. The herbicide-tolerance traits and some of the Bt traits have been approved for import and processing in the EU. Unapproved Bt lines generally do not hinder the cotton trade with the EU, as usually only the fibres are traded and not the seeds that may contain transgenic DNA (*Stein & Rodríguez-Cerezo, 2009*).

Bt cotton is a crop in which a protein is expressed that leads to resistance against certain Lepidoptera species, in particular the caterpillars of specific moths. Bt cotton contains one or more genes isolated and adapted from the bacterium *Bacillus thuringiensis* (Bt) encoding Bt or Cry proteins, comparable with what has been described for Bt maize (see Section 3.2.1). Various genes that lead to the production of different Bt proteins have been incorporated in cotton. Different Bt proteins provide different control spectra of targeted pests. Bt cotton is primarily used to reduce crop losses due to infestation of the cotton bollworm (*Heliocoverpa zea*, a moth) or to reduce pesticide use against this bollworm. Also other pest Lepidoptera such as the pink bollworm (*Pectinophora gossypiella*) and *Heliothis virescens* can be controlled with the help of Bt proteins. Monsanto Company introduced the first Bt cotton around 1996 and since then other companies and institutes, among others in China and India, developed their own Bt lines using their own research capacities or licensing Bt constructs that were developed by others. Recently the public institute The Indian Council for Agricultural Research (ICAR) released a non-hybrid Bt variety that allows farmers to save their own seed without losing the efficacy of the Bt gene or other properties of the seed (*Karihaloo & Kumar, 2009*). Bt cotton is a very popular crop among small-scale farmers in developing countries. About 12.1

million small-scale farmers in China, India, Pakistan, and South Africa cultivated Bt cotton in 2008 (*James, 2009*). In China 61% and in India 63% of all cotton farmers grew Bt cotton in 2007 (Table 4.2). The Bt trait is also popular among large-scale cotton producers in the US, Australia, Argentina and Brazil.

Various herbicide-tolerant (HT) GM cotton lines have been developed with the aim to facilitate weed control in cotton. Roundup Ready® (RR) cotton is tolerant to applications of the aselective, broad-spectrum herbicide glyphosate. RR cotton was introduced in the US in 1997 by Monsanto Company and is currently cultivated in a large number of countries. Its use however is less widespread than Bt cotton. Liberty Link® (LL) cotton has an event that makes the cotton plant tolerant to applications of the aselective, broad-spectrum herbicide glufosinate ammonium. The LL trait has been patented by Bayer CropScience. LL cotton was commercially launched in the US in 2004 and is now cultivated in various other countries as well. Two other HT cotton lines have been deregulated in the US (providing tolerance to sulfonylurea and bromoxynil), but these are currently not available in seeds for commercial plantings as far as we are aware of.

The Bt trait in cotton can be combined with HT traits. A cotton line containing a Bt and an RR trait is already commercially available. Also a cotton line containing both the LL and a Bt trait will be launched in the near future.

Table 4.2. Adoption and area of Bt and herbicide-tolerant (HT) cotton in various countries in 2007 (Source: Brookes & Barfoot, 2009*).*

Country	% Bt relative to the total cotton area	Area Bt cotton (1,000 ha)	% HT relative to the total cotton area	Area HT cotton (1,000 ha)
China	61%	3,782		
India	63%	3,698		
US	59%	1,534	70%	1,820
Brazil	32%	115		
Argentina	49%	152	38%	118
Australia	86%	55	79%	51
Mexico	48%	29	40%	24
South Africa	76%	8	75%	7

4.2.2 Events in the pipeline

Companies and public research institutes are developing various new Bt lines with insect resistance (all resistance to Lepidopterans) (*Stein & Rodríguez-Cerezo, 2009*). There is also another GM HT cotton in the pipeline with tolerance to glyphosate based on an event different from the currently available glyphosate tolerant RR cotton. Events are also increasingly combined, resulting in GM cotton lines with multiple insect resistance genes or combining herbicide tolerance with insect resistance (so-called stacking of GM traits). In the long term (after 2015) new GM cotton lines may be commercially introduced with so-called second generation traits, such as drought tolerance.

4.3 GM related sustainability – Planet

Bt cotton is widely cultivated by both small-scale and large-scale farmers. HT cotton is primarily cultivated by a relatively small number of large-scale farmer in the US, Argentina, Australia, Mexico and South Africa. In the following sections, we focus on the sustainability impacts of Bt cotton as this trait is widely used and a great deal of data is available on the sustainability impact of this type of GM cotton.

4.3.1 Production efficiencies

4.3.1.1 Land

Bt cotton can help to reduce yield losses from pest insects when pest control is not optimal. Higher yields lead to a higher land use efficiency. Pest control is often not optimal in developing countries such as India where input use is generally low. Differences in yield between GM and non-GM cotton are reduced when pest control in non-GM cotton is more effective. If pest insects targeted by the Bt proteins are not a yield-limiting factor, the cultivation of Bt cotton obviously does not lead to increased yields. Other factors that are not directly related to the Bt trait may also affect the yield difference between Bt and non-GM cotton, such as the genetic background of the varieties, field management and agro-ecological conditions. The possibility that farmers adopting Bt cotton may be different from non-adopting farmers in other respects as well, is referred to as selection bias. This selection bias often complicates the comparison between the performance of Bt and non-GM cotton farmers as it produces correlations that are not based on causal relationships, and it may explain why results of studies to the impacts of Bt cotton can vary a lot, as far as yield is concerned. Below follows a review of studies comparing the yield of Bt and non-GM cotton from different countries.

An extensive field study in China by Huang *et al.*, (2002 & 2003) involving more than 1000 farmers in the provinces of Hebei, Shandong, Henan, Anhui en Jiangsu in 1999-2001 suggested that Bt cotton gives an average yield increase of 8-15% relative to non-GM cotton.

In India a comparison between the yield of legal Bt cotton, non-GM cotton and illegal Bt cotton under 618 farmers in Gujarat in 2003-2004 showed that legal Bt cotton varieties gave 20-37% more yield than non-GM cotton (Morse *et al.*, 2005). Illegal cotton is cotton that was sold as Bt cotton, but that was not produced by Bt-license holders. Often such illegal cotton was first-generationoffspring (F_2) of legal Bt hybrid seeds, so roughly half the seeds contained the Bt trait. Illegal Bt cotton also gave a higher yield than non-GM cotton, but the difference between the two was smaller. Another large study on the basis of 9,000 cotton fields in Maharashtra in 2002-2003 indicated that Bt cotton gives on average per season 45-63% higher yields than non-GM cotton (Bennett *et al.*, 2004a & 2006). A large variation between regions was observed however and in some regions Bt cotton did not give a yield increase at all, which indicates that several other factors are important in determining whether there is a difference in yield between GM and non-GM cotton. Sadashivappa & Qaim (2009) monitored cotton yields of farmers in the main cotton producing states of India (Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu) for four consecutive growing seasons (2002-2007) and found that on average, Bt cotton gave 30-40% higher yields than non-GM cotton.

In the field studies with farmers mentioned above, comparisons between GM and non-GM cotton may be influenced by the possibility that farmers switching to Bt cotton already had higher yields than non-adopters before the switch. Crost *et al.* (2007) studied this effect of self-selection by farmers on yield increases from the adoption of Bt cotton. With the help of 718 observations in Maharashtra State in India and econometric techniques, it was attempted to separate the real yield increase from Bt cotton from other factors that may influence yield. This study indicated that the yields of Bt cotton were 31-92% higher if the other factors were not compensated for. The yield increase that could be attributed to the Bt trait was 11-31% if the other factors were left out.

Research on the impacts of Bt cotton in South Africa focussed on the Makhathini plains in Kwazulu-Natal. This is an area with a low potential for cotton production and also atypical in the sense that biotechnology companies and agricultural support institutes are unusually well presented (Thirtle *et al.*, 2003). The Makhathini plains represent 31% of the total cotton area in South Africa. According to a study published by Bennett *et al.* (2004b) and Morse *et al.* (2006) the yield of Bt cotton, relative to that of non-GM cotton, was higher among small-scale farmers on the Makhathini plains in 1998-2001. From year to year, the average yield increase from the adoption of Bt cotton was between 56 and 85%. Hofs *et al.* (2006c) concluded in a different study conducted in 2002-2004 among small-scale farmers with and without Bt cotton that the differences in yield between Bt and non-GM cotton were too variable to make any statements with regard to structural yield differences. Apart from the different time periods in which the studies were conducted, also the set-up of the studies by Bennett *et al.* (2004b) and Morse *et al.* (2006) were different from the study by Hofs *et al.* (2006c). The studies by Bennett *et al.* and Morse *et al.* were based on a survey involving annually 441 to 1283 farmers, while the study by Hofs *et al.* was based on observation amongst 20 farmers growing Bt and non-GM varieties with similar genetic backgrounds and under comparable agro-ecological conditions. In field experiments with large-scale cotton cultivation under irrigation on the Makhathini plains, Bt cotton showed a 13% higher yield potential (Hofs *et al.*, 2006b). A study by Gouse *et al.* (2004) compared the yield advantage among large-scale and small-scale farmers in 1999-2001. This study suggested that small-scale farmers realized a 46% yield increase due to the adoption of Bt cotton, while large-scale farmers had a yield increase of 19 and 14%, with and without irrigation, respectively.

In Argentina, the cultivation of Bt cotton was compared with that of non-GM cotton in 1999-2001 by Qaim *et al.* (2003). Argentinean Bt farmers had on average 32% higher yields than non-GM cotton farmers. In the US and Australia, the yield increase due to the adoption of Bt cotton was low, in comparison with that reported in developing countries, as pest insects are also well controlled in non-GM cotton in the US and Australia. Brookes & Barfoot (2009) reported an average yield increase of Bt cotton of 9-11% in the US and no yield increase in Australia.

Conclusion

The Bt transgene has no direct impact on potential yield of the crop. Primarily through a change in pest management, actual crop yields (*i.e.* land use efficiencies) are affected. A great deal of evidence is available that Bt cotton has contributed to an improved yield, especially in developing countries such as India, China and South Africa. The magnitude of the increase varies a lot (0-85% increase over non-GM cotton) and it is often uncertain to what extent improved crop management of Bt cotton, unrelated to the transgene, and self-selection by farmers have contributed to the observed relative yield increases. The one study in India on this issue indicated that around one third of the reported yield increase could be attributed to the Bt trait and the remaining to other factors unrelated to the Bt trait.

4.3.1.2 Fertilizer

THEORIZED EFFECTS
As the Bt trait has no direct impact on nutrient use by the plant, it is expected that the impact of Bt cotton on fertilizer use efficiency is minimal.

Evidence of differences between GM and non-GM cotton

We found no reports stating that nutrient management in Bt cotton is any different from that in non-GM. If yields in Bt cotton are higher than in non-GM cotton, fertilizer rates should be adjusted accordingly, but there are no reasons to assume that nutrient use per kg of product is affected by the Bt trait.

Conclusion

We found no evidence that fertilizer use in Bt cotton is somehow different from that in non-GM cotton.

4.3.1.3 Biocides

While the Bt proteins do not provide resistance to all pests in cotton, they do control some of the main pest insects. When Bt cotton was introduced, it was expected that it would enable farmers to change pest control strategies and biocide use. Lots of evidence is available that this has been the case.

The study by Huang *et al.* (2002 & 2003) indicated that insecticide use (expressed as quantity of active ingredients) under 1000 farmers in China in 1999-2001 was 58-81% lower in Bt cotton than in non-GM cotton. The effect of Bt cotton on pesticide use was very large in certain areas due to an extremely high pesticide use in non-GM cotton, which was related to widely spread resistances among pest insects against the commonly used insecticides. Especially the use of the relatively toxic pyrethroids, organophosphates and organochlorides was strongly reduced in Bt cotton. Wang *et al.* (2009) noticed in a study partly based on the same data as used by Huang *et al.* (2002 & 2003) an increase in insecticide use in Bt cotton between 1999 and 2004 and a reduction in the insecticide use in non-GM cotton. Thus, the relative difference in insecticide use between Bt and non-GM cotton decreased during that period. In 2004, insecticide use in Bt cotton was only 38% lower than in non-GM cotton, while in 2006 the advantage of Bt cotton above non-GM cotton increased again. The diminishing advantage of Bt cotton above non-GM cotton in terms of insecticide use in 2001-2004 was probably related to an increase in secondary pest insects (especially mirid bugs, Miridae) in cotton. Bt proteins are not effective against these pest insects. The analysis by Wang *et al.* (2009) suggested this increase in secondary pest insects was primarily caused by particular weather conditions in 2001-2004. A more recent study, however, does link the cultivation of Bt cotton in China to increased outbreaks of these secondary pests (Miridae) in cotton and in other crops grown in the vicinity of Bt cotton (Lu *et al.*, 2010).

The study by Sadashivappa & Qaim (2009) among Indian farmers over 2002-2007 indicated that insecticide use (expressed as the amount of active ingredients) was reduced in Bt cotton by 40%, relative to non-GM cotton. Other studies on Bt cotton in India, referred to above in the section on yield, only gave data on the number of insecticide applications and the costs of insecticides, but not on the quantity of active ingredients applied.

In South Africa, Bt farmers on the Makhathini plains used 40-63% less insecticides than non-GM farmers in 1998-2001, according to Morse *et al.* (2006). The application of all types of insecticides used in cotton (organophosphates, pyrethroids and organochlorides) was reduced in Bt cotton. In the study by Hofs *et al.* (2006a) among 20 small-scale farmers in 2002-2004, the use of pyrethroids was strong reduced among Bt farmers (<35% of the use in non-GM cotton), while Bt cotton had no significant impact on the use of organophosphates.

A study by Qaim *et al.* (2003) in Argentina suggested that insecticide use (active ingredients) among Bt cotton farmers was on average 57-66% lower than among non-GM farmers.

In the US, insecticide use in Bt cotton in 2007 was 6.7% lower than in non-GM cotton and in Australia, insecticide use in Bt cotton was 69% lower than in non-GM cotton (Brookes & Barfoot, 2009).

From the beginning, concerns with regard to the possibility that pest insects develop resistance against the Bt proteins were expressed and laboratory tests indeed showed that various pest insects can develop this type of resistance (*Van Rie & Ferré, 2000*[18]). However, up to now cases of insects developing resistance against Bt in the field have been rare and the Bt proteins have maintained their effectiveness (Naranjo, 2009; Tabashnik *et al.*, 2009).

Conclusion

Lots of evidence is available that the adoption of Bt cotton has resulted in a reduction in pesticide use in cotton. The reported magnitude of the reduction varies a lot between countries and studies (6.7% - 81%). Up to now, cases of insects developing resistance against Bt proteins in the field have been rare.

4.3.1.4 Energy

THEORIZED EFFECTS
Energy use for the cultivation and processing of Bt cotton may be different from that of non-GM cotton. Less application of insecticides and a lower production of pesticides help to save energy. Small-scale farmers in developing countries usually apply pesticide with a knapsack sprayer. In this case, less pesticide applications help to save labour demands, rather than energy use.

Evidence of differences between GM and non-GM cotton

We found no studies quantifying the energy use in Bt and non-GM cotton.

Conclusion

Bt cotton has the potential to slightly reduce energy demand for cotton production. No studies were found quantifying energy use in Bt and non-GM cotton.

[18] Chapter in edited scientific monograph.

4.3.1.5 Water

THEORIZED EFFECTS
The Bt trait has no direct impact on water use by the crop, and it is therefore expected that Bt cotton has a water use efficiency similar to that of non-GM cotton. If inputs costs of Bt cotton at the beginning of the season are higher, relative to non-GM cotton, there could be a stronger economic rationale for a farmer to irrigate a Bt cotton crop in case of drought in the beginning of the growing season in order to recover the investments in seed.

Evidence of differences between GM and non-GM cotton

We found no evidence of an interaction between the presence of Bt genes and drought resistance of the crop. Therefore, water use efficiency of Bt cotton is unlikely to be basically different from that of non-GM cotton. We found no evidence for a higher usage of irrigation with Bt cotton as compared to non-GM cotton.

Conclusion

Water use efficiency is an important issue in cotton, but no studies were found indicating that water use in Bt and non-GM cotton is different.

4.3.2 Soil conservation

THEORIZED EFFECTS
Bt cotton is not associated with changes in soil cultivation practices and is therefore unlikely to have an impact on soil conservation.

Evidence of differences between GM and non-GM cotton

We found no evidence that Bt cotton has a different impact on soil conservation as compared to non-GM cotton. Possible effects on soil biota are treated under the biodiversity section, 4.3.4.

Conclusion

No studies were found indicating a specific impact of Bt cotton on soil conservation.

4.3.3 Water conservation

THEORIZED EFFECTS
Water use efficiency in Bt cotton is unlikely to be different from that in non-GM cotton. Bt cotton could be expected to benefit the quality of water resources by reducing the use of relatively toxic insecticides.

Evidence of differences between GM and non-GM cotton

No studies were found quantifying and comparing water use in Bt and non-GM cotton (see section 4.3.1.5). The study by Huang *et al.* (2002) in China stated on the basis of survey data that the reduction of the use of pesticides for Bt-cotton has significant implications for the environment, particularly for the quality of drinking water for local farmers in cotton-producing regions.

Conclusion

There is some evidence from China that Bt cotton can help to improve the quality of groundwater in cotton producing areas. There is no evidence that Bt cotton has an impact on direct water use that is basically different from non-GM cotton.

4.3.4 Biodiversity

The Bt proteins are generally more selective than the insecticides used in cotton, among others because primarily insects ingesting cotton plant parts come in contact with the Bt proteins. Studies to the consequences of Bt crops on the incidence of arthropods in general and beneficial insects in particular indicate that the cultivation of Bt cotton results in a similar or higher agro-biodiversity in cotton fields in comparison with the cultivation of non-GM cotton (Head *et al.*, 2005; Torres & Ruberson, 2005; Shen *et al.*, 2006; Sisterson *et al.*, 2007; Hofs *et al.*, 2008). Scientific literature on the effects of Bt cotton on non-target organisms and soil ecosystems was extensively reviewed by Romeis *et al.* (2006), *Sanvido* et al. *(2007*[19]) and Naranjo (2009). Several studies looked into possible effects of Bt proteins in crop residues on soil biota. However, as in maize (section 3.3.4), no clear or relevant effects have been found on soil micro- or macro-organisms (e.g. Shen *et al.*, 2006; *Sanvido* et al*., 2007*).

On a different scale, it can be stated that increased yields of Bt cotton reduced the area of arable land required to satisfy the global cotton demand, if cotton consumption remained the same, which could help to preserve areas with a high biodiversity value that are threatened by expanding agricultural activities. As this impact from Bt cotton is difficult to measure, we found no studies quantifying the impact of Bt cotton on the demand for agricultural lands (see also ‘Profit’ section 4.4.2).

Conclusion

The selectivity of Bt proteins and reduced pesticide application in Bt cotton implies that the impact of Bt cotton on agro-biodiversity is neutral or positive. Higher cotton yields observed in Bt fields can reduce the area of land required to satisfy global cotton demand, thereby reducing the need to clear new natural areas for farming. However, this latter impact has not been confirmed by scientific studies.

4.3.5 Climate Change

THEORIZED EFFECTS
Apart from Bt cotton offering the potential to save energy required for insecticide production and application, as mentioned above (section 4.3.1.4), Bt cotton is not expected to have any other direct impacts on the emission of greenhouse gasses.

Evidence of differences between GM and non-GM cotton

We found no studies comparing energy use or greenhouse gas emission in Bt cotton relative to non-GM cotton.

Conclusion

The cultivation of Bt cotton could result in a slightly lower energy demand for insecticide production, but we found no evidence on this subject in this review of the literature.

4.4 GM-related sustainability – Profit

Similarly to the ‘Planet’ section (4.3), the review of impacts of GM cotton on profit is in principle restricted to Bt cotton varieties in sections 4.4.1 and 4.4.4. Sections 4.4.2 and 4.4.3 contain exceptions to this restriction, because the studies reviewed in these sections address both Bt and herbicide tolerant (HT) cotton.

[19]Chapter in edited scientific monograph.

4.4.1 Farm income

Cotton is an important crop in certain developed as well as developing countries. Particularly with respect to developing countries, there is an ongoing debate on whether (small-scale) farmers actually benefit from GM technology. As a result, much research has been devoted to quantifying farm income effects of Bt cotton adoption, with a strong focus on developing countries. Below, we will first provide an overview of average effects on revenue, production costs and gross margins. This overview is largely based on reviews in which results have been aggregated. In a separate subsection, we pay special attention to potential heterogeneity in farm income effects among farm types and regions.

Effects on revenue

According to the conclusion of section 4.3.1.1, yields generally increase when switching from non-GM to Bt cotton. Ignoring price effects (but see section National Income), this implies that revenues will increase as well. *Brookes & Barfoot (2010),* in a review on economic impacts of GM crops, provided similar or higher numbers for a range of countries. Yield effects are generally smaller for developed than for developing countries; yet, this is not always reflected in the revenue, due to differences in output prices between countries and the influence of pest pressure on revenues.

Raney (2006) compared the relative impact of Bt cotton on farm income specifically in developing countries. For Bt cotton, a positive effect on revenue is reported for all evaluated countries (Table 4.3). The revenue increase is relatively lower in China and Mexico, countries where crop losses are traditionally lower due to high pesticide use. Note that country-specific yield effect estimates, which comprise the basis for assessing revenue effects, differ considerably between Table 4.3 and 4.4. We will discuss this later.

Prices for Bt cotton do not differ from those for non-GM cotton *pur sang*. Pray *et al.* (2002) reported virtually identical prices in China in the period 1999-2001, as did Bennett *et al.* (2004a) for India in 2002 and 2003. Nevertheless, prices may vary in practice as a result of differences in product characteristics. For instance, Bt cotton prices in Mexico were lower than non-GM cotton prices in 1997, but higher in 1998, due to quality differences (Traxler & Godoy-Avila, 2004). In India, one particular Bt cotton variety appeared to have a lower output price than the prevailing non-GM variety because it has a shorter average staple length, which is a quality criterium (Qaim *et al.*, 2006).

Table 4.3. Percentual change in performance of Bt cotton compared to non-GM cotton in developing countries. Source: Raney, 2006.

	Yield	Revenue	Pesticide costs	Seed costs
Argentina	33	34	-47	530
China	19	23	-67	95
India	34	33	-41	17
Mexico	11	9	-77	165
South Africa	65	65	-58	89

Table 4.4. Country-specific impacts of Bt cotton adoption on farm income in 2008 (USD per ha). Source: Brookes & Barfoot, 2010.

Country	Presumed yield effect (%)	Change in revenue	Change in production costs	Net effect on gross margin
US	11	100.93	2.71	98.22
China	10	76	-148	224
Australia	0	0	-199.86[1]	199.86
Argentina	30		68.5	25-249[2]
Mexico	6-9 [2]	130.5	-19.9	150.4
South Africa[2]	24		2-32	27-232
India	40 [3]	232.45	-24.28	256.73
Brazil[4]	-2.7			2
Burkina Faso	20	104	20	124

[1] Reported cost of technology was 264.26 USD per ha.
[2] Data present average over a range of (recent) years.
[3] Yield gain in 2008 was lower than average due to lower pest pressure.
[4] Available Bt varieties performed suboptimal compared to available non-GM varieties.

Effects on production costs

Cotton production is traditionally characterized by high production costs and high levels of production inputs, particularly chemicals and fertilizers (*Carpenter et al., 2002*). As Bt cotton reduces the need for insecticide applications (section 4.3.1.3), adoption of Bt cotton is thus likely to decrease production costs considerably. This hypothesis is supported by many studies, as shown in Table 4.3. Particularly large cost savings have been reported for China, as Chinese growers traditionally use large amounts of pesticides. Pray *et al.* (2002) reported pesticide cost savings of 66 to 146 USD per ha for cotton producers in China in 1999-2001, resulting in net cost reductions of several hundred US dollars in two of the three years. While all reviewed literature sources agreed that Bt cotton reduces pesticide costs, several studies warn for overestimation. The actual effect on pesticide costs may be lower because of incorrect substitution between Bt and pesticides. Pemsl *et al.* (2005) showed that many Bt cotton growers in 2002 still applied insecticides against cotton bollworm. Also, while Bt seed price was positively correlated with control effectiveness (*i.e.* higher price implied better resistance), farmers who paid more for their seed appeared to spend more money on insecticides and other inputs. The authors suggested that the continued promotion of chemical pesticides by extension agents, who receive part of their income from pesticide sales, reduced the potential effect of Bt cotton on pesticide costs. Also uncertainty of farmers about the control effectiveness of Bt varieties (see section 4.4.4) was supposed to contribute to the high level of pesticide use. In a study of Bennett *et al.* (2004b) on Bt cotton adoption in South Africa, Bt cotton adopters initially appeared to reduce not only insecticides aimed at the cotton bollworm, but also those pesticides controlling pests against which Bt cotton does not provide protection. The authors attributed this to farmers' misunderstanding of the control effectiveness of Bt cotton.

Seed prices strongly vary among countries, depending on the value of the technology and the strength of the IP protection. *Qaim* et al. *(2008*[20]*)* provided an overview of seed prices in relation to gross margin gains (Table 4.5). *Brookes & Barfoot (2010)* used slightly different numbers. According to their review, US farmers paid on average an extra 26 USD/ha in 2008, as compared with Australian farmers who faced a 250 USD per ha difference in seed costs (*Brookes & Barfoot, 2010*). Even so, Australian adopters have realized large net cost savings since the introduction of Bt cotton, while in the US the balance between insecticide cost reduction and increased seed costs has remained more or less neutral over time. In Argentina, excessively high technology fees charged by Monsanto have led to a net increase in production costs (Qaim & De Janvry, 2003). In contrast, Chinese Bt cotton growers face relatively low seed prices because private seed suppliers experience competition from public sector breeding programmes (Smale *et al.*, 2006).

Sometimes, seed technology fees may even differ within a country. In South Africa, seed price discrimination occurs between small- and large-scale farmers, the latter ones paying a higher technology fee than the former ones (Gouse *et al.*, 2004). Seed suppliers accept a lower seed price from small-scale farmers who cannot pay the high prices paid by large-scale farmers. In Mexico, a differential pricing strategy is applied that reflects regional differences in the marginal value of Bt cotton production (Traxler & Godoy-Avila, 2004).

Table 4.5. Bt cotton seed costs increases and gross margin gains (USD per ha). Source: Qaim et al., 2008.

Country	Seed cost increase	Gross margin gain
Argentina	87	23
China	32	470
India	56	111
Mexico	58	295
South Africa (small farms)	23	52
South Africa (large farms)	47	129
USA	79	58

Net effects on gross margins

Brookes & Barfoot (2010) collated data on farm income effects of Bt cotton for a number of countries (Table 4.4). They concluded that farm income increased through the adoption of Bt cotton, mainly because of the positive effect on yield. According to the authors, the global farm level impact of using Bt cotton was 2.9 billion USD in 2008, of which 65% was derived from yield gains and 35% from reduced production costs. Also the overview provided by Raney (2006, Table 4.3) showed a positive impact on gross margin for all countries evaluated. While aggregated net effects on gross margin tend to be positive in general, tracing data presented in the above-mentioned reviews to their original source revealed that aggregated data should be interpreted carefully. In the next subsection, we offer a more critical perspective by providing insight into the complexity of the relation between Bt cotton adoption and farm income.

[20] Chapter in edited scientific monograph.

Representativeness of average data

Some additional aspects have to be kept in mind to interpret these results. The following aspects will be highlighted: the duration of the observation period, the geographical scale, the selection criteria for the sample and differences between small-scale and large-scale farmers.

Firstly, presented numbers are often based on one or two years of observation. Given the large fluctuations in pest pressure and resulting yield losses, these do not necessarily provide representative long-term averages. For instance, the average net profit in Mexico as presented in Table 4.4 is based on data of 1997 and 1998 (the first two large-scale adoption years); net farm income benefits in these years were 44 USD per ha and more than 600 USD per ha, respectively (Traxler & Godoy-Avila, 2004). In the original survey underlying the Chinese data in Table 4.3, net cost reductions due to Bt cotton production were obtained in 1999 and 2001, but in 2000, net cost increases were observed (Pray *et al.*, 2002). *Brookes & Barfoot (2010)* used the same source for presenting Chinese farm income effects in early years, but included only the two positive years. Besides differences in pest pressure, cotton prices may also fluctuate over time. In an Argentine case study, low cotton prices caused insignificant net benefits from Bt adoption in the 2000-2001 growing season, although yield effects were the same as in the year before, when a significant net benefit was measured (Qaim & De Janvry, 2003).

Another aspect to bear in mind is that impact studies often focus on a particular region, especially when they are based on surveys among farmers. The Mexican study mentioned above was performed in a particular region, and results are probably not representative for other regions, where pests thrive against which Bt cotton does not provide resistance. This is supported by low adoption rates in other Mexican regions. In another analysis, on Bt cotton adoption in India, gross margins on average increased when adopting the Bt crop, but in one region gross margins significantly decreased (Qaim *et al.*, 2006). The reason was that available Bt varieties were less suitable for the climatic circumstances in that region than available non-Bt varieties. However, both Raney (2006) and *Brookes & Barfoot (2010)* extrapolated region-specific results to country-level.

Furthermore, the selection of farmers may be arbitrary, or the test group and reference group may not represent the same population. The effect is that observed effects of Bt cotton adoption may be partially attributable to other differences between the two groups. Even when using similar populations (e.g., by including only farmers for which both Bt and non-Bt cotton data are available), results can be biased by other factors, such as soil type and use of other inputs. One way to deal with these biases is by estimating production functions that include such factors as variables, as has been done amongst others in Pemsl *et al.* (2005), Qaim & De Janvry (2003), Qaim *et al.* (2006), and Bennett et *al.* (2004b). Pemsl *et al.* (2005) criticized the Chinese study of Pray *et al.* (2002) for the above-mentioned shortcomings and believed that reported benefits possibly overestimated the benefits actually experienced by farmers in developing countries (see also their findings on pesticide cost savings cited earlier in this section). In studies on Bt cotton adoption in South Africa, analyses of the same population and period have led to different results. Bennett *et al.* (2004b) performed regression analysis on a dataset of a major seed supplier containing records of over 400 farmers, and concluded that Bt technology has led to a yield (and revenue) increase of 65 percent. Gouse *et al.* (2004) used survey data from 100 farmers who purchased seed from the same seed supplier. They concluded that the yield benefit of Bt cotton was 22%, leaving the remaining observed differences between adopters and non-adopters to other factors such as weather variability.

There is much debate on whether farm income effects of transgenic crops are different for large scale farmers and smallholders in developing countries. Bennett *et al.* (2004b) have analyzed farm income effects of Bt cotton adoption in South Africa. Data were obtained from a large sample of smallholder farmers over three seasons, to avoid biases from seasonal effects and differences among farms. Results showed that Bt cotton adopters obtained significant higher gross margins than non-GM cotton growers (an increase of 562 South African Rand per ha, or approximately 80 USD per ha, in the period of data collection, 1998-2001). Moreover, farmers with smaller holdings benefited proportionally more, as indicated by the fact that income inequality reduced within the population of Bt cotton adopters, compared to an increase in income inequality among non-adopters. Similar results were obtained by Gouse *et al.* (2004), who showed that large-scale farmers in irrigated areas benefited most, followed by dryland small-scale farmers and, lastly, dryland large-scale farmers. *Qaim* et al*. (2008)* compared the net benefits of Bt cotton cultivation among small-scale (less than 5 ha) farmers and large-scale farmers (more than 5 ha) in India and found a small difference (33 USD per ha more net benefits for large-scale farmers according to Morse *et al.*, 2007).

Other effects on farm income

Among the other effects that have been reported, labour is the most important one (see, e.g. Pray *et al.*, 2002, Gouse *et al.*, 2004). For instance, the study by Huang *et al.* (2003) in China indicated that the labour costs for Bt cotton were on average 11% lower than for non-GM cotton. Results of Crost *et al.* (2007) indicated that labour input in India reduced with 8% when switching from non-GM to Bt cotton. Bennett *et al.* (2006) even found a reduction of 53% in labour costs in India. Gouse *et al.* (2004) suggested that particularly small-scale farmers experience benefits from labour savings, since they perform most farming activities by hand, which is time-consuming. Large-scale farmers, in contrast, benefit more from lower diesel and tractor costs and managerial freedom (Gouse *et al.*, 2004). Nevertheless, there is some controversy in reported effects on labour (and machinery) costs. Several sources reported that the time saved with reduced pesticide applications is at least partly offset by more time required for harvest due to higher yields (*Tripp, 2009*; Smale *et al.*, 2006, Qaim & De Janvry, 2003, Bennett *et al.*, 2004b).

In a study on Indian farm households, Bt cotton was shown to increase family income (based on a survey in 2004). Bt cotton production leads to more female labour input but less male labour input. However, male family members can efficiently re-employ their labour in alternative agricultural and non-agricultural activities (Subramanian & Qaim, 2009). Positive effects are larger for large-scale farmers than for small-scale farmers; the former type of farmers had a higher opportunity income because they are better educated.

Conclusion

Bt cotton on average increases farm income, caused by an increase in revenue and/or a decrease in pesticide costs. High technology fees in certain countries reduced the benefits for the respective farmers. Year-to-year fluctuations in pest pressure, local circumstances, and farmers' common practice cause considerable variation in the actual farm income benefits and may incidentally lead to a negative net effect on farm income. Differences between large- and small-scale farmers occur, but do not consistently favour one group over the other.

4.4.2 National income

The analysis of the introduction of GM cotton will differ from that of the introduction of GM maize or soy since it does not involve the consumer issues related to differential adoption rates associated with GM food, and the environmental and farmer health contributions are positive (see section 4.3). Moreover, being an important input into the textiles industry, large cotton producers in large textile-producing countries (developing Asian countries) export only a small fraction of their crop in contrast to countries where textile production is relatively minor (Sub-Saharan Africa and Central Asia) (Anderson *et al.*, 2008).

THEORIZED EFFECTS
As discussed in Chapter 1, the introduction of GM crops influences income at the sector or national level in various ways. First, the introduction of GM cotton is likely to have an impact on producer (output) prices since the introduction has an impact on yield (positive) and inputs costs (negative). Farmers may in this case be expected to switch from non-GM cotton to GM cotton, but also from other arable crops to GM cotton. As a result, the supply of cotton will increase and the price of cotton will drop. While for GM cotton growers, the income decrease is compensated by the savings in inputs, Non-GM cotton growers face a reduction in profits. The decreases in costs per unit and prices of cotton may cause major shifts in production and trade patterns away from non-GM cotton in favour of GM cotton, and in favour of the textiles industry since cotton is an important input for this industry.

Second, cotton market changes may lead to major shifts in employment and land use. An increase in the amount of land used for cotton production may lead to a decrease in the amount of land available for other arable crops, but also for nature.

Third, in response to changes in production of and trade in GM cotton, changes in the exchange rate and non-cotton imports and exports may occur. In terms of overall welfare, net importers of GM cotton are likely to benefit from lower prices, whereas non-adopting exporters would lose out from the increased competitiveness. If the adverse terms of trade effect, *i.e.* rise of prices of imports relative to prices of exports, is strong enough compared to the production and export expansion, net exporters of GM cotton may also lose out. In that case, due to changes in the exchange rate, prices of all products from net exporters of GM cotton increase, which makes import from these countries less attractive. Empirical analysis is needed to see how these effects balance out.

Evidence of differences between GM and non-GM cotton

Macro-economic effects of GM crop adoption have largely been studied through (ex ante) modelling studies. The GM crops evaluated in this and other chapters, i.e. soybean, maize, and cotton, are major, internationally traded commodities. Moreover, GM and non-GM crops are often imperfect substitutes for each other, causing market segregation between products that have been produced with GM material and products that have not. For these reasons, general equilibrium models, which account for international trade linkages and linkages with multiple sectors, are of particular relevance in studying effects on national income (*Smale* et al*., 2009*). Therefore, the review below mainly contains references to studies applying general equilibrium models. One such model, which is widely applied, is GTAP. Concerning the general equilibrium studies, the reader has to bear in mind that presented quantitative figures should be interpreted trend-way, because model studies are based on assumptions and are by definition a simplification of reality. Yet, specific results highlighted may be different. be We come back to the use of models in the discussion chapter.

Anderson *et al.* (2008) modelled the introduction of GM cotton (Bt Cotton) via an increase in total factor productivity (TFP) for cotton of 5% for most new adopting regions, using the standard GTAP model, however allowing for a productivity rise of 15% for regions with a large yield potential (Sub-Saharan Africa excluding South Africa, and India).[21] The authors reported the results of three GM cotton adoption simulations. In the first simulation the US, China, Australia and South Africa adopt GM cotton, which reflects the effects that had already taken place by 2001. The factor productivity increase in China was set at 2.5% as the adoption process in this country was only half way at that time. Results of the simulation show that due to the productivity rise, producer prices for cotton drop in the GM producing countries and output expands. As a result, world prices of cotton decrease by 2.5% on average, leading to output and export contractions in the non-adopting regions, including the EU. Value added in cotton production decreases, particularly in non-adopting regions. Value added also decreases in the US and China, due to the decrease in production and export prices. Yet, this decrease would have been much worse if farmers in these countries had not adopted GM cotton. China experiences a decline in cotton exports because its domestic textiles production expands following the decrease in raw cotton prices. In a second and third simulation, an increasing

[21] Several global impact studies on the introduction of GM cotton have been carried out (for an overview see Qaim, 2009). Differences across studies partly reflect differences in the version of the basic model used. We report the results of the most recent study that is available, namely Anderson *et al.* (2008).

number of countries adopts GM cotton. TFP increases by 5%, except for India (where it is 15%) and China (where it is 2.5%). In the third simulation the rest of Sub-Saharan Africa also adopts GM cotton and thus experiences a 15% TFP shock. Results show that if all other countries, except Sub-Saharan Africa, adopt GM cotton, cotton output in the early adopting countries (and so exports and value added) declines in response to the cotton-output expansion of the new adopters. With Sub-Saharan Africa not adopting GM cotton, its cotton output, value-added and exports decline even further compared to the first simulation. If Sub-Saharan Africa would adopt GM cotton, its cotton output, exports and value added would expand by more than any other (by 26.9%, 22.3% and 10%, respectively). Also global exports of cotton decrease more in these last two simulations (by 5.3% and 6.2% respectively) since more cotton would be grown in regions where it is also consumed if more developing countries adopt GM cotton.

Elbehri & MacDonald (2004) evaluated the impact of Bt cotton adoption in West and Central Africa (WCA). They compare the status quo, in which WCA suffers from a negative total factor productivity rate of -2.3% (due to higher production costs and declining production efficiency), with a scenario in which WCA adopts Bt cotton and experiences a productivity shock of 5.29%. Productivity rates are based on (partially) empirical data. Under the status quo, production output in WCA falls with over 7% and domestic cotton prices increase due to higher production costs. Exports decrease with 14% because production in adopting countries increases and causes a global price decrease. Land use in cotton declines and labour moves out of cotton and into other crops. In contrast, under the adoption scenario cotton output would increase and prices would decrease, but less than productivity increases. Compared to the status quo, land use and employment are moved into cotton. Output in textiles and clothing industry also increases, and exports expand with almost 10% instead of decreasing. Under the status quo, WCA would experience a welfare loss of over 87 million USD, while under the adoption scenario, the region would gain almost 82 million USD.

Frisvold *et al.* (2006) developed a three-region partial equilibrium model to estimate impacts of Bt cotton adoption in the US and China (defining the Rest of the World (ROW) as a third region). They concluded that Bt cotton adoption leads to increased cotton production and consumption, while reducing prices. The ROW increases consumption and reduces production at increasing imports. If only the US adopts, production also decreases in China and imports increase. If, on the other hand, only China adopts, production in the US remains the same, due to a highly inelastic US supply function and the government price support for US cotton producers. According to the results, The impact of adoption in both the US and China is nearly identical to the sum of effects of individual country adoption.

Conclusion

The model studies reviewed project the introduction of (amongst others) GM cotton to cause a shift in production (and income) from non-adopting to adopting regions, and to lower cotton prices. Export volumes decrease more if more developing countries adopt GM cotton, since they (and particularly developing Asian countries) are at the same time large consumers of cotton as input into their textiles industry. These results support the theorized effects, except that no reported interactions with the environment (land use) have been found.

4.4.3 Economic welfare distribution

THEORIZED EFFECTS

The macro-economic changes described under 4.4.2 cause changes in the welfare generated through cotton production. These changes apply not only to total welfare, but also to the welfare distribution, both vertically (between different stakeholders of the production chain) and horizontally (between different regions or countries in the world). Concerning vertical welfare distribution, the introduction of GM crops has led to changes in farmers' relation vis-à-vis their suppliers and their customers. With respect to horizontal welfare distribution, some adopting countries may benefit more, or experience more disadvantages from adopting GM crops, than others. Examples of factors affecting horizontal and vertical welfare distribution are country-dependent adoption levels, the level of IP protection, GM regulations, and consumer preferences. Below, we will first discuss horizontal welfare distribution, followed by vertical welfare distribution.

Horizontal welfare distribution

The introduction of GM cotton as modelled by Anderson *et al.* (2008) resulted in different welfare effects across regions. Table 4.6 displays the total welfare changes for different numbers of countries having adopted Bt cotton. Up to 2001, with producers in the US, China, Australia and South Africa adopting GM cotton, the estimated overall welfare gains of the introduction of GM cotton amounted to 742 million USD per year. Global welfare rises to approximately two billion USD per year if developing countries excluding Sub-Saharan Africa (SSA) would adopt GM technology in the production of cotton, and even higher with adoption in SSA. Adopting countries gain despite negative terms of trade effect and a negative resource allocation effect (i.e. reallocation of resources from sectors that were less assisted by governments than cotton). Non-adopting countries also benefit, mainly from the improvement in their terms of trade and an increase in imports. The exception is Sub-Saharan Africa (excluding South Africa), which experiences losses from resources moving to sectors in which it is less good at and losses from lower prices on its cotton exports. As more countries adopt Bt cotton, also Australia experiences welfare losses due to the fall in its cotton export price. In contrast, South Asia (including India) experiences major welfare gains, being a large producer of both cotton and textiles. If Sub-Saharan Africa (excluding South Africa) were to adopt Bt cotton, it would experience major welfare gains, capturing two thirds of the total global welfare gains that their adoption would cause.

Comparing these numbers to the countries' Gross Domestic Product (GDP) reveals the relative impact of GM cotton in each country. When welfare change is expressed as percentage of the GDP, the relative gains to Central Asia, Sub-Saharan Africa and South Asia are 0.048%, 0.091%, and 0.158%, respectively, which is 10, 13, and 23 times higher than the global gains (0.007%) (Anderson, 2010).

Table 4.6. Effects of GM Cotton Adoption as of 2001 on Welfare (Equivalent Variation, US$ million). Source: Anderson et al. (2008).

	First adopters only	New and prospective adopters excl. SSA	All new and prospective adopters
Adopters as of 2001 (first adopters)			
United States	324	61	57
China	162	113	100
Australia	26	-14	-28
South Africa	2	5	12
Non-adopters/new and prospective adopters as of 2001			
Other high income countries (incl. EU)	147	271	337
Eastern Europe and Central Asia	5	325	317
Southeast Asia (excluding China)	36	31	63
South Asia	14	964	970
Middle East and North Africa	14	157	175
Sub-Saharan Africa (excluding South Africa)	-17	-18	187
Latin America and Caribbean	29	124	135
World	742	2,018	2,323

According to the results of Frisvold *et al.* (2006), Bt cotton adoption in the US and China causes a global welfare increase of over 800 million USD (representative for the year 2001). China contributes 51% to this welfare increase, mostly because of an increase in producer surplus. The ROW captures only 8% of the gain, with consumers winning and producers losing. Welfare increase is larger in China than in the US, because Chinese farmers started from a situation of less effective pest control.

Elbehri & MacDonald (2004) show the effect of WCA adopting Bt cotton on other adopting and non-adopting countries and regions. All adopting regions experience a price drop; the magnitude of this decrease depends on factors such as relative size of cotton production, imports and exports, and intersectoral price linkages. All regions not adopting Bt cotton experience a decrease in cotton output, lower domestic cotton prices, and reduced export. Aggregate welfare is positive for most regions, except for certain non-adopting Asian countries that suffer from worsened terms of trade because they are net exporters. China experiences relatively large welfare gains, because farmers benefit from increased factor productivity, while the country as a net importer does not experience terms of trade losses.

Gruère et al*. (2007)* perform a general equilibrium modelling analysis on the adoption of GM maize, soy, and cotton, with special focus on India, Bangladesh, Indonesia, and the Philippines. They assume production of these crops in the countries that had adopted them by 2005. Using initial adoption rates in these countries (i.e. the level of GM crop production in the first years after adoption), they come to a global welfare gain of 4.4 billion USD. Of all countries in the world, India experiences the largest relative gains, a welfare increase of 0.07 percent (254 million USD). Total gains are reduced to 2.7 billion USD when applying a trade filter representing trade restrictions in GM-sensitive countries. These losses come mostly at the stake of GM-sensitive countries. Under a scenario with more countries adopting GM crops at a higher rate, global welfare gain increases to 5.1 billion USD. In this case, the highest relative gains (0.3 percent, 44 million USD) are obtained by Tanzania and Uganda. Of the four countries with a special focus in the study, only the first three are assumed to adopt – amongst others – GM cotton.

Vertical welfare distribution

A number of researchers have studied the distribution of the welfare gains of GM cotton (and other GM crops) over the respective stakeholders. *Price* et al. *(2003)* used a spatial (partial) equilibrium model to analyze the worldwide welfare effects of US Bt cotton production in 1997. World benefit was valued at 200 to 300 million USD, depending on the data source used. The main actors gaining from Bt cotton were technology suppliers and US farmers, capturing 35 and 29 percent, respectively. Consumers in the US and the rest of the world had a larger share than was the case for HT soybeans, because Bt cotton adoption causes a larger increase in factor productivity and thus has a larger price effect. For the same reason, welfare losses for farmers outside the US (i.e. non-adopters) were larger than was the case for HT soy. For HT cotton, the net welfare gain from US production as estimated by *Price* et al*. (2003)* was 230 million USD, similar to that from Bt cotton. Welfare distribution among the different stakeholders was much different, however. The authors calculated a drop in world prices of 3.4 percent from HT cotton adoption in the US, as compared to 0.7-1.1 percent decrease from Bt cotton adoption. As a result, much of the welfare gains accrued to consumers. US farmers only gained a small welfare increase, and technology suppliers also had a relatively small share in total welfare gains.

Trigo & Cap (2006) used a dynamic simulation model to evaluate distribution of national welfare gains in Argentina. Their results are representative for the 1996-2005 period. The authors assumed a 30% yield increase per hectare under Bt cotton adoption, due to reduced losses from insect pests. Argentine farmers turned out to have by far the largest share in total net benefits, namely 86%. Technology providers had a share of 8%, based on a price difference of 54 USD between conventional and Bt cotton seed. The national government had a share of 5%, due to the tax levied on exports.

The results of *Price* et al. *(2003)* and *Trigo & Cap (2006)* are supported by a study on the Bt cotton seed market in India, which states that – despite a major increase in seed prices in the first years after introduction – farmers on average have gained substantially from Bt cotton (Murugkar *et al.*, 2007). The study also showed that the leading position of MMB (a joint venture of Monsanto and Mahyco) in the Bt cotton seed markets has not withheld other seed companies to put Bt cotton seeds on the market. At the time of the study, 20 firms had licenced Bt genes from MMB. Even for small firms, the licence fee and subsequent R&D investments was not consedered an entrance barrier.

Frisvold *et al.* (2006), in their study on adoption in the US and China, highlight the potential differences in vertical welfare distribution between countries. In the US, more than 80% of the welfare gains go to the seed suppliers as profit from technology fees. In China, no quantitative information was available for the year of analysis (2001), but surplus for seed suppliers was presumed to be close to zero. Motivations for this assumption are a greater formal competition in the seed sector and farmers saving and replanting Bt seed. Nevertheless, the authors suggest that the increase of Bt cotton adoption in this country may affect the surplus for the seed suppliers, requiring a new investigation. In addition to a stronger position of the seed suppliers, welfare gains in the US are also affected by the government payments to cotton producers. If only the US were to adopt Bt cotton, these payments would account for 82% of the gains in producer surplus. In the scenario of both the US and China adopting, US farmers would experience negative welfare effects in absence of the price support. In effect, the government payments redistribute welfare gains from tax payers (consumers) to the farmers.

Since 75% of the global poor are rural labourers or smallholder farmers, the introduction of GM technology may have implications upon poverty and income distribution in developing countries. If only rich farmers would benefit, inequality would rise. If smallholder farmers would benefit, the poverty and distribution effects may be positive. This depends not only on the technology itself, but also on the institutional environment. According to Qaim (2009) smallholder farmers have not widely adopted HT crops, since they often weed manually. Bt crops are mostly grown by smallholder farmers, which seem to benefit at least to the same extent as larger-scale producers. There are however few studies that analyze the impact upon employment, poverty and income distribution. An exception is the study by Subramanian & Qaim (2010), which analyzed the welfare and distribution effects of the introduction of Bt cotton in rural India. They found that an additional hectare of Bt cotton generated an increase in aggregate income of 82% relative to non-GM cotton, of which rich farmers benefited most and the landless and poor farmers benefited least. They nevertheless found that all farm household types (including the poor) benefited significantly more from Bt than from non-GM cotton. These results suggest that Bt cotton may contribute to poverty reduction and rural development in absolute terms, but not in relative terms, provided that it is usable and accessible by smallholder farmers.

Conclusion

Welfare effects of introducing GM cotton (Bt cotton) are shown to be generally very positive across all countries/regions in the world, and considerably higher as more countries adopt the technology. Particularly regions with a large production of both cotton and textiles, e.g. South Asia (including India), experience welfare benefits. GM adopters as well as non-adopters experience welfare gains, with few exceptions. Vertical welfare distribution in a country depends amongst others on the level of IP protection: technology suppliers receive a higher share as IP protection gets stronger. In a competitive market, consumers receive a larger share as the total welfare gain increases. Bt cotton may contribute to poverty reduction and rural development, provided that it is usable and accessible by smallholder farmers.

4.4.4 Financial and other risks

Production risks

Bt cotton decreases variability in output and thus decreases production risk. However, uncertainties regarding its effectiveness in bollworm control have led to suboptimal economic benefits. In China, many Bt cotton varieties are available, against different price levels. Cheaper varieties generally provide lower protection; however, even higher priced varieties sometimes show poor performance. A high seed price thus does not guarantee effective control. Uncertainty regarding inputs hinders optimal resource allocation because, when decisions are made, natural conditions change and previously optimal decisions may become suboptimal with new information (Antle, 1983). As a consequence, Chinese farmers only partly substituted Bt varieties for chemical insecticides (Pemsl *et al.*, 2005).

Institutional risks

In the soy and maize chapters, institutional risks mainly comprised uncertainties regarding market access of GM commodities. With cotton, this risk comprises less of an issue as the main Bt cotton product, fibers, do not enter the feed or food chain. Nevertheless, biosafety regulations may retard the adoption of GM crops in countries, resulting in potential losses for farmers in those countries. Empirical evidence for this effect is mostly absent.

However, Pray *et al.* (2005) found that acceleration of the approval of Bt cotton in India by two years would have improved farm income by 100 million USD.

Experiences in several countries illustrate how local institutional failure can limit the adoption of Bt cotton (Raney, 2006). In Argentina, a very high technology fee discouraged cotton growers to switch to Bt cotton. The excessively high seed prices have probably contributed to the widespread use of illegal seeds for Bt cotton cultivation in Argentina. Therefore, although being profitable for farmers in the short run, the use of illegal seeds will retard technological progress in the longer run (Qaim & De Janvry, 2003). In South Africa, on the Makhathini Flats, Bt cotton seed was initially supplied on credit by a private company, Vunisa, which was also the sole buyer of harvested cotton at the time of introduction. Credit risk was shared between Vunisa and the Land Bank. The institutional arrangements worked well until a second company (Makhathini Cotton) entered the market, which enabled farmers to avoid repaying their loans for obtaining seeds by selling their harvests to this new company. As a result, Vunisa quit offering Bt seed on credit, and Bt cotton acreage declined considerably (Gouse *et al.*, 2005a). In Mexico, Monsanto has successfully avoided such institutional failures by introducing field inspections on the illegal use of Bt seed (with high penalties) and by contracting all gins as ‘authorized Monsanto cotton gins’. Farmers of Bt cotton are contractually obliged to have their cotton ginned at Monsanto-authorized gins (Traxler & Godoy-Avila, 2004).

Legal risks

To ensure the safety of novel (e.g. GM) food, countries all over the world have developed laws and institutions to regulate GM crops. However, many smaller developing countries have not been able to put a biosafety regulatory system in force so far. Biotechnology companies are reluctant to sell their products to such countries to avoid the liability risk of being held responsible for the unregulated introduction of Bt crops. As a result, farmers in these countries are not able to grow Bt crops (*Qaim* et al*., 2008*). This issue is particularly relevant for Bt cotton, which is an important crop in many developing countries.

Financial risks

For farmers in countries where cotton yields are relatively low because of suboptimal pesticide use, Bt cotton may decrease financial risks. Particularly smallholders often have limited resources and have more difficulties to obtain credit for financing inputs as seed and pesticides. As a consequence, reducing the need for pesticides decreases smallholders’ dependency on access to credits and thus decreases yield losses (Gouse *et al.*, 2005a, Zilberman *et al*, 2007). Whether this is actually the case depends amongst others on the financing structure of inputs and the financial resources that farmers have for purchasing more expensive seed at the start of the season. In certain parts of India, crop protection agents are supplied to farmers on credit, while farmers must pay directly for seed (Kambhampati *et al.*, 2005), discouraging the use of more expensive seeds. The situation is different in countries where the main benefit from Bt cotton adoption comprises a yield effect, rather than reduced pesticide use. Particularly if Bt seed costs are relatively high, farmers in these countries experience an increase in production costs, which intensifies the financial risk they face (Qaim & De Janvry, 2003).

Conclusion

Bt cotton reduces production risk, provided that the seed meets the quality criteria. Financial risks may decrease or increase for small-scale farmers, depending on whether they have difficulties in financing seed, pesticides, or both. Institutional risks occur mainly due to country-specific circumstances regarding seed supply. Institutional risks related to (lack of) safety regulations can lead to legal risks for companies introducing GM cotton, which in turn may exclude farmers in certain countries from GM cotton adoption.

4.5 GM-related sustainability – People

Millions of (small-scale) farmers in China and India cultivate Bt cotton. Herbicide-tolerant cotton (RR and LL cotton) is primarily cultivated by a relatively small number of (large-scale) farmers in the US, Argentina, Australia and Mexico. The focus of this section is mainly on the sustainability impacts of Bt cotton as this trait is more widely used in cotton than herbicide-resistance traits and as most people issues are present in developing countries, such as China and India.

A source which is frequently used in the analysis is the publication edited by *Tripp, 2009*. 'Biotechnology and agricultural development; transgenic cotton, rural institutions and resource-poor farmers', which analyzes existing studies on the subject of Bt cotton and the effects on (resource-poor) farmers and contains case studies (original studies or reviews of the data and experiences available) that examine the performance of transgenic cotton in four developing countries; India, China, South Africa and Colombia.

4.5.1 Labour conditions

In general the cotton industry is labour-intensive (*Tripp, 2009, Venkateswarlu, 2007*) and is characterized by high levels of production inputs, particularly chemicals and fertilizers (*Carpenter* et al.*, 2002*). Cotton production and cotton seed production are often associated with child labour, the exposure of farmers and labourers to harmful crop protection agents (*Tripp, 2009*) and other chemicals used during processing *(Slater, 2003*). Thus, the impact of GM cotton cultivation on labour conditionswill be treated below under the separate headings, child labour, occupational health, employment opportunities, and wage levels and non-discrimination.

Child labour

General situation in cotton production

Six of the world's top seven cotton producing countries (China, India (see also Venkateshwarlu & Da Corta, 2001), Pakistan, Brazil, Uzbekistan and Turkey) have been reported to use children in the field (*EJF, 2007*). Child labourers are involved in sowing and picking of cotton, weeding, hoeing, the removal of pests (spraying of pesticides) and in the transportation (carrying) of heavy loads (*EJF, 2007*). Particularly for the production of hybrid (Bt) seed, child labour is often used for cross-pollination as labour is intense and the intricate process is easier the smaller the worker's fingers (*Venkateswarlu, 2007*). Children are often forced to work, as for example in Uzbekistan where children are forced by the government to conduct seasonal work (*Kandiyoti, 2008*; Carley, 1989), and/or have to perform tasks that can damage their health, safety, well-being, education or development (*Kandiyoti, 2008*; *EJF, 2007*). Children may be subjected to beatings, threats of violence, and overwork (*EJF, 2007*). Children are often trapped in debt-bondage due to loans extended to their impoverished parents, while others are only guaranteed payment – usually very low sums – at the end of several months' work (*EJF, 2007*). Bonded labour of adults due to debt bondage also occurs (*Busse & Braun, 2002*). Farmers in India state that with the current procurement prices of companies, they cannot afford to pay better wages to labourers and still make reasonable profits (*Venkateswarlu & Da Corta, 2005*; *Khandelwal* et al.*, 2008*).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
The use of Bt cotton could possibly result in a reduction in the use of child labour as a consequence of a change in farmer's income and labour intensity. A higher farmer's income due to Bt cotton cultivation (due to higher yields and reduced costs for pesticides, see 'Profit' section 4.4.1) and a reduced risk of crop failures (contributing to a more stable income) could possibly result in employment of adults instead of children, contributing to a reduction in the use of child labour. However, this does not mean that once procurement price of Bt cotton indeed is increased, farmers will automatically shift to adult labour and pay better wages to labourers (*Venkateswarlu & Da Corta, 2005*; *Khandelwal* et al.*, 2008*). Bt cotton may require less labour inputs than non-GM cotton (see section 4.4.1), since in general, less crop protection agents (pesticides) are used, which are, in the case of small-scale farmers, usually applied by workers in the field. This may also contribute to a reduction of the use of child labour. On the other hand, profits will be higher when the use of child labour remains unchanged and in case now unemployed adults send their children to conduct work, it may also contribute to an increase of the use of child labour. Thus, a consistent impact on the use of child labour is not expected.

Summary of theorized impacts of Bt cotton versus non-Bt cotton
A higher farmer's income and less need for labour for Bt cotton could possibly result in a reduction in the occurrence of child labour, but it is doubtful whether there is a consistent effect.

Evidence of difference between GM and non-GM production

Data on child labour are reported at regional levels, which does not provide specific enough information to make comparisons between Bt-cotton and non-Bt cotton cultivation. For example, with the introduction of Bt cottonseed in India in 2002, it was expected that the incidence of child labour would drop. However, in 2007, the trends in employment of child labour in hybrid cottonseed production in different states in India clearly indicated that the overall number of children employed in the hybrid cottonseed industry was on the rise (*Venkateswarlu, 2007)*. According to *Venkateswarlu (2007)*, this was due to an increase in the total area under cottonseed production in the country, which is largely attributed to the shift from traditional hybrids to Bt-cotton hybrids and favourable climatic conditions. More specifically, after the introduction of Bt-cotton in 2002, the demand for Bt-cotton hybrids substantially increased. As the demand for Bt-cotton increased, the area under Bt-cotton seeds also increased resulting in an additional demand for labour for production of seeds. *Venkateswarlu (2007)* has estimated that the total number of children (below the age of 14) employed in cottonseed farms in Gujarat, Andhra Pradesh, Tamilnadu and Karnataka states (which account for nearly 92% of the total production area in the country) in 2006-07 was 224,960 compared to 200,675 in 2003-04 (*Venkateswarlu, 2007*). In the 2006-07 cultivation season, nearly 416,460 children under the age of 18 were employed, the majority of them (54%) younger than 14 (*Venkateswarlu, 2007*). According to *Venkateswarlu (2007),* several Indian companies and multinationals were involved in this. In 2007, the biggest among them, the Indian companies Nuziveedu, Raasi, Ankur and Mahyco, made use of around 200,000 children, who were employed by the farmers to which they have sub-contracted the cultivation of Bt-cotton seeds (*Venkateswarlu, 2007*). Children were employed on a long-term contract basis through advances and loans extended to their parents by local seed producers, who had agreements with the large national and multinational seed companies. Children were made to work long hours (8 to 12 hours) and were paid less than market and official minimum wages (*Venkateswarlu, 2007*).

While the total number of children employed in the hybrid cottonseed industry in the four states mentioned above increased, the total number of children employed in the industry per hectare in the four states, slightly decreased in 2006-07 compared to 2003-04 (*Venkateswarlu, 2007*), which makes it difficult to draw conclusions about any differential effects of Bt-cotton on the incidence of child labour.

New research by *Venkateswarlu (2010*) indicates that, although the total acreage of cottonseed production in India has increased, child labour (children younger than 14) in the Indian cotton seed industry has decreased by 25% since 2006-07 as a result of initiatives by government, seed companies, international and local organizations. Yet, with around 170,000 children below 14 years and around 212,000 children from 15-18 years (this category increased), child labour is still a major issue in cottonseed production. In areas where Bayer and Monsanto have substantial control over the cottonseed production, the large reduction in child labour was the result of combined efforts of these companies, civil society groups and local government to address the issue of child labour on the suppliers' farms (*Venkateswarlu, 2010*).

These efforts by NGO's, government and companies are probably also directed at non-GM cotton seed production (the research by *Venkateswarlu (2010*) does not make a specific distinction between the effects of Bt-seed companies and non-GM seed companies). However, the initiatives undertaken by the Bt-seed companies Bayer and Monsanto have great potential to influence other Bt-seed companies to implement measures to address the problem of child labour in their supply chain and pave the way for broader initiatives. Monsanto, as the supplier of Bt technology to all the leading companies in India (including Mahyco in which Monsanto has a 26% share), could play an important role in this (*Venkateswarlu, 2010*). So, although efforts to reduce child labour are not Bt cotton-specific, the efforts of large Bt companies may have a significant impact on the use of child labour in cotton production in general.

Conclusions for Bt cotton versus non-Bt cotton

No sufficiently specific information was available to support or reject the theorized impacts. A Study from India from 2007 indicated that Bt cotton provided for an increase in the occurrence of child labour since 2002 due to an increase in the total area of (Bt) cotton seed production. The number of child labourers per hectare decreased according to the study. According to a study from 2010, the recent trends in employment of child labour in hybrid cottonseed production in India indicate that despite an increase in the production area, the number of children employed in this sector is declining.

Occupational health and safety

General situation in cotton production

Cotton production often involves the use of crop protection agents such as organophosphates and pyrethroids that may have a relatively large impact on human health and the environment, in comparison with other crop protection agents (see section 4.3.1.3). The use of hazardous chemicals can cause poisoning and possibly death of cotton farmers (*Kooistra* et al*., 2006*). A study by the 'Sustainable Development Policy Institute' (SDPI) conducted on the health effects of pesticide application in Pakistani cotton cultivation found that 74% of (female, also children) cotton pickers were moderately pesticide-poisoned, while the remaining quarter had reached dangerous levels of poisoning. The result is chronic pesticide poisoning (*Siegmann, 2004*). In addition, the availability and promotion of cheap broad spectrum insecticides has led to high dependence, which in turn promoted the emergence of insecticide resistance and the decline or disappearance of many natural enemies that formerly helped to control pest insects (*Tripp, 2009*), thus creating potential problems for farmers. Most studies indicate that for Bt cotton lower amounts of crop protection agents, such as organophosphates and pyrethroids, are used. The magnitude of the reduction in the use of pesticides varies (see section 4.3.1.3).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

With decreased use of biocides in Bt cotton, worker exposure to crop protection agents is expected to decrease. Mainly in developing countries, working conditions are expected to improve when Bt cotton is used due to reduced accidents, spillage and exposure to toxic insecticides, as the workers are often poorly protected there. In the US and Australia, the exposure of workers to pesticides is low already and the use of Bt cotton will probably have little effect. By reducing the use of relatively toxic insecticides Bt cotton could also have a positive impact on the quality of the (drinking) water that farmers and workers use (see section 4.3.3).

Summary of theorized impacts of Bt cotton versus non-Bt cotton

Worker exposure to crop protection agents is expected to decrease for Bt cotton, mainly in developing countries. A positive impact on the quality of (drinking) water resources is expected.

Evidence of difference between GM and non-GM production

A reduced insecticide use has brought health benefits for Chinese field workers (Huang *et al.*, 2002). The study by Huang *et al.* (2002) quantified the effects of agrochemical poisoning in a comparison of Bt cotton with non-GM cotton in China. It showed that in China 12 – 29% of the farmers suffered from poisoning due to the application of insecticides in the non-GM cotton industry. In the Bt cotton industry this percentage was lower, namely 5-8%. The study by Huang *et al.* (2002) also stated that the reduction of the use of pesticides for Bt cotton had significant implications for the quality of drinking water. Another (modelling) study also provides evidence for a reduction in pesticide poisonings due to Bt cotton in China (Hossain *et al.*, 2004). Bennett *et al.* (2003) have analyzed the health effects of Bt cotton in South Africa. They came to the conclusion that with an increase in the cultivation of Bt cotton among smallholder farmers, the reported rates of accidental insecticide poisoning have been declining (reviewed in *Qaim* et al*., 2008*).

Conclusions for Bt cotton versus non-Bt cotton

Three studies, two in China and one in South Africa, show reductions in pesticide poisoning for Bt cotton through a reduced insecticide use. The reduced use of pesticides may also impact positively on the quality of drinking water for farmers as was stated in a Chinese case study.

Employment opportunities

General situation in cotton production

In general the cotton industry is labour-intensive (*Tripp, 2009, Venkateswarlu, 2007*). Bt cotton is estimated to provide higher yields than non-GM cotton, providing farmers with more returns per hectare (see section 4.3.1.1) and reduced yield losses and yield uncertainty.

THEORIZED IMPACTS OF GM VS. NON-GM PRODUCTION

Bt cotton may require less (seasonal) labour inputs than non-GM cotton as less pesticide spraying is needed. Increased yields of Bt cotton will require more (seasonal) labour for harvest. Since the harvesting in some areas, such as in India, is mostly a women's (and children's) job (*Qaim* et al*., 2008*), while spraying is a men's job, this will influence the gender division in the sector. The net effect on labour inputs resulting from increased yields and reduced use of pesticides is hard to predict, but replacement of insecticide spraying by harvesting or other activities is considered as an advantage. However, a net effect could be (seasonal) unemployment for workers, which could possibly lead to migration of workers. Whether this should be perceived as a negative impact from a 'People' point of view will depend on the job alternatives available to the workers that become unemployed. This may be influenced by the level of education and skills of the workers and will differ per country and region. On a macro-economic level, shifts in employment from rural areas to urban areas and from low-skilled work to higher-skilled work may be perceived as a sign of economic development. However, on a micro-level, increased unemployment may contribute to poverty. At the same time, a reduction in labour inputs will lead to lower labour costs and increased profits for farmers (see section on farm income, 4.4.1). In this regard, It could also be hypthesized that there will be more jobs available for adults in Bt cotton due to a higher farmer's income resulting in employment of adults instead of children and higher labour costs for farmers (see under the subheading of 'Child labour' above).

Summary of theorized impacts of Bt cotton versus non-Bt cotton

Although the use of Bt cotton is generally expected to be less labour intensive than non GM-cotton, the net effect of Bt cotton on employment opportunities resulting from increased yields and reduced use of pesticides is hard to predict. It may vary between farms/regions/countries. A shift in the labour profile is expected as spraying activities decrease and harvesting activities increase. Since harvesting in some areas, such as in India, is mostly a women's job, while spraying is a men's job, this will influence the gender division in the sector.

Evidence of difference between GM and non-GM production

As reported in section 4.4.1, based on several papers, it is acknowledged that Bt cotton can provide for a reduction in labour used for spraying in both large-scale and small-scale conditions. This could however be compensated by more harvest labour due to higher yields. A study by Subramanian & Qaim (2009) analyzed the economy-wide effects of Bt cotton for rural households in semi-arid India by developing and using a micro-social accounting matrix (SAM) for one village, representative for the semi-arid tropics in India. The model shows that overall the Bt-cotton technology is generating employment, that is, it led to more female labour input but less male labour input (see under 'Other effects on farm income' in section 4.4.1 and also see under subheading 'Wage levels and non-discrimination' below). Thus, on balance, family labour in cotton production is saved, but it is re-employed efficiently in alternative activities.

Results of the study by Elbehri & Macdonald (2004) that evaluated the potential impact of Bt cotton on West and Central Africa using a multiregion general equilibrium model and multicountry estimates of Bt cotton-induced productivity (GTAP), show that by a reduction in season labour from lower pesticide applications, the Bt technology helps channel some of this labour to other products, such as food crops. This, in turn, reduces labour shortage constraints in food crops hence improving food crop yields and overall farm productivity.

Conclusions for Bt cotton versus non-Bt cotton

In several papers, it is acknowledged that Bt cotton can provide for a higher labour productivity due to a reduction in labour used for spraying. This could however be compensated by more harvest labour due to higher yields. In an Indian modelling study, Bt cotton production led to more employment opportunities for women in harvesting and less employment opportunities for men in spraying. Saved family/male labour was re-employed efficiently in alternative activities.

Wage levels and non-discrimination

General situation in cotton production

Workers in cotton production generally receive low wages. In India for example, wages are often below wages in other agricultural activities (*Venkateswarlu & Da Corta, 2005*) and the average wage rate is much less than the legal entitlements of the workers (*Khandelwal* et al*., 2008).* Alternative sources of income are few, partially because unemployment is high in many cotton-growing regions (for Pakistan: *SDPI, 2008*) and, due to low levels of education, for women and children in particular. Educational limitations also weaken the bargaining power vis-à-vis their employers. Uneducated workers (especially children) are easily cheated on their (daily) wage (*Khandelwal* et al*., 2008*). Overall, it is difficult to negotiate better wages and working conditions. The fear of unemployment (normally without much support from social protection) and/ or bondage to debts, makes workers reluctant to challenge authority and insist on their rights (*Venkateswarlu & Da Corta, 2005*). The majority of workers are women/girls (in India for example harvesting is usually done by women/girls, *Qaim* et al*., 2008*), who often face discrimination in (amongst others) wages. In India, there is an important gender division in wage rates. Women's wages are far below men's (*Venkateswarlu & Da Corta, 2005*). Whilst there is little or no difference between wages for adult men and women if they do the same activity, they rarely do the same activity (*Venkateswarlu & Da Corta, 2005*). Women and girls also on occasion face sexual harassment (*Gent & Braithwaite, 2006*). Cases of sexual harassment and abuse of girls have been reported in cotton production in India, China and Pakistan (*EJF, 2007*).

THEORIZED IMPACTS OF GM VS. NON-GM PRODUCTION

The use of GM or non-GM cotton is not expected to have a consistent impact on wage levels and the occurrence of gender discrimination in cotton production. In theory, if employment in the sector changes (due to increased yields that require more labour for harvest, see above under subheading 'Employment opportunities'), this could have a positive impact on women's wages in areas such as India where harvesting is a woman's job. At the same time, in such areas, men's wages might decrease as a result of a reduced labour demand for spraying, which is mainly a men's job. A higher farmer's income due to Bt cotton cultivation (see section 4.4.1; due to higher yields and reduced costs for pesticides) and a reduced risk of crop failures (contributing to a more stable income) could possibly result in higher wages for farm labourers (or employment of adults instead of children, see above under subheading 'Child labour'). However, this is a purely theoretical impact as farmers could also opt for higher profits. Overall, it is not likely that there will be a consistent impact on wage levels.

Summary of theorized impacts of Bt cotton versus non-Bt cotton

Impact of GM production is not expected to consistently differ from non-GM production.

Evidence of difference between GM and non-GM production

The study by Subramanian & Qaim (2009) in India shows that beyond the direct impacts of cotton profits, labour market effects are an important component of the income changes caused by Bt technology. For poor and vulnerable farmers, higher returns to labour are due to *more employment* of female household members as hired workers on other farms, as well as *higher returns* to agricultural family labour in alternative employments (Subramanian & Qaim, 2010). The study by Subramanian & Qaim (2009) also shows that women benefit more from Bt-cotton than men due to the fact that (the increased) cotton harvesting is largely carried out by hired female labourers, whose employment opportunities improve remarkably. Pest control, on the other hand, is often the responsibility of male family members, meaning that Bt technology reduces their employment in cotton production. However, the SAM results (see above under subheading 'Employment opportunities') show that, on average, the saved family labour (in this case saved family male labour) can be re-employed efficiently in alternative agricultural and non-agricultural activities, so that — also for men — the overall returns to labour increase. This is an indirect positive effect of the use of Bt-cotton. Apparently, use of *family* male labour in cotton is associated with a significant opportunity income. Most of this opportunity income is realized in self-employed activities (*i.e.*, own agricultural and non-agricultural businesses) (Subramanian & Qaim, 2010). In contrast, Subramanian & Qaim (2010) find that the returns to *hired* male agricultural labour are lower in Bt than in conventional cotton, suggesting that there are fewer alternative employment opportunities for this category of workers. As a result, for landless households, effects on total household incomes are relatively small since especially the poorer landless households derive most of their income from employment as hired agricultural labourers. In this case, the higher employment of female workers in Bt cotton is almost offset by the lower employment of male workers. Overall, the study states that all types of households, including those below the poverty line, benefit considerably more from Bt than from conventional cotton (Subramanian & Qaim, 2010). An article by Subramanian *et al.* (2010)[22] that summarizes the above two studies by Subramanian & Qaim (2009 and 2010) states that compared with non-GM cotton, Bt cotton generates additional employment, raising the total wage income by 40 USD per hectare. The largest increase is for hired women with a gain of 55% from Bt cotton.

Conclusions for Bt cotton versus non-Bt cotton

An Indian modelling study shows that when looking at *income*, all types of households, including those below the poverty line, benefit considerably more from Bt than from conventional cotton, except for poorer landless households where net results are relatively small. This is a result from *more employment* for hired female workers (resulting from increased harvesting) and from *higher returns* to agricultural family labour in *alternative* employments. No evidence was found that (daily) wages in cotton production are higher when comparing Bt to non-GM cotton production.

[22] Correspondence in peer-reviewed journal.

4.5.2 Land rights, community rights and rights of indigenous people

General situation in cotton production

Land conflicts arise when land is not distributed well, and are often an indirect effect of various historical socio-economic and cultural factors (*Spoor, 2007*; *Grigsby, 2002*). So far, no land conflicts have been found that are specific to cotton. Some land conflicts include governmentally imposed land reforms that are either directed at cotton farmers or also affect cotton farmers (*Spoor, 2007*, Peters, 2004), and harassment by those who do not have access to land (Hammar, 2001). Cotton cultivation may increase the value of land, as for example happened in southwestern Burkina Faso where cotton has emerged as the single most important economic activity. Animal traction has replaced cultivation by hoe; extensification of land under (non cotton) cultivation led to land scarcity in the area before (Kevane & Gray, 1999). Sales of land that has now become more valuable may cause land conflicts in the future (*Mathieu* et al.*, 2003*). When land possession becomes more profitable, one would expect increased interest of more powerful individuals or companies, which might contribute to an increase in land conflicts.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
Bt cotton production itself is not likely to have a direct connection with land rights issues, except maybe for the fact that Bt cotton production may possibly encourage or facilitate larger-scale production (as a result of higher profits, see also section 4.4.1), which may result in an increased demand for land, in turn leading to land right issues. It is thus expected that Bt cotton has no or a minor impact on land rights, community rights and rights of indigenous people in general, as compared to non-GM cotton, and if there is an impact this will be difficult to measure.

Summary of theorized impacts of Bt cotton versus non-Bt cotton
It is expected that Bt-cotton has no or a minor impact on land rights, community rights and rights of indigenous people, as compared to non-GM cotton.

Evidence of difference between GM and non-GM production

Little information has been found that supports the existence of the relation between Bt cotton crops and land or community rights conflicts. In Pakistan, however, such a relation was reported; the Pakistan government negotiated land deals with Monsanto and other agro-chemical companies promoting genetically-modified crops, especially Bt cotton, leading to ‘land grabbing’ according to the organization ‘Roots for Equity’ (*Farmlandgrab.org, 2009*).

According to a study by Biowatch South Africa on the socio-economic impact of Bt cotton, Bt cotton appears to exacerbate the inequities in land access and ownership in South Africa (*Pschorn-Strauss, 2005*). In South Africa, there has been political tension over the years, with a history of displacement, political favouritism and resource disputes. Biowatch South Africa states that Bt cotton has contributed to political and land conflicts in the Makhathini Flats, in northern KwaZulu Natal, by favouring better-off farmers at the expense of the poor. Both national and regional governments have injected money into supporting the expansion of Bt cotton in this area. Government funding flows to a single company, Makhathini Cotton, that leases land from the farmers to plant Bt cotton on a large scale. The company has plans to hugely expand the area under irrigation, raising questions around water availability for other cultivations, among which food crops, and environmental impact on the floodplain. Makhathini Cotton employs farmers as labourers on their land after having leased it from them. In this way, farmers are becoming further removed from their land and knowledge (also see under technical lock-in and deskilling in section 4.5.3 on freedom of choice) and do not participate in the farming operations but apparently they can choose to be ‘employed’ in their own fields to do menial tasks, such as weeding. The company put in place a one-channel marketing system that is in control of ginning, credit and irrigation. Many farmers have accumulated massive debts (as most Bt cotton farmers in the area did not make profit and have defaulted on their loans), which could ultimately lead to land displacement. Power is concentrated in the hands of fewer companies, contributing to greater control by these corporations. GM cotton would therefore appear to perpetuate the injustices of the past and exacerbate the inequities in land access and ownership.

Conclusions for Bt cotton versus non-Bt cotton

Two NGO reports, concerning Pakistan and South Africa, have been found that suggest a relationship between (the profitability of) Bt cotton crops and land or community rights conflicts. Other information about a relationship between Bt cotton and land or community rights has not been found.

4.5.3 Freedom of choice

While the possibility to cultivate GM cotton has in a sense widened the farmer's options, there are factors that might limit the farmer's freedom of choice for cultivating non-GM cotton. The following types of impacts on the freedom of producers to choose between GM and non-GM production are treated under separate subheadings below: decreasing availability of non-GM seed, pressures from financers to use GM-seeds and/or lack of market outlets, lack of a functional segregation system, and technical lock-in.

Choice reduction by availability of seed (including IPR and technology fee systems)

General situation in cotton production

In 2002, GM cotton was planted on 67,000 km² worldwide (20% of the total area planted with cotton in 2002). In 2008, 15.5 million ha of GM cotton was cultivated, which is slightly less than half the total cotton area (*James, 2008*), indicating that GM cotton was quickly adopted (*Tripp, 2009*). GM cotton acreage in India continues to grow at a rapid rate, reaching 82% of the cotton area in India in 2008 (*James, 2008*) and 87% in 2009 (*James, 2009*). This makes India the country with the largest area of GM cotton in the world, surpassing China (*James, 2008 and 2009*). For adoption rates of Bt cotton and information on the area of Bt cotton in particular countries (in 2007), see Table 4.2 in section 4.2.1.

Research shows that new GM varieties are expected to be introduced in the near future (*Stein & Rodríguez-Cerezo, 2009*). The fact that the events are patented and that technology fees have to be paid to (international) seed companies by farmers as part of the seed price or by seed companies (to license the gene construct to incorporate it into their own hybrids), affects investment opportunities and decisions for seed manufacturing companies (*Tripp, 2009*). The level of the technology fee charged by private companies on GM seeds depends on the strength of IPR protection and enforcement in a country (*Qaim* et al*., 2008*). In India, a few seed firms developed their own Bt constructs or obtained it from the Chinese Academy of Sciences. In this way, licensing fees to international companies could be avoided, but, among others, the considerably higher development costs may seriously hamper the competitiveness of this approach (Murugkar *et al.*, 2007). Seed prices are however lower in China due to competition from such public breeding programmes in China (Smale *et al.*, 2006, see section 4.4.1).

True-to-type seed of cotton can be harvested by the farmers themselves from crops, or can be returned to the farmer after ginning elsewhere, and kept as seed for the next crop in the case of open-pollinated varieties (OPV). This is not the case for hybrid cotton varieties, as the hybrid vigour of the hybrid plants, which means more production, is quickly lost in subsequent generations of self-pollination. These seeds must thus be purchased every year from a seed supplier. Recently, the public institute The Indian Council for Agricultural Research (ICAR) however released a non-hybrid Bt variety that allows farmers to save their own seed without losing the efficacy of the Bt gene or other properties of the seed (*Karihaloo & Kumar, 2009*). This would decrease the number of farmers that are dependent on seed supplying companies.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

It is expected that the options to choose between different Bt-cotton varieties will increase because of the fact that incorporating transgenes in locally adapted cotton varieties is economically very interesting considering the large market size and the fact that cotton varieties must be locally adapted in order to be attractive for farmers to grow them. More competition between national or international companies may lower technology fees, which should benefit farmers. However, when a large part of the market consists of GM cotton, it may be more difficult for farmers to buy non-GM cotton-seeds, which may limit the farmer's freedom to choose non-GM seed. Investments by seed companies in Bt cotton seed varieties may possibly negatively affect the development of improved non-GM seed varieties. This may limit the availability of different non-GM varieties and the options to choose between them and GM varieties. Public research and development of both GM and non-GM varieties will influence both aspects of freedom of choice for farmers (between GM varieties and between GM or non-GM).

Bt cotton was put on the market as Bt hybrid varieties. It can be expected that GM cotton will initially replace non-GM hybrid varieties. The dependency of the farmers who already buy hybrid seeds, will not change. However, if Bt cotton becomes widely accepted, it may also be adopted by farmers who used to save their own seeds for the next crop. This may increase the number of farmers that are dependent on seed supplying companies.

Summary of theorized impacts for GM versus non-GM cotton

Investments by seed companies in GM varieties (in part stimulated by fees linked to Intellectual Property Rights) may possibly affect the development of improved non-GM seed varieties, which could limit the availability of different non-GM varieties. Replacement of farm-saved seed from non-GM OPV by GM hybrids may further limit farmers' choice.

Evidence of difference between GM and non-GM production

Tripp (2009) concludes that seed markets are amongst the most important determinants of farmers' access to Bt cotton. In South Africa, the cotton seed market has always been controlled by a very small number of companies. Bt cotton further narrowed this field. The US supplier Delta & Pine Land Company is the major supplier of cotton seed in South Africa and was able to introduce several of its transgenic varieties on the market (*Gouse, 2009*)[23]. It was very popular and rapidly spread amongst large farmers. At the same time, a pre-existing credit programme was used to introduce Bt cotton to smallholders in South Africa. Presently, non-GM cotton in South Africa is almost completely replaced. Whether this was due to the fact that there was no freedom to choose anymore for non-GM cotton (for example as a result of non-GM seed not being available anymore), is not clear from the available information.

On the basis of available literature, it could not be established whether and to what extent intellectual property rights systems impacted on the availability of non-GM. The changing roles of state agricultural research institutes and the privatized seed systems may affect the development of seed markets. In China, in reaction to enforcement of IPR and seed regulation, an illegal seed market developed (*Huang* et al*., 2009*)[24]. The illegal Bt seed market in India was a reaction to the initially strict control of access to technology and the high price of Bt seed (*Qaim* et al*., 2008*, *Tripp, 2009*). Although the initial social gains from the diffusion of the seeds from these illegal markets seemed to have been positive (they provided for lower seed prices and a wider availability, for more information see under technical lock-in and deskilling below), they undermine the intellectual property of official varieties, which potentially results in a situation where incentives to introduce new technology are insufficient (Murugkar *et al.*, 2007). Moreover, they contributed to making the market so complex that farmers had trouble identifying appropriate varieties (*Tripp,* 2009). Since 2004/2005 the lower price and wider availability of legal Bt cotton hybrids has probably contributed to a reduction in the area of illegal Bt cultivation in India, albeit trustworthy statistics are hard to come by (Sadashivappa & Qaim, 2009). By now, many legal Bt cotton varieties are available from a series of breeding companies (Rangasamy & Elumalai, 2009).

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[23] Chapter in scientific monograph edited by Tripp (see footnote 17).

[24] Chapter in scientific monograph edited by Tripp (see footnote 17).

Conclusions about Bt cotton versus non-Bt cotton

On the basis of available literature, it could not be established whether and to what extent intellectual property rights systems impacted on the availability of non-GM. Illegal seed markets (in India and China) contributed to farmers having trouble choosing appropriate varieties, limiting the option to make well informed choices. In India, the lower price and wider availability of legal Bt cotton hybrids have probably contributed to a reduction in the area of illegal Bt cultivation.

Choice reduction by financial means (including market demand)

General situation in cotton production

The choice of inputs in cotton production may be affected by organisations or companies that provide the financing to buy the necessary inputs. These organisations may be directly tied to input provision (influencing or even prescribing the choice of inputs) or not (*Tripp, 2009*).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

Farmer financing may be provided by processors or traders that only accept GM or non-GM cotton, thereby stimulating or even requiring farmers to grow GM or non-GM varieties. This may limit their freedom of choice. Since Bt seeds are more expensive than non-GM seeds and loans may be supplied by seed suppliers for purchasing Bt seeds, the dependency on seed suppliers might increase. When higher costs of Bt cotton seed are not compensated by higher yields and reduced production costs, e.g. in the event of other production circumstances (like a period of drought) negatively affecting yields, this could result in a situation where farmers (and possibly also their children) are bonded to work to pay off debts to the seed company. In this case Bt cotton may limit the freedom to choose non-GM seeds.

Summary of theorized impacts for GM versus non-GM cotton

Market demand and pressures from financers may stimulate farmers to use Bt-cotton.

Evidence of difference between GM and non-GM production

In South Africa the introduction of Bt cotton was implemented through a system of tied credit that was managed by the area's sole ginnery (*Gouse, 2009*). In this case, market demand (processor demand) pushed farmers towards adoption of Bt cotton.

Conclusions about Bt cotton versus non-Bt cotton

One example in South Africa showed that market demand (in this case the demand by a single processor that provided the financing) pushed farmers towards adoption of Bt-cotton.

Choice reduction by infrastructural segregation

General situation in cotton production

There is no distinction between GM cotton and non-GM cotton in processing and infrastructure. There is, however, a distinction between organic cotton and non-organic cotton. GM admixture excludes farmers from organic markets that are by definition non-GM.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
In crops with separate chains to process and consume GM and non-GM crops, it could be expected that when a large part of the market becomes to consist of GM, it may be more difficult to sell non-GM, since segregation systems in general are threatened by insufficient transport and storage space (*Sundstrom* et al*., 2002*). This suggests a developing challenge for farmers interested in cultivating organic (non-GM) cotton (especially in areas where the majority of the cotton produced is non-organic and where functional segregation systems may be lacking), as admixture with GM excludes them from organic markets. This may affect their freedom to choose to deliver to organic (non-GM) cotton markets.

Summary of theorized impacts for GM versus non-GM cotton
Deficiencies in infrastructural segregation systems may impact the freedom to choose to deliver to organic (non-GM) cotton markets.

Evidence of difference between GM and non-GM production

No literature was found on segregation systems separating GM from organic cotton.

Conclusions about Bt cotton versus non-Bt cotton

No literature was found on segregation systems separating GM from organic cotton.

Choice reduction by technical lock-in and agricultural deskilling

Due to rapid introduction of new technology and concomitant pressure from multinational seed companies to change, agriculture skills based on local varieties could get lost or deteriorate. This is called agricultural deskilling by *Parthasarathy (2002*). A reason for this is that farmers are not asked on their experiences and local knowledge and are overwhelmed by the new technology.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
Due to rapid introduction of Bt cotton, agricultural deskilling could occur in cotton production. Expected implications are a backfall in local environmental and agricultural knowledge and skills, which will make farmers even more dependent on seed providers.

Summary of theorized impacts for GM versus non-GM cotton
Agricultural deskilling could potentially lead to a technical lock-in of Bt-cotton farmers, making it impossible to return to non-GM cotton.

Evidence of impacts on freedom of choice between GM and non-GM cotton production

An empirical study performed by Stone (2007) analyzed the link between agricultural deskilling and the spread of Bt cotton in one of the important cotton growing districts of India, Warangal. The study concludes that the fast adoption of Bt cotton in Warangal resulted from agricultural deskilling, in which farmers fail to experiment and evaluate, e.g. by testing new varieties first on a small part of their fields. This was evidenced by the observation that farmers were consistently unable to justify their choice based on seed traits or environmental processes, such as field testing (so-called environmental learning). Stone (2007) explains that inconsistency in performance of seeds, unrecognizability of seeds and excessive rates of technology change accompanying the diffusion of hybrid cotton and the rise of the seed vendors caused an exceedingly low accuracy of environmental learning for Warangal farmers, whereas producers of Bt-cotton (seeds) attribute the quick adoption of Bt-cotton to farmer wisdom based on environmental learning. Stone (2007) also states that there is nothing intrinsically deskilling about the Bt technology and potential deskilling effects depend on local conditions, such as in Warangal where Bt introduced new sources of inconsistency in seed performance and unrecognizability of seed and accelerated technological change. The deskilling in Warangal was however already in full effect before the Bt-seeds arrived with quick changes in seed brands that not always have a consistent relationship with seed quality and/or variety, thus hampering the farmers' ability to obtain experience in varietal performance under his cultivation over the years. Several reviewers (e.g. S. Brush and R. Herring in the comments section following the article by Stone (2007)) were not convinced that Warangal farmers have been deskilled by (all of) the factors mentioned above. Herring argues that cotton farmers in Gujarat (another important cotton growing district in India) do not seem as deskilled as farmers in Warangal, despite longer exposure to deskilling conditions, whereas Stone (2007) states that different seed systems in Gujarat in fact greatly reduce inconsistency, unrecognizability and acceleration of technological change. In Gujarat, farmers, however, also were able to gain experience in the cultivation and breeding of Bt cotton based on illegal introduction of a successful Bt variety (Stone, 2007). Where conditions are different, GM-seeds may thus even mitigate deskilling (Stone, 2007). Brush argues that the diffusion of technology might be seen as offering farmers new skills. Herring expresses doubts about the applicability of the concept of 'deskilling' and states that generally the technology was very popular with farmers for good reasons (positive effects on income, health and safety), but that economic evidence in different studies on India was often contradictory and one explanation for that may be offered by Stone's (2007) observations on the seemingly haphazard adoption of Bt-cotton in Warangal. In a later publication, Herring (2008) again concludes based on an own survey that it was the successfulness of the technology that also drove quick adoption of Bt-cotton in Warangal. However, he also confirms the local problems in obtaining consistent seed lots, due to the lack of certification systems, that are conditional for farmers to base their judgement of Bt cotton on own experience.

Conclusions about Bt cotton versus non-Bt cotton

Studies in India show that depending on local conditions, agricultural deskilling (according to one study potentially but not necessarily caused by Bt cotton) has influenced farmer's decisions to choose for Bt cotton (one study claims to a large extent). Whether deskilling is an issue depends on local conditions such as consistency in seed performance, recognizability of seed and opportunities for experimenting and evaluating. Bt cotton may also mitigate deskilling when local conditions are different.

4.5.4 Competition with food production

General situation in cotton production

Although cotton is mainly a fibre crop, its by-products are widely used for consumption. Cotton seed oil is used for human consumption and is also used in animal feed, and cotton seed cake is used for animal consumption, but consumption is mostly local. Particularly for human consumption, oil needs to be refined and with animal consumption, basically only ruminants can be fed with the seed cake. Removal of toxic gossypol is required before seed cake could be used in other animals' feed or in products for human consumption.

Modernization trends in large-scale farming could negatively affect local food security and production for local markets. Cotton production may also compete with food production for land and labour. However, the conventional view that cash crops compete with food crops for land and labour neglects the potential for cash crop schemes to make available inputs on credit, management training, and other resources that can contribute to food crop productivity, which might otherwise not be accessible to farmers if they did not participate in cash crop programmes (Govereh & Jayne, 2002). The study by Govereh & Jayne (2002) builds on previous research by hypothesizing key pathways by which cash crops may affect food crop activities and empirically measuring these effects using the case of cotton in Gokwe North District in Zimbabwe. Results of the study indicate that — after controlling for household assets, education and locational differences — households engaging intensively in cotton production obtain higher grain yields than non-cotton (maize) and marginal cotton producers. They also found evidence of regional spill-over effects whereby cotton programs (and probably also other cash crop programmes) induce second-round investments in a particular area that provide benefits to all farmers in that region, regardless of whether they engage in the specific cash crop programme. This suggests that the potential spill-over benefits for food crops through participation in cash crop programmes are important to consider. It should also be realized that an impact on food production does not necessarily mean an impact on food security. When revenues from cash crops are used to import food at affordable prices (not just for farmers and land owners, but also for workers), food security may not be threatened.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION

Since cotton seed oil is locally used for human consumption and cotton seed cake as animal feed (mainly ruminants), cotton production may have a direct impact on human food security. If Bt cotton would influence the amount of seeds available for the production of cotton seed oil and cotton seed cake (compared to non-GM cotton), Bt cotton could directly impact on local food production. However, this is unlikely to be the case.

Bt cotton production may indirectly impact on food production when:

- increased yields of Bt cotton reduce the area of arable land required to satisfy the (global) cotton demand, which leaves more area to grow food on (however, this impact has not been confirmed by scientific studies, see also 'Planet' section 4.3.4) or, alternatively, higher profits (due to higher yields) for Bt cotton lead to an expansion of cotton production, leaving less area to grow food on (see 'Profit' section 4.4.2). Globally, increased yields would probably lead to a reduction in the production area, unless demand goes up if consumer prices decrease (see also 'Profit' section 4..4.2).
- non cotton farmers switch to Bt cotton because it proves to be more interesting financially. The shift from subsistence crops to cash crops is more likely if the cash crop promises high profits. It may also involve a shift from mixed agriculture to monoculture. In the case of cotton, the shift will increase the financial dependence of farmers on the price trends of cotton. This may give rise to expansion of the cultivated area in times of high prices (as higher profits are expected). An increase in the amount of land used for cotton production may lead to a decrease in the amount of land available for other arable crops, including food crops, which would negatively impact food production. However, low prices will result in a reduction of the production area. A study from Tanzania shows that smallholders moved out of cotton production and started growing alternative cash crops (like maize, rice or tomatoes) when prices went down (*Meertens* et al*., 1995*). This could have a positive effect on food production and food security in case these smallholders shift to food production.
- Bt cotton competes with or puts stress on the neighbouring subsistence crop production, e.g. if more Bt cotton production leads to less water for surrounding crops.

Although these potential impacts are not specific to Bt cotton, the shift towards cotton production may be increased by the higher profit potential of Bt-cotton compared to non-GM cotton.

Summary of theorized impacts of Bt cotton versus non-Bt cotton

Bt cotton could directly impact on local food production (positively or negatively), if Bt cotton would influence the amount of seeds available for the production of cotton seed oil and cotton seed cake (compared to non-GM cotton). However, this is unlikely to be the case.

Bt cotton production may indirectly impact on food production as a result of increased yields or a shift from subsistence crops to Bt cotton (positively or negatively affecting food production) or as a result of competition with neighbouring crops (negatively affecting food production).

Evidence of difference between GM and non-GM production

On a macro-level, the introduction of GM cotton is shown to lead to a shift in production and income from non-adopting to adopting regions, and to lower cotton prices (see 'Profit' section 4.4.2). No evidence was found that these developments lead to an expansion of the cultivated area for cotton or a decrease in the amount of land available for food crops and no evidence of an impact on food production and subsequent threats to food security were found.

On a micro-level, Bt-cotton may compete with food production. However, an increased income due to Bt cotton may allow farm families that do not have enough food, to increase their food purchases and food consumption as is shown by the modelling study by Pray *et al.* (2001) in China. Results of the study by Elbehri & Macdonald (2004) (that evaluated the potential impact of Bt cotton on West and Central Africa using a multiregion general equilibrium model and multicountry estimates of Bt-induced productivity, GTAP) show that the positive income effect of the Bt cotton technology enables West and Central Africa to slightly raise its food imports while maintaining initial production levels. In addition, the study shows that by reducing in-season labour use from lower pesticide applications, the Bt technology helps channel some of this labour to other products such as food crops reducing labour shortage constraints in food crops hence improving food crop yields and overall farm productivity.

Conclusions for Bt cotton versus non-Bt cotton

No evidence was found that the above mentioned production trends (related to changes in land and resource allocation) and subsequent threats to food security on a macro-level exist and are different for GM cotton and non-GM cotton.

On a micro-level, Bt-cotton may compete with food production (to a large extent dependent on the prevailing farming system). However, an increased income as a result of growing Bt-cotton may allow farm families to increase their food purchases and food consumption as is shown by a Chinese modelling study and a West and Central African GTAP modelling study. This means that a reduction in food production on a micro-level does not necessarily mean a reduction in food consumption. Moreover, the GTAP modelling study in West and Central Africa shows that released labour from cotton is shifted to food crops, reducing labour shortage constraints in food crops and thereby contributing to food production on a macro-level.

4.5.5 Contribution to livelihoods of producers and local communities

Impacts of GM cotton cultivation on the livelihoods of producers and local communities are examined under separate subheadings below: community health and safety related to the influence of crop protection agents on the environment, economic impacts of GM cotton cultivation, as discussed in 'Profit' section 4.4.1., on income security and the distribution of benefits to farmers, and prosperity-related investments.

Impact on the natural environment on which local communities depend

General situation in cotton production

As stated in 'Planet' section 4.3.3, Bt-cotton could have a positive impact on the quality of water resources by reducing the use of relatively toxic insecticides that are often used in cotton production. Heavy use of chemicals contributes to a loss of fertility and downstream pollution (*CREM, 2009*).

Bt cotton was estimated to provide higher yields than non-GM cotton (see section 4.3.1.1). Although this increases land use efficiency, the consequential increase in farm income ('Profit' section 4.4.1) will initially induce farmers to switch from less profitable crops to GM cotton ('Profit' section 4.4.2). As a consequence, increased land use efficiency is unlikely to cause a decrease in acreage of cotton production, and thus will probably not reduce the impact on the natural environment on which local communities depend (see also 'Planet' section 4.3.4). The higher production level causes prices to decline, thereby (partly) compensating for the positive effect of higher yields. Yet, even if this would cause farm income from cotton production to decrease compared to before the introduction of GM cotton, cotton growers would still initially switch from non-GM to GM cotton, because if not, they would suffer from the price fall without benefiting from the higher yield. Farmers are thus unlikely to reduce their acreage for as long as they make at least some profit from cotton production - or crop production in general, particularly if they have no better alternatives (see 'Profit' section 4.4.2).

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
Reduced usage of insecticides with Bt cotton could benefit the environment in general and more specifically the quality of the (drinking) water that communities (including farmers and workers) use. The local net effects of higher yields from Bt cotton on possible changes in land use and concomitant changes in the natural environment are hard to predict. Thus, no clear link with Bt cotton is expected.

Summary of theorized impacts of Bt cotton versus non-Bt cotton

- Quality of (drinking) water: Bt-cotton could have a positive impact due to a reduced use of pesticides compared to non-GM cotton.
- Impact on the natural environment on which local communities depend: The net effects of a lower demand for cultivation area due to higher land use efficiency and the potential increase in cultivated area as a result of higher profits are hard to predict.

Evidence of difference between GM and non-GM production

The study by Huang *et al.* (2002) in China states based on survey data that the reduction of the use of pesticides for Bt cotton has significant implications for the environment, particular for the quality of drinking water for local farmers in cotton-producing regions, where farmers depend on water for both domestic and irrigation uses. No literature was found on possible changes in land use following from higher yields with Bt cotton.

Conclusions for Bt cotton versus non-Bt cotton

Bt cotton may impact positively on the quality of drinking water as is stated in a Chinese case study, but the study did not provide clear evidence for this. No literature was found on possible changes in land use following from higher yields with Bt cotton.

Income effects and distribution of benefits

General situation in cotton production

Farmers and workers in cotton production generally receive low income/wages (*Venkateswarlu & Da Corta, 2005; Khandelwal* et al.*, 2008*). 90% Of cotton farmers live in developing countries working with an area size of less than 2 hectares. Decreasing international prices, and subsidies in western producing countries and China, directly affect farmers' revenues. In India, farmers must in many cases pay directly for seed, whereas insecticide purchase is normally through credit (Kambhampati *et al.*, 2005). Some publications state that this leads to structural losses and debts and in some cases to suicide as is frequently reported in India (*Stone, 2002*[25]; Stone, 2007). However, the extent to which suicides are directly linked to cotton cultivation, or even agriculture in general, is open to discussion (Mohanty, 2005). Also in a number of places in Africa, these issues have been reported (*Ismael* et al.*, 2001*). Bonded labour of adults and children due to debt bondage also occurs (*EJF, 2007*, *Busse & Braun, 2002*).

Effects of Bt-cotton on labourer's income (wage levels) and child labour are discussed in paragraph 4.5.1. For more specific information about farmer's income see 'Profit' section 4.4.1.

[25] Commentary in scientific news journal of American Anthropological Association.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
Expected reduced yield losses and reduced yield uncertainty in Bt cotton as compared to non-GM cotton provide positive effects for farmers (a more stable income). As a result of an increased income, the risks for lenders might be reduced and the nutritional demands of families might be better met. It could also be hypothesized that Bt-cotton helps to reduce suicide rates by improved yields and net benefits, and reducing variation in income from year to year. However, national producer organizations and activist groups accuse Bt cotton of being the main reason for a resurgence of farmer suicides in India, based on the hypothesis that the costly and ineffective technology of Bt cotton is a contributor to debts, ultimately leading to suicides. Since for Bt cotton in general lower amounts of pesticides are needed, debts to companies that supply crop protection agents could in theory be smaller making farmers less dependent on these companies. However, since Bt seeds are more expensive than non-GM seeds and since loans have also been supplied for purchasing Bt seeds, the net effect on a farmer's debts is not necessarily positive. When higher costs of Bt cotton seed are not compensated by higher yields and reduced production costs, e.g. in the event of other production circumstances (like a period of drought) negatively affecting yields, this could result in a situation where farmers (and possibly also their children) are bonded to work to pay off debts and to the situation that farmers may employ children to save costs. When the use of Bt-cotton leads to higher profits, this effect on bonded labour may prove to be the opposite.

On the other hand, Bt cotton may lead to a greater marginalization of non-Bt cotton farmers (less profit, less market access, lower revenues). Moreover, smaller farmers might be excluded from the new GM production option since it requires a certain level of capital, know-how and market linkage. It is possible that the additional costs of Bt seed deter small-scale farmers from adopting Bt cotton, as for example in India, credits are often only provided for the purchase of insecticides and not for seeds. Even if the higher seed costs are retrieved in the course of the season through lower insecticide costs or higher output benefits, a lack of cash at the beginning of the growing season may limit the adoption of GM production.

Summary of theorized impacts of Bt cotton versus non-Bt cotton
A higher and more stable income is expected for Bt cotton farmers than for non-Bt cotton farmers. Bt cotton may lead to a greater marginalization of non-Bt cotton farmers. The effects of Bt cotton on bonded labour may be positive or negative, depending on whether a farmer is able to compensate for the higher costs of Bt-cotton seed (e.g. by higher yields). Similarly, the relation between Bt cotton and the occurrence of debt-related suicides could both be upward (based on the hypothesis that the costly and ineffective technology of Bt cotton is a contributor to debts) or downward (based on the fact that Bt cotton has improved yields and net benefits, and has reduced variations in income).

Evidence of difference between GM and non-GM production

A conclusion from 'Planet section 4.3.1.1 and 'Profit' section 4.4.1 was that Bt cotton on average leads to increased production. In a survey by Gouse *et al.* (2004) in South Africa, farmers have reported pesticide and application cost savings and yield increases as some of the major benefits of Bt-cotton. A high percentage of large-scale farmers has indicated that peace of mind (not having to worry) about bollworms is also one of the very important benefits of Bt cotton as it gave farmers managerial freedom to devote time to other crops or general farming activities, generating additional income. As also reported in section 4.4.1, differences between large- and small-scale farmers occur, but do not consistently favour one group over the other. Not all the studies on the issue define the production area used by small- and large-scale farmers, respectively, but the study by *Qaim* et al*. (2008)* in India does and defines small-scale farmers as having less than 5 ha. and large-scale farmers as having more than 5 ha.

The studies by Bennett *et al.* (2004b) in South Africa and Morse *et al.* (2007) in India indicate that the inequality among smallholders is lower among Bt-cotton farmers than among non-GM cotton farmers (see also section 4.4.1). This suggests that Bt cotton provided for a decrease in inequality between small-scale farmers. Evidence showing that Bt cotton may lead to marginalization of non-Bt cotton farmers (as compared to Bt cotton farmers) was not found.

Discouragement of the use of more expensive seeds, caused by the fact that farmers must pay directly for seed instead of using credit in India (Kambhampati *et al.*, 2005), is not supported by the available information. The acceptance of Bt cotton in India has rapidly grown in recent years (*Qaim* et al*., 2008*), even among resource-poor farmers (*Lalitha* et al*., 2009*)[26]. In India, initial limited access to transgene varieties was broken, first by the illegal seed market and then by the licensing of the transgenes to an increasing number of domestic seed companies. The Indian government also took steps to establish price limits on the seed. At the same time, the study shows that the small minority who did not yet try Bt cotton in one of the research areas, appeared to be those with smaller landholdings (*Lalitha* et al*., 2009*).

In Colombia, where bollworm is not the major pest problem, half of the country was planted with Bt cotton in 2007 (*Zambrano* et al*., 2009*)[27]. The choice of cotton variety is determined mainly by the Colombian grower associations. They are the sole providers of Bt cotton seed. Even though farmers might be able to select an association that will supply their choice of seed, Bt seed requires a significant investment from farmers, and not all of them are able to afford it. Moreover, there is a lack of information about options and the (dis)advantages of new varieties (*Tripp, 2009*), limiting the ability to make informed choices.

The study by Herring (2008) concludes that Bt-cotton cannot be responsible for suicides in the Warangal district in India, since the technology does not cause increased crop failure or indebtedness in comparison with other cultivars. A study by the International Food Policy Research Institute (IFPRI) *(Gruère* et al*., 2008)* investigated the relation between Bt cotton and the resurgence of farmer suicides in India this last decade. It was concluded that the first set of hypotheses, namely that the costly and ineffective technology of Bt cotton is a contributor to the suicides, was rejected. The study shows that there is no evidence of a 'resurgence' of farmer suicides in India in the last five years (despite the fast adoption of Bt cotton in India in these years) and that the Bt cotton technology has been very effective overall in India. It was however noted that Bt cotton in some cases may have indirectly contributed to farmer indebtedness, leading to suicides, as a consequence of the fact that the extra seed costs for Bt cotton are not compensated for by higher yields, which was mainly a result of institutional, climatic and economic constraints. The analysis clearly shows that Bt cotton is neither a necessary nor a sufficient condition for the occurrence of farmer suicides.

Conclusions for Bt cotton versus non-Bt cotton

- A study in South Africa shows that farmers report pesticide and application cost savings, yield increases and the peace of mind (not having to worry) about bollworms as very important benefits of Bt cotton.
- Differences in income benefits between large- and small-scale farmers occur, but do not consistently favour one group over the other.
- Two studies (in India and South Africa) suggest that Bt cotton provided for a decrease in inequality between small-scale farmers of Bt-cotton.
- Evidence supporting the expectation of marginalization of non-Bt cotton growers versus Bt-cotton growers was not found.
- Many farmers but not all small-scale farmers can afford the investment necessary for buying Bt-cotton seed. Discouragement of the use of more expensive seeds, caused by the fact that farmers must pay directly for seed instead of using credit in India, is not supported by the available information.
- No evidence was found that Bt-cotton impacts differently on the occurrence of suicides (that are reported to occur in India and Africa as a result of indebtedness) than non-GM cotton.

[26] Chapter in scientific monograph edited by Tripp (see footnote 17).
[27] Chapter in scientific monograph edited by Tripp (see footnote 17).

Prosperity related investments

General situation in cotton production

Relationships between profits from GM production and GDP have been addressed in Profit section 4.4.2.

THEORIZED IMPACTS OF GM VS NON-GM PRODUCTION
In theory, higher profits from Bt-cotton production could result in an increase of the GDP (Gross Domestic product), which could lead to growth investments in infrastructure. On a company level, higher profits from Bt cotton production may allow for higher investments in social infrastructure, such as health and social amenities. In general however, it may be expected that investments in social infrastructure are more closely linked to a company's values than to profits.

Summary of theorized impacts of Bt cotton versus non-Bt cotton
Higher profits from Bt-cotton production could potentially result in an increase of the GDP which could lead to growth investments in infrastructure. On a company level higher profits from Bt-cotton production may allow for higher investments in social infrastructure. In general however, it may be expected that these types of investments are more closely linked to a company's values than to profits.

Evidence of difference between GM and non-GM production

No literature was found on impacts on prosperity-related investments.

Conclusions for Bt cotton versus non-Bt cotton

No literature was found on impacts on prosperity-related investments.

5. Discussion

We compared the sustainability of GM soy, maize and cotton varieties that have been allowed and are often widely used for cultivation and processing, with that of conventional, non-GM varieties. Note that the basic element distinguishing GM from non-GM, the technology used to make them, which is already assessed with regard to environmental and food safety before regulatory release, is not the topic of this report.

The discussion of the results of our study is structured in the following way. We start with the research question that this study set out to answer, and discuss what sort of answers have been generated by our approach and what limitations were encountered. Secondly, we discuss some methodological aspects that are characteristic for desk studies on the sustainability of agriculture in general and for GM cropping systems in particular. Thirdly, we highlight some of the findings per crop. Fourthly, we discuss to what extent our results are relevant for issues that frequently appear in discussions in the context of GM and sustainability.

1. Validity of the research question and research approach

Starting point of the current study was the question whether the cultivation of GM crops for import in the Netherlands, as compared to the cultivation of their conventional (non-GM) counterparts, is in line with the Dutch policy and societal aims that strive for more sustainable forms of agriculture worldwide and for utilization of biotechnology in a responsible manner.

This question of relative sustainability performance was made concrete by defining specific themes/indicators in each of the three frequently used sustainability components *Planet*, *Profit* and *People* (for pragmatic reasons the sequence in this study is 'Planet, Profit, People' instead of the more commonly used 'People, Planet, Profit'). These were subsequently evaluated through detailed case studies on soybean, maize and cotton. Though effects on Planet, Profit and People could be interacting and also partly overlapping, the research question itself thus was sufficiently operationalized in concrete terms.

The case studies clearly showed that there is no single value of sustainability for all GM crops across all regions and under all conditions:

Firstly, though polarization has tended to frame the debate about GM crops into a binary choice between either completely in favour of or completely against any use of genetic modification, our results show that GM crops encompass such a broad range of traits that the effects of the modifications cannot be summarized for all traits together. This can already be seen from the two traits commonly used and discussed extensively in this report, herbicide tolerance (HT) and insect resistance (IR) provided by Bt. With HT, it is not the transgene itself but the changed possibilities in herbicide usage enabled by the transgene that have effects on sustainability performance. In the most common case of transgenic glyphosate-tolerant crops, a potential double advantage was a rise in efficiency of weed control for the grower combined with the use of an environmentally less damaging herbicide. Furthermore, HT crops had a wider influence on cultivation as they likely facilitated to various extents the implementation of conservation tillage. With Bt, it is the transgene itself that provides a specific insect resistance, with an advantage of enabling lower insecticides usage. However, both traits may fail when not accompanied with good agricultural practice (GAP), but in each case this works out differently. For instance, using glyphosate-tolerant crops too intensively has led to development of resistant weeds, which in turn may have led to increased herbicide usage negating the original advantage of HT crop introduction. With Bt, measures as non-Bt refuge areas are required in order to avoid the possible resistance development in the targeted pest insects that could also lead to a negation of the previously lowered insecticide usage. In this regard, there could also be a partial trade–off in insecticide usage necessitated by possibly emerging secondary pests. These are pests that previously were not important due to the overriding effects of the primary pest targeted by Bt or that were offered an opportunity by lowered insecticide usage, which in some cases may even have been too optimistic with regard to the presence of pests not targeted by Bt.

Secondly, the sustainability of agricultural production itself greatly varies with crop and geographical region, and is not stable in time as agricultural practices change. As a consequence, when an effect on one or more of the sustainability components was identified, the available information was often only relevant for a specific context (crop, GM trait, geographical region, institutional context, time period – for GM crops, 1996 to the present). For example, Bt maize against the European corn borer (ECB) did not always have a strong influence on insecticide use, because it is difficult to control ECB by insecticides and therefore some Bt maize farmers did not use insecticides against ECB in non-GM varieties in the past and accepted the yield loss. The economic advantage in terms of relative yield improvements of Bt maize depended on local ECB infestation levels, which vary strongly over the years. In cotton cultivation on the other hand, insecticide usage was on average already higher and so Bt varieties often had a large impact on amounts of insecticides used. This led, amongst others, to an improvement of the health of farmers in China and South Africa, due to reduced exposure to various highly toxic agrochemicals. Again, also in cotton, net results depended on local conditions, such as bollworm infestation levels. With HT crops, relative advantages also depended on the efficacy of weed control in the conventional variants. Thus, HT varieties took off much slower in maize than in soybean in the US, among others, because weed control using glyphosate needed some agronomical refinements to attain good results in maize. In addition, when making comparisons, one should also take into account that herbicide usage in conventional crops also changed significantly in the time period encompassing the rise of GM crops. Another factor is the local institutional context, which affects the distribution of welfare benefits of GM crops among the breeding industry, farmers and consumers. For instance, GM soybean was more profitable for Argentinian farmers than for their colleagues elsewhere in the Americas because of the local lack in the exertion of IP rights on the seeds. More such complexities that came from the studies about the situation around Bt cotton in India are discussed below under IP rights.

Thirdly, the GM traits in many respects do not represent changes largely or essentially different from other agricultural innovations. A simple example of this is that HT varieties are also attained through conventional breeding methods, such as mutagenesis, which is not subject to regulatory assessment in the US and the EU (in the latter case as a specific exemption to the GM definition used in EU Directive 2001/18/EC for mutagenesis), but is in Canada (in this case treated as novel trait) (Smyth & McHughen, 2008). Another example is the introduction of hybrid crop varieties, which went also very swift and had quite some similarities in effects on production or marketing practices to GM varieties (see below under IP rights). For instance, hybrid maize varieties were introduced in the US in the 1930s. In the Corn Belt, where yields were highest, they were adopted very quickly (from 6% of the acreage in 1934 to 80% in 1939) (*Grigg, 1995*).

Fourthly, there is a wide array of agricultural developments in which the specific role of GM is difficult to disentangle from other drivers. For instance, there is a strong worldwide economic driver for the production of cost-effective feed, in which large-scale soy production apparently fits well at present. Increased efficiencies attainable by using HT soybean varieties play a role in facilitating large-scale soy production. As these varieties likely facilitated conservation tillage practices they could also be helpful to cultivate areas where potential weed infestations or soil erosion used to prevent cultivation of land. However, HT varieties are apparently not essential for large-scale soy cultivation in Latin America, as evidenced by the large-scale cultivation in Mato Grosso in central Brazil using conventional soybean varieties on some of the largest arable farms in the world.

Furthermore, we emphasize that we looked at relative differences in sustainability between GM and non-GM crops, not at the absolute sustainability of agricultural production. A consequence of this comparison is that if we concluded that there was no effect of GM, this does not mean that the crop production system did not have negative sustainability impacts, or that the sustainability performance of the crop could not be improved. Instead, a limited effect implies no more than that GM did not determine to a great extent the level of sustainability performance of a specific cropping system. For instance, deforestation in the Amazon is basically only indirectly related to GM soy, while other drivers exist that have a large impact on this process. It is realized that, because of its focus, the study even runs the risk to disproportionately enlarge any difference between GM and non-GM cultivation, and to acknowledge insufficiently the role of other innovations and changes in agricultural practices that affected agricultural sustainability in recent years. This can be envisaged by the existing large variability in sustainability performance between regions and time periods irrespective of the presence of GM crops. For instance, studies reviewed in this report noted that Bt cotton increased yields, relatively to non-GM cotton, with yield increases varying between 0 and 85%. However, national average cotton yields of main cotton producing countries in 2007/2008 varied 566%, from 367 kg/ha (Burkino Faso) to 2077 kg/ha (Australia) (USDA, 2009). This illustrates that there are more ways of increasing cotton production yields than just the use of the current GM varieties.

We only compared the sustainability of GM crops with that of conventional agriculture, for which data availability was relatively good. Even so, disentangling the GM effect from other drivers already proved to be quite complicated. To perform this comparison also for organic agriculture, systems for integrated pest management (IPM) and integrated farming in development, etc., would have become too complicated a subject to handle within the framework of this desk study, as much fewer comparison data would be available, or only for specific situations. Field studies on the relative performance of GM crops traced for this review usually took the common conventional agriculture in the region as a comparison.

2. Methodology

Peer reviewed and grey literature

We employed a literature search in which we, as much as possible, tried to use results from peer-reviewed scientific literature. Whenever such literature was not found, we also used other types of reports, but we indicated a distinction between information from peer-reviewed and other sources of information (grey literature) by the lay-out of the citation. While authors may write their paper from a certain perspective on GM technology, peer review obliges scientific studies to report their methodology and data in a transparent way so that they can be assessed for their quality and in principle can be repeated. For lack of other sources, data may come from not completely unbiased sources, but at least, these sources will have to be mentioned and so can be assessed by both the reviewer and the readers. Thus, evaluation of conclusions from peer-reviewed studies should be relatively straightforward and these conclusions should have gained in reliability from the extra control step in the publication process.

This does not imply that other types of reports by definition do not attain the same quality level, some reports certainly do, but there is obviously a wide range in data and analysis quality and so this has to be assessed on a case-by-case basis, assessing the methodologies applied whenever possible. Wherever felt necessary, this issue has been addressed with the specific topics in the chapters. An example could be the report on yields by Gurian-Sherman (2009), which was not (yet) published in a peer-reviewed scientific journal: it has clearly been written from a critical standpoint about GM crops, but the evaluation of yields is sufficiently transparently described to be useful for our review. Another example is formed by the reports of Brookes and Barfoot, who clearly show a more optimistic view on the sustainability of GM crops. They are also relatively unique in their wide scope thereby providing many useful data for this review, but need critical assessment of the sources of their data and the methodologies followed in the analyses as they sometimes tend to extrapolate local (positive) results, thereby ignoring heterogeneity in time and place. This bias also sometimes occurs in peer-reviewed publications of the same authors.

The use of theorized effects

Many agro-ecological ('Planet') impacts of GM traits in soy, maize and cotton have been relatively well studied, especially the effects in and around the production field. The 'Profit' impacts of GM crops at the farm level and at regional or global levels have also been studied through farmer surveys and modelling studies, though not as extensive as certain 'Planet' aspects. Various People aspects (e.g. impact of GM soy on land rights of indigenous people in Latin America) have rarely been included in scientific studies, even though these aspects are heavily debated in society. More research on People impacts of GM crops would be helpful for GM crop sustainability assessments, including studies using alternative research methods such as local expert interviews and extended case studies in the countries concerned. Based on the studies that have been published, many impacts on People issues seem to be only indirectly related to GM crops, or the impacts are related to much broader issues than GM technology. For instance, the effects of GM crops on employment depend not only on the magnitude of the decrease of labour demand due to higher efficiency of GM crops but also on employment opportunities elsewhere in the economy. An Indian study showed that there were labour shifts both within cotton cultivation and elsewhere as a consequence of Bt cotton introduction. There was more employment for hired female workers (due to increased harvesting related to higher cotton yields). In addition, male workers faced less employment in pesticide application to cotton. In this case, these men found their way into alternative employments that led to higher net returns to agricultural family households, including those below the poverty line.

In an attempt to pre-empt potential gaps in the literature we formulated hypothetical (theorized) effects for 'People' aspects and for some 'Planet' and 'Profit' aspects for which less information was at hand. This allowed us to structure scanty information and to distinguish between effects that were well documented and in which the scientific studies indicated evidence of positive, negative or neutral impact, and impacts that can be theorized but for which no scientific studies were found that assessed or confirmed such impacts. To clearly distinguish theorized effects, their descriptions were put in a separate text box.

The use of models

The evaluation of the macro-economic effects of the introduction of GM crops (on sectoral production, employment and remuneration of factors, household income and consumption, and welfare) is largely based on *ex-ante* model studies using Computable General Equilibrium (CGE) analysis. The overarching reasons for using such models are:

1. the lack of detailed time series or cross section data to accurately estimate effects *ex post*,
2. their theoretical tractability, key behavioral and accounting relationships being satisfied,
3. the comprehensive coverage of the interactions between the various sectors in the economy (in contrast to a partial modelling approach to which econometric analysis often has to resort),
4. their flexibility with respect to adjusting the data and model so as to fit the purpose of the study and
5. the possibility of counterfactual analysis, *i.e.* simulations that answer 'what if' questions as opposed to being restricted to 'learning from the past' as econometric studies are.

With respect to the introduction of GM crops, data on multiple variables that simultaneously affect impacts of GM crop introduction are required. For instance, extreme weather circumstances affect harvest – and thus prices. Another example is that, in the past decade, crop production for biofuel production has become increasingly important. One would also have to distinguish short-run from long-run effects since it takes time before a new global market equilibrium has established. Moreover, countries adopt the GM crop at different rates and with different efficiencies (see also next topic). As a consequence, it is impossible to perform analysis of macro-economic impacts entirely on the basis of empirical results (i.e. *ex-post*). Instead, researchers often make use of 'what if' scenarios to explore the effects of, e.g. adoption of GM crops in a particular set of countries, or the introduction of a regional import ban on GMO products. The objective of scenario analysis is not necessarily to predict the changes observed in reality. They are also performed in order to better understand how particular mechanisms work, and therefore sometimes contain hypothetical scenarios that may seem unrealistic given actual circumstances. Examples used in this report are the analysis of market segregation of GM- and non-GM crops, and the introduction of an EU import ban.

Naturally, a CGE model is not without limitations itself. First and foremost, unlike econometric studies, it is not possible to statistically validate the structure and underlying assumptions of the CGE model. As the Social Accounting Matrix (SAM) used to calibrate the model only reflects a 'snapshot' in time and does not contain detailed time series such as are used in econometric analyses, the (long-run) direction of effects is more reliable than the magnitude, the more so since many of the parameters and elasticities are imposed rather than empirically estimated. CGE modellers address this issue by carrying out sensitivity analyses, which goes some way to assessing the potential errors from using parameters not acquired through econometric methods.

Using a CGE model, effects on income and welfare caused by the introduction of a GM crop can be isolated from confounding factors that affect the same markets. By simulating the introduction of GM crops under different scenarios, potential (future) circumstances can be accounted for. A model is by definition a simplification of reality, so simulation results generally only provide a general sense of the magnitude and direction of effects.

General equilibrium models that cover the global production and trade of virtually all (categories of) agricultural crops and commodities are rare. GTAP (Global Trade Analysis Project) is one of the few models and it is the most commonly used one. Such models are intended for predicting general trends, rather than making exact projections of the future. Such general trends are not very sensitive to minor changes in datasets and assumptions, and publishing new analyses is only relevant if it concerns completely different, yet plausible scenarios. This explains why the number of published studies using CGE models are rather limited and often refer to Nielsen & Anderson (2001), which was the first comprehensive CGE study performed on GMOs.

Time needed for effects of GM crop introduction to materialize

Effects on sustainability can be evaluated properly only after they have fully materialized on farmers' fields and after they have been studied and published. For instance, productivity of a GM crop may be lower in the first years after introduction of the event, when it is available only in a few varieties that may not be optimally adapted to local cultivation conditions or that may not be the best varieties in terms of (potential) yield. However, in the course of some years the transgenic event becomes available in a large set of varieties and the difference with conventional varieties largely disappears (e.g. GM soybean) or the potential for higher productivity is realized (e.g. Bt cotton). This 'lag phase' generally lasts several years and needs to be considered when interpreting the results of the reviewed studies. When we say 'materialize', we not only include the time for adoption of new technology by farmers (some GM crops have been accepted in a few years time), but also the time needed for other effects to become established, such as effects on the use of herbicides and pesticides.

3. Brief overview of findings per crop

Soy

The main 'Planet' impact of HT RR (Roundup) Ready soy related to a change in weed management and the use of soil conservation tillage techniques. Available studies suggest that the introduction of HT soy initially resulted in a reduction in herbicide use, as well as a reduction in the environmental impact from these herbicides. In recent years herbicide use in HT soy appears to be rising to levels similar to, or above the levels as they were before the introduction of HT soy. This increase is likely to be, at least partly, related to the emergence of glyphosate-resistant weed biotypes. In the case of HT soy cultivation, this is not a direct general effect of using herbicide-tolerant crops, but it is driven by an over-reliance on glyphosate as the central pillar in weed control, which is enabled by a rotation often also including RR maize, and sometimes RR cotton, in the US. As always when using herbicides (or any biocide, for that matter), it is essential to use alternating herbicides with different modes of action in the crop rotation to prevent the development of resistance in weed species.

The availability of HT soy facilitated the implementation of soil conservation tillage systems, which have several environmental benefits above conventional tillage systems. GM soy may thus also be helpful to cultivate areas where potential weed infestations or soil erosion used to prevent cultivation of land. Any relationship between soy and deforestation appears to be mainly the consequence of the expansion of large-scale soy production for export. There is apparently no direct relationship with the GM trait, as is indicated by the observation that the strongly expanding soy production in central Brazil is based on conventional soy produced on some of the largest arable farms in the world.

Regarding the 'Profit effects', HT soy has a positive effect on farm income through savings in herbicide costs and/or labour, which generally outweigh increases in seed costs. Effects on revenue are only significant in countries where soybean yield was low or quality losses from weed pressure were common. Other benefits for farmers are greater flexibility in crop management (extending the application time for herbicides from a few days to several weeks) and lower production risks. Using *ex-ante* (CGE) model analysis, the introduction of HT soy (together with maize) is expected to lead to net welfare gains at the global level, which increase as more countries adopt the technology. GM crop introduction leads to increased production at lower prices, and production and exports are likely to shift from GM-free to GM-producing countries. An import ban in Western Europe results in a much smaller welfare gain, since as a result of an import ban, Western Europe will produce more crops for animal feeding itself, whilst it is a less efficient producer of such crops. Moreover, the increase in production in GM-producing countries (particularly North-America) is smaller, while non-GM adopters benefit from increased access to Western European markets. Note that results are based on modelling studies and should be interpreted with care. Vertical welfare distribution (i.e. within the production chain) depends amongst others on IP protection. In countries with weak IP protection, e.g. in Argentina, farmers mostly benefit from HT soy introduction. In countries with strong IP protection, the seed industry benefits most. Uncertainties regarding (future) approval of GM soybeans create considerable institutional risk and can affect the competitive position of soy producers and dependent industry, such as feed and livestock producers.

From a 'People' perspective, reduced labour input for GM soy production resulted in fewer on-farm employment opportunities. The impact of GM soy production on working conditions is more related to the comprehensiveness of the law and efficiency and effectiveness of the legal system than to the type of agricultural technology itself. While child and forced labour occurs in the soy sectors of some countries, on the basis of available literature no difference between GM and non-GM production could be observed in this regard. Large-scale expansion activities, rather than the choice for GM, are the primary cause of land rights conflicts in Argentina and in Brazil, where also conventional soy cultivation is expanding dramatically. The farmer's freedom of choice for cultivating GM or non-GM soy has been limited by various factors, including pressures from financiers to use GM or non-GM seeds, lack of market outlets, market demand, arrangements for royalty payments for GM seed ('technology fee'), lack of a functional segregation system, and decreasing availability of non-GM seed. No link between GM soy production and food security has been observed from the available scientific literature. There are likely to be positive impacts on income security and distribution for farmers who are able to adopt GM soybean. No studies were found indicating that aerial crop spraying and community exposure to agrochemicals is more common in GM production than in non-GM, although some civil society organizations state that it is.

Maize

Various GM maize traits are on the market, notably glyphosate-tolerant HT maize and different variants of Bt maize engineered to confer resistance to the corn rootworm and several species of corn (stem) borers. We found and included data on these three forms in our study.

The main 'Planet' impacts of HT maize are similar to those of HT soy and are likewise related to a change in weed management and the use of soil conservation techniques. In important maize producing countries such as the US, maize may be rotated with soybean and thus the relationship in impacts is even closer. However, HT crop adoption rate has been slower in maize than in soy, and thus, a relationship with the use of soil conservation techniques could less clearly be established than with soy, which was also partly due to less studies being found in the scientific literature. The main impacts of Bt maize are related to either an increase in yield with other inputs remaining essentially the same, or to lower insecticide usage. With the Bt system (using the Cry1Ab form) against the European Corn Borer (ECB), these changes were generally less dramatic than with cotton. This is due to the irregular occurrence of the pest insect and the difficulty in the application of insecticides against it. Thus, many non-GM farmers do not use pesticides against ECB, leading to smaller differences in insecticide use between GM and non-GM cultivation, while yield improvements of Bt maize as compared to non-GM are only striking in years with large ECB infestations. However, harvest security and quality is better with Bt maize, and these may be important arguments for farmers (see following paragraph on 'Profit').

When looking at 'Profit' aspects, Bt maize has a positive effect on farm income, by reducing production costs (for corn rootworm resistant GM varieties) or increasing revenue (for both corn rootworm and corn borer resistant GM varieties). Yet, the magnitude of these benefits is highly sensitive to pest pressure and pest control in conventional maize production. HT maize generally has a positive effect on farm income due to cost savings from reduced herbicide use. However, the effect is sensitive to herbicide use in conventional maize production and herbicide prices, and may be neutral or negative for farmers in particular years and countries. GM maize – Bt maize in particular – decreases production risks for farmers. On the other hand, extra costs may have to be made to enable coexistence. Institutional risks, particularly with respect to production in and import into the EU, may slow down GM maize adoption rate by farmers.

Using *ex-ante* (CGE) model analysis, the introduction of HT maize (together with soy) is expected to lead to net welfare gains at the global level, which increase as more countries adopt the technology. GM crop introduction leads to increased production at lower prices, and production and exports are likely to shift from GM-free to GM-producing countries. An import ban in Western Europe results in a much smaller welfare gain, since as a result of an import ban, Western Europe will produce more crops for animal feeding itself, whilst it is a less efficient producer of such crops. Moreover, the increase in production in GM-producing countries (particularly North-America) is smaller, while non-GM adopters benefit from increased access to Western European markets. Note that results are based on modelling studies and should be interpreted with care. The EU Common Agricultural Policy (CAP) moderates the effects on welfare changes in the EU, whether they are positive or negative.

With regard to 'People' aspects, GM (Bt) maize cultivation is likely to require less labour input, also on small-scale farms. Whether this has led to reduced labour opportunities of farm workers or movement of workers to other jobs and regions in both developed and developing countries could not be established. There is a positive impact from reduced risks of exposure of farm workers to insecticides. The (potentially) increased income as benefit (reduced costs for insecticides and labour) seems to outweigh the costs (the technology fee on GM sowing seeds). Most countries in which inroads into the freedom of choice among farmers are found, either have not promulgated adequate regulations or measures to prevent cross-pollination and other types of admixture enabling co-existence of GM and non-GM crop cultivation, and to guarantee proper and meaningful participation of stakeholders, or lack effective and efficient means of enforcement of such measures. As a particular case, indigenous people and local communities in Mexico and Colombia were faced with GM maize presence in their production. In Mexico this was a consequence of import of GM maize seeds that were approved for consumption but not for cultivation, so that no consultation had been deemed necessary prior to the introduction. In Colombia indigenous local communities were not engaged during the granting process of GM crop cultivation despite the existence of national regulations in this regard. These cases may underline the need for public consultation and prior information and risk management procedures based on the participation of farmers to enable farmers' freedom of choice. For instance, the International Maize and Wheat Improvement Center (CIMMYT) decided to carry out public awareness campaigns, capacity building and monitoring activities in eastern and southern Africa in the frame of the IRMA (Insect-Resistant Maize for Africa) programme to improve the consultation with and information to farmers and community members. There are, however, no simple solutions to this, as can be illustrated by the fact that also the IRMA approach has been criticized for not being fully in line with participatory approaches for lack of presenting all possible alternative solutions (see further below under 5.4, subheading 'Freedom of choice').

Cotton

On the 'Planet' side of sustainability, many studies indicated that the introduction of Bt cotton has resulted in a lower insecticide use in cotton production and/or higher yields. In countries where pest control in non-GM cotton was carried out well, Bt cotton primarily led to a reduction in insecticide use. In countries where insecticide use in non-GM cotton was low, Bt cotton primarily resulted in a yield increase. Cases of insects developing resistance to the Bt toxins in the field have been rare so far.

With regard to the 'Profit' aspects, Bt cotton on average increases farm income, through an increase in revenue and/or a decrease in pesticide costs. Yet, data on farm income should be interpreted carefully as they are not always representative for the entire observed population. High technology fees in certain countries reduce the benefits for the respective farmers. Bt cotton reduces production risk for farmers, provided that seed meets the quality criteria. Financial risks may decrease or increase for small-scale farmers, depending on whether they have difficulties in financing seed, pesticides, or both. Using ex-ante (CGE) model analysis, the introduction of GM cotton is projected to cause a shift in production and income from non-adopting to adopting regions, and to lower cotton prices. Export volumes are expected to decrease more if more developing countries adopt GM cotton, as these countries then become more self-sufficient. Welfare effects of introducing GM cotton are shown to be generally positive across all countries/regions in the world, and considerably higher if all new and prospective countries adopt the technology. For HT cotton, a substantial part of the benefits is projected to accrue to consumers rather than the biotech and seed industry or farmers. For Bt cotton, farmers and the seed industry together have the largest share, although consumers still have a significant share. Bt cotton may contribute to poverty reduction and rural development in absolute terms, provided that it is usable and accessible by smallholder farmers. Institutional failure regarding seed supply has occasionally impeded the adoption of Bt cotton. Also, liability risk in the absence of biosafety laws has withheld seed companies to sell their products in particular (developing) countries.

With regard to 'People' aspects of Bt cotton, several studies showed reductions in exposure to pesticides through a reduced insecticide use. The reduced use of pesticides may also impact positively on the quality of (drinking) water for farmers. Farmers reported pesticide and application cost savings, yield increases and 'peace of mind' about bollworms (as they do not need to worry so much and do not need to constantly monitor) as very important benefits of Bt cotton. Some studies suggested that Bt cotton provided for a decrease in inequality between small-scale farmers of Bt cotton. Evidence supporting the expectation of marginalization of non-Bt cotton growers versus Bt cotton growers was not found. Many farmers, but not all small-scale farmers, could afford the investment necessary for buying Bt cotton seed. Bt seed is more expensive, and for some smallholder farmers this may be financially problematic at the start of the growing season, as the return on investment will only become available after the harvest. However, this constraint is not singly related to GM, as a similar constraint may occur when a farmer wants to buy seeds of hybrid varieties, which are more expensive than seeds of self-pollinating varieties that farmers keep from the previous harvest, but which will also yield more.

No evidence was found that Bt cotton impacted differently on the occurrence of suicides among farmers (reported to occur in India and Africa as a result of indebtedness) than non-GM cotton. In several papers it is acknowledged that Bt cotton could provide for a reduction in labour used for spraying. One might expect that this negatively affects income of those working in cotton production. However, an Indian study showed that when looking at income, all types of households, including those below the poverty line, benefited considerably more from Bt than from conventional cotton. This was a result from more employment for hired female workers (resulting from increased harvesting) and from higher returns to agricultural family labour in alternative employments. No evidence was found that (daily) wages in cotton production were higher when comparing Bt to non-GM cotton production. Insufficient evidence was found to conclude that Bt cotton was positively or negatively related to child labour or forced labour (compared to non-GM cotton). Neither was any evidence found that Bt cotton production may impact on food production or food security on a macro-level. On a micro-level, Bt cotton may compete with food production. However, an increased income as a result of growing Bt cotton may also allow farm families to increase their food purchases. Therefore, a reduction in food production on a micro-level did not necessarily mean a reduction in food consumption. Moreover, the GTAP modelling study suggested that in certain regions the labour force that is released from cotton may shift to food crops, reducing labour shortage constraints in food crops and thereby contributing to food production on a macro-level. Two NGO reports suggest a relation between (the profitability of) Bt cotton crops and land or community rights conflicts. Additional information that supports a relation between Bt cotton and land or community right conflicts has not been found. One study showed that market demand and pressures from financers may pose a limitation to a farmer's freedom to choose non-GM cotton seed. Whether and to what extent intellectual property rights impacted on the availability of non-GM cotton seed and the freedom to choose non-GM seed could not be established based on the studies available.

4. Some outcomes on issues with relevance to debates around GM crops

Several issues that have been looked into in the present study are usually popping up in discussions about sustainability and GM crops: Intellectual property rights (IPR), market power and distribution of benefits of different participants in the agricultural chain (biotech/breeding companies, farmers, processing and retail industry, consumers) and Freedom of choice. Another aspect that emerged from our study was Technical lock-in. All these issues are often associated with GM technology in crops, but on close inspection they are not unique for the technology.

Intellectual property rights (IPR) and distribution of welfare benefits in the production chain

Plant varieties can be protected by Plant Breeders' Rights (PBR). For breeding companies this protection is important as breeding requires a lot of investment, and return on investment may take a long period of time. PBR thus are basic to sustaining optimal conditions for innovation in crop production because otherwise interest in risky R & D would diminish as a disproportional part of benefits could go to parties not having made such investments. Illegal seed trade also may come along with quality problems for the users.

The development of GM crops is particularly costly and constitutes a high-risk investment. However, the results have been protected by patents, which is a different form of intellectual property protection than Plant Breeders' Rights. The relation between R&D costs and patent revenues depends on the extent of patent protection, for instance patent duration. Patent duration may be longer than necessary to make up R&D expenses. However, if this is the case, companies may be expected to invest more in R&D. The extra revenues flow back to society as extra R&D. The simultaneous current trend of consolidation in the breeding sector gives companies a stronger market position, as a result of which their share in welfare gains further increases. This consolidation is partly driven by costly technological developments, as larger companies are more capable of making large investments in research (15-25% of the sales, *Louwaars* et al*., 2009*). Patents redistribute value added from farmers and consumers to the patent holders but are necessary to allow R&D and innovation. Consolidation – if abused - redistributes value added from farmers and consumers to patent holders without any justification. Patents and consolidation are two different forces influencing the welfare distribution in the supply chain. Note, however, that firms in consolidated industries may use R&D and patents to strengthen their market position.

In a competitive market, welfare gains are more equally distributed and the value of a patent is determined by the benefits of the patented product. GM traits are only successful in the long term if they are clearly beneficial for the farmers, for instance, by improving their flexibility, reducing their production risks, and/or improving yield and quality of the product. Indeed, the 'technology fee' that is charged to farmers in the prices for seeds is seen to vary in time and space, which will often depend on expected profits. For instance, prices for Bt seeds in Spain varied between regions, seemingly in line with local infestation levels of the targeted ECB. Further down the production chain, there are also other companies and in the end, consumers who also could reap a larger or smaller part of welfare gains. Our review on 'Profit' aspects showed that the distribution of benefits across all parties depends on specific GM traits and on local circumstances in a particular time frame. For instance with cotton, a substantial part of the benefits of HT varieties was projected to accrue to consumers rather than the biotechnology and seed industry, whereas with Bt varieties, farmers and the seed industry together had the largest share, although consumers still had a significant part of it. In some countries, the seed industry reaped more of the benefits than farmers through higher technology fees.

The comparison of Plant Breeders' Rights with patents is a complex issue. It was the subject of a separate study (*Louwaars* et al*., 2009*), which we refer to for more detailed information on this subject. This latter study, however, did not cover the interaction with traditional farming systems. Here farmers could for instance be affected by restrictions on seed saving coming with IPR on GM varieties. However, this is not an entirely new development for farmers. They were confronted with the same choice already when hybrid varieties were introduced. Hybrid seeds give a higher production, but loose their advantage upon subsequent regeneration by the farmer. Another relevant aspect for our study is that breeding companies are on the one hand seeking IP protection for genes and events in GM crops, and on the other hand for other innovative methods in plant breeding, such as traits introgressed using marker-assisted selection (e.g. aphid resistance from a wild relative, poisonous lettuce, into cultivated lettuce). Therefore, we expect that the discussion about patents in relation to plant variety protection will continue, also outside the realm of genetic modification.

Technical lock-in

One risk of adopting new technology is that of a technical lock-in: if everybody absorbs a new technology and uses it under exclusion of other options, existing valuable technology may be lost that could have contributed to a more flexible and sustainable agricultural system. The disadvantage then lies in that alternatives cannot be easily re-implemented, for loss of knowledge, when the new technology at some point would fail. In the Netherlands, this happened with loss in mechanical weed control expertise upon the introduction of herbicides in the 1960s-1970s. Likewise, a technical lock-in could also be envisaged for weed control in large-scale HT crop production, especially if farmers do not use alternative weed control methods in the crop rotation anymore. In this way, the development of weeds resistant to glyphosate has been observed for example in the US, where three glyphosate-tolerant crops may be used in the same rotation or area: soybean, maize and cotton. As a consequence of dependence on a single herbicide that is now also more extensively used than ever before, a continuous selection pressure is exerted on weeds for developing resistance. Stewardship programmes therefore aim at a diversification of weed management, either by alternating herbicides with different modes of action in the crop rotation or through alternative non-chemical weed control options.

Authors have also expressed a fear for a technical lock-in for Bt-cotton farmers. In this case, surveys in Warangal (India) showed that already before the introduction of Bt cotton, the fast changes in seed brands (not necessarily representing newly bred lines) hampered the farmers in developing their own experiences by first testing new hybrid seed brands on part of their acreage (leading to so-called ‘agricultural deskilling’). Therefore, seed choice appeared to be based more on social grounds, e.g. following locally important farmers. As a result, the quick adoption of a specific Bt cotton hybrid could in the first instance not be attributed to own testing or so-called ‘environmental learning’. However, this depends on local conditions, for instance in Gujarat (India), other seed systems reduced seed lot inconsistencies and so enabled farmers to better assess new technology. Environmental learning may also have been hampered in India by the early trading of seeds that illegally contained the Bt event, and to variable degrees. On the other hand, farmers and traders could also profit from the illegal Bt cotton seed trade, as this enabled them to test whether the Bt trait would be advantageous, while regulation was lagging behind, which actually happened in Gujarat. Since then, many companies licensed the use of Bt events from Monsanto’s Indian joint venture company, a few developed their own events, and they brought this in the genetic background of their own germplasm, so that now they produce a large array of locally adapted Bt cotton varieties. It once again shows that socio-economic impacts of GM crops are strongly dependent on local institutional frameworks (e.g. infrastructure for providing the necessary knowledge to farmers for assessing new varieties and ascertaining seed quality of seed lots on sale) and are mostly not different in that regard from previous innovations, such as the introduction of hybrid varieties.

At a more fundamental level, it is difficult to assess whether the development of transgenes came with a cost of less classical breeding improvements or less input into the development of agro-ecological measures, such as intercropping or use of natural enemies. With regard to breeding, Scott & Pollak (2005) mention that extra effort is needed to introduce transgenes efficiently in breeding programmes and this may come at a cost of creating new conventional lines and hybrids. Vanloqueren & Baret (2009) have argued that technical lock-in may even already occur at the very basis of innovative developments, that is, because GM solutions fit in favourably both with the competitive structure of fundamental research (likely publication in high-ranking journals) and industrialized commercial plant breeding, they will be pursued at the cost of funding of basic and applied science targeting alternative solutions, such as agro-ecological measures. This simple opposition of GM and agro-ecological measures may however overlook the whole array of possible alternatives where GM crops could or could not fit in with other measures aiming at sustainability of the total system, depending on specific situations and requirements. For instance, in a system using agro-ecological measures avoiding the use of biocides, HT crops clearly have no use. On the other hand, as the use of Bt cotton involves much less insecticide usage, it could be implemented alongside biological control of the other insect pest species through natural enemies, which would otherwise be wiped out by the insecticides used against the bollworm. GM crops may thus play a role in broader integrated solutions, such as in integrated pest management (IPM) schemes, but this has only recently begun to receive attention in the literature.

Freedom of choice

The discussion on the freedom for the farmer to choose between GM or non-GM production is by definition uniquely associated with the introduction of GM crops. However, as a (non-subsistence) farmer produces a crop in order to sell the produce, his freedom of choice for the crop or variety has never been absolute: for the larger part, market prospects have always determined which crop or variety a farmer chooses to cultivate. This is most clear in the case of soy cultivation in South-America. Brazilian farmers in northern Mato Grosso primarily deliver soybeans to the traders that operate from harbours in the Amazon River basin, as transport costs to deliver to traders in the south are very high. The traders at two specific harbours along the Amazon River only accept non-GM soybean to satisfy the demand for non-GM soy in foreign markets such as the EU and Japan, thereby limiting the choice of the farmers, given the long transport lines. In Argentina, nearly all soybean is GM and there are no segregation systems, so farmers that would choose to produce conventional soybean will see it become mixed with GM soybean, and they thus they cannot benefit from higher prices for non-GM soy.

For some smallholder farmers, as for instance with cotton in India, the higher prize of Bt seed may be difficult to finance at the start of the growing season, while the return on investment will only become available after the harvest. However, this constraint is not unique to GM, as a similar constraint has occurred with seeds of hybrid varieties, which are more expensive than seeds of open-pollinated varieties that farmers can keep from the previous harvest, but which will also yield more than the farm-saved seeds. On the other hand, research in public institutes in China is partly focussed on GM varieties, enabling their transfer to farmers at lower prices.

As mentioned in the previous section, the continuation of development of both GM and non-GM varieties could pose some problems, but as improvements for many traits are still generated by conventional breeding, transgenic events could be introgressed into such lines. Whether companies will continue to bring improved varieties on the market in both GM and non-GM versions, may for the larger part be a commercial decision. It is possible that, as GM varieties generate higher prices and receive better IPR protection, not all improvements will also be marketed as non-GM varieties. On the other hand, niche markets may develop specifically for non-GM varieties and small breeding companies may focus on such niche markets, as is already happening in the US. Whether well-adapted non-GM varieties remain available may also depend on the activity of local institutes and local breeding companies. For instance, the public research organization Embrapa in Brazil clearly has a mandate to breed non-GM varieties as well. Finally, a farmer's choice can also be limited by constraints in legislation or rules. Farmers in Romania were blocked in their choice of growing GM soybean, which was exceptionally profitable because of problems with weed infestations in conventional cultivation, when Romania entered the EU.

Another aspect that emerged with regard to freedom of choice with the introduction of GM crops is the possibility of spread of transgenes. In the EU, legislation to enable coexistence in the face of transgene flow has been conceived and is being implemented to regulate this issue. However, from the point of view of crop biology, varieties have always been able to pollinate each other and in traditional cultivation systems this has often been welcomed for the maintenance of genetic diversity necessary for the sustainability of these farming systems. With the appearance of transgenes, a need has arisen to address the issue of gene flow between fields of the same crop in order to prevent admixture through pollination with consciously non-GM production. Gene flow can never be brought back to nill in the open agriculture system, and this necessitates the use of thresholds. Thresholds are used in the production of certain speciality crops that are variants of mainstream agricultural crops. For instance, sugar maize or 'waxy' maize needs additional measures to keep cross-pollination with mainstream varieties below a certain threshold, as otherwise the product value would be diminished. With GM and non-GM chain separation, the definition of product value is more difficult, as there is no objective standard for setting a threshold. Therefore, a complicated balance with economical feasibility has to be sought, which in the EU led to a 0.9% threshold above which labelling as GM is obligatory. In the most recently proposed EC recommendation and already on a voluntary basis in trade, room is available for setting lower thresholds for organic cultivations. Still, some organic growers in Spain felt overwhelmed by GM maize cultivations (Binimelis, 2008), as specific legislation was not yet and still is not enabled, and on the other hand, economic modelling indicates remaining problems with economic feasibility of coexistence measures (e.g. 'domino effect', Devos *et al.* 2009). In the US, coexistence is viewed as a market issue, but currently there are several court actions with regard to this issue in other crops than discussed in this report, i.e. alfalfa and sugar beet. Whether coexistence could be enabled for instance in cases of perceived interference with indigenous rights, as in the case of GM admixture in Mexican maize landraces (where gene flow is an integral part of the maintenance of diversity), is not clear yet.

As to institutional frameworks and freedom of choice, there is also discussion about ways of improvement of agriculture by the resource-poor farmers working in traditional systems. Modern varieties together with their necessary inputs may be introduced (top-down), or participatory approaches may be followed, with a whole range of possible combinations in between. A well-known example of a bottom-up approach is the farming system in which farmers employ various landraces that they maintain themselves (personally, of by exchanging with farmers in the village or the region), according to their own selection of what appears best adopted to their conditions. Studies in maize in Mexico have shown that these farmers may actively cross with modern hybrid varieties, in order to introgress better traits into their germplasm. They could view the GM trait as an additional trait with possible advantages or as not useful or even inconsistent with their view of crop quality. An example of a bottom-up approach in which GM was actually adopted in smallholder farming, is the case of illegal Bt cotton varieties in India described in the previous section. However, also the Bt cotton case in India indicated that there needs to be adequate consultation with and reliable information and seed provision to farmers and community members to enable them to make informed choices and to assess and handle modern germplasm optimally. For instance, CIMMYT has recognized that, and has included public awareness campaigns, capacity building and monitoring activities in eastern and southern Africa in the frame of earlier phases of the IRMA (Insect-Resistant Maize for Africa) programme (the current, third, phase of IRMA uses conventional breeding for problems in harvest storage). However, also the IRMA approach has been criticized for not being in line with truly participatory approaches (cf. Soleri *et al.*, 2008) as farmers were consulted about relevance of stem borer infestations for which Bt maize could be relevant, and were involved in stakeholder meetings, but were not asked about desirability of GM approaches as compared to possible alternatives in breeding or agronomic measures. However, improving consultation under complete avoidance of bias is not a simple issue, as for instance evidenced by the approach by Soleri *et al*. (2005): in order to avoid bias, they avoided using the term GM and instead, hypothetical varieties were proposed, e.g. a variety with a disease resistance that may be overcome by the pest in due time enforcing obtaining another variety. Even this could not fully count as a completely neutral representation: for example, this could apply to a Bt variety without accompanying good agricultural practice (stewardship programs), but also to conventional varieties containing single resistance genes.

6. Conclusions

Our study clearly showed that no single value of sustainability can be given that is valid for all GM crops under all conditions.

The term ‘GM crops’ encompasses such a broad diversity of traits with various goals and accompanying effects that sustainability effects cannot be simply summarized for all traits together. Apart from the technology by which they were made (which was not the subject of this review), GM traits in many respects often do not represent changes largely or essentially different from other agricultural innovations, and there is a wide variety of agricultural innovations and changes in agricultural practices in which the specific role of GM is difficult to disentangle from other drivers. Overall, the performance of agriculture varies tremendously between regions and time periods irrespective of the presence of GM crops. Effects of a GM crop on one or more of the sustainability components depend on time and space as well, and effects found for a particular crop, region, and year cannot be simply extrapolated to generic conclusions. Despite this, our study provides a systematic framework of sustainability aspects and their interrelationships that can be used for future case-by-case assessments of second and subsequent generations of GM crops. In addition, some general trends can be given that, however, also apply to most agricultural innovations in general.

Until now, successful GM traits are those that fulfil a niche or a need for the farmer. For the farmer the reason to choose GM crops is not necessarily an increase in production but may also be a reduction of risks and/or an increased flexibility of operations. The former makes the inherently risky operation of a farm less insecure, the latter will decrease costs of operation and make it easier to manage a farm, so that a farmer may choose to operate larger farms, to hire companies to perform particular tasks, or to take on another job to increase family income.

In the past, many agricultural developments were adopted first by the larger-scale and more productive farmers. When they address the need of smallholders they also can be adopted quickly by small-scale farmers, though their profitable use can be seriously hampered by problems such as high seed prizes, inconsistency in performance of seeds on offer and deficiencies in knowledge systems (e.g., Bt-cotton in India, China and other developing countries).

In general, sustainability of the two types of GM crops discussed in this study (herbicide tolerance (HT) and Bt insect resistance) depends on the way that they are used. Bt maize and Bt cotton generally contribute to sustainability in the ‘Planet’ sense. When they are cultivated according to Good Agricultural Practice (GAP) on the basis of recent agronomic and agro-ecological knowledge, also GM HT varieties could contribute to improvement of the sustainability of agricultural production. Otherwise, for instance when weed control in GM crops comes to rely on the use of a single herbicide (glyphosate) with consequent development of herbicide-resistant weeds, sustainability advantages are jeopardized or could turn into the opposite situation, such as a rise in herbicide usage. A similar caveat applies to Bt crops where the opportunity to diminish insecticide use could be jeopardized by non-compliance to methods aimed at delaying resistance development in insect pests. With regard to ‘Profit’ and ‘People’ themes, the contribution of GM crop production to sustainability is highly dependent on local legal and institutional systems. The legal and institutional system should provide an optimal extension infrastructure to farmers, should diminish uncertainties in logistics and trading, should enable freedom of choice and should protect the rights of farmers, employees and consumers.

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7. Literature

ACIN (Asociación de Cabildos Indígenas del Norte del Cauca), Consejo Regional Indígena del Cauca (CRIC), Cacique Mayor del Resguardo de San Andrés de Sotavento, Red Agroecológica del Caribe (RECAR), Corporación Grupo Semillas, Contaminated Crops, 2009.
Threatened Cultures; GMOs and the Human Rights of Indigenous Peoples in Colombia, A report to the United Nations Special Rapporteur on the situation of human rights and fundamental freedoms of indigenous peoples.

Acworth, W., A. Yainshet & R. Curtotti, 2008.
Economic impacts of crops in Australia ABARE research report 08.4. ABARE, Canberra, 35 pp.

Aerni, P., 2005.
Stakeholders attitudes towards the risks and benefits of genetically modifies crops in South Africa. Environmental Science & Policy 8: 464-476.

Aerni, P. & T. Bernauer, 2006.
Stakeholder attitudes toward GMOs in the Philippines, Mexico, and South Africa: The issue of public trust. World Development 34: 557-575.

Amnesty International, 2008.
Contested land in Brazil handed to state.
http://www.amnesty.org/en/news-and-updates/good-news/contested-land-brazil-handed-state-20081022.

Anaya, J., 2010.
Report of the UN Special Rapporteur on the situation of human rights and fundamental freedoms of indigenous people. The situation of indigenous peoples in Colombia: follow-up to the recommendations made by the previous Special Rapporteur. Report on visit to Colombia, 22-27 July 2009. Human Rights Council, UN, A/HRC/15/37/Add.3, 21 pp. http://unsr.jamesanaya.org/docs/countries/2010_report_colombia_en.pdf.

Anderson, K., 2010.
Economic impacts of policies affecting crop biotechnology and trade. New Biotechnology 27: 558-564.

Anderson, K. & L.A. Jackson, 2005a.
Some implications of GM food technology policies for Sub-Saharan Africa. Journal of African Economies 14: 385-410.

Anderson, K. & L.A. Jackson, 2005b.
GM crop technology and trade restraints: economic implications for Australia and New Zealand. Australian Journal of Agricultural and Resource Economics 49: 263-281.

Anderson, K., L.A. Jackson & C.P. Nielsen, 2004.
Genetically modified rice adoption: implications for welfare and poverty alleviation. Journal of Economic Integration 20: 771-788.

Anderson, K., E. Valenzuela & L.A. Jackson, 2008.
Recent and prospective adoption of genetically modified cotton: a global computable General Equilibrium Analysis of economic impacts. Economic Development and Cultural Change 56: 265–296.

Anonymous, 2000.
Integrale nota biotechnologie. Tweede Kamer, vergaderjaar 200-2001, 27 428, nr. 2. Tweede Kamer der Staten Generaal, ’s-Gravenhage, 107 pp.

Antle, J. M., 1983.
Incorporating risk in production analysis. American Journal of Agricultural Economics 65: 1099-1106.

Aramyan, L.H., C.P.A. van Wagenberg & G.B.C. Backus, 2009.
EU policy on GM soy: tolerance threshold and asynchronic approval. LEI Wageningen UR, The Hague. 46 pp.

Backus, G., P. Berkhout, D. Eaton, T. de Kleijn, E. van Mil, P. Roza, W. Uffelmann, A.C. Franke & L.A.P. Lotz, 2008.
EU policy on GMOs. A quick scan of the economic consequences. Report 2008-070, LEI Wageningen UW, the Hague, the Netherlands, 77 pp.

Baker, J.M., T.E. Ochsner, R.T. Venterea & T.J. Griffis, 2007.
Tillage and soil carbon sequestration - What do we really know? Agriculture Ecosystems & Environment 118: 1-5.

Baltazar, B.M., J. de Jesús Sánchez-Gonzalez, L. de la Cruz-Larios & J.B. Schoper, 2005.
Pollination between maize and teosinte: an important determinant of gene flow in Mexico. Theoretical and Applied Genetics 110: 519-526.

BASF, 2010.
BASF and Embrapa's Cultivance®soybeans receive approval for commercial cultivation in Brazil. Press release. http://www.basf.com/group/pressrelease/P-10-148.

Bayer CropScience, 2009.
Liberty Link® cotton fact sheet.
http://www.bayercropscience.com.au/resources/pdf/LibertyLinkCottonFactSheet080806.pdf.

BCI, 2010.
Better Cotton Initative. http://www.bettercotton.org/.

Beckie, H.J., K.N. Harker, L.M. Hall, S.I. Warwick, A. Legere, P.H. Sikkema, G.W. Clayton, A.G. Thomas, J.Y. Leeson, G. Seguin-Swartz & M.J. Simard, 2006.
A decade of herbicide-resistant crops in Canada. Canadian Journal of Plant Science 86: 1243-1264.

Beckmann, V., C. Soregaroli & J. Wesseler, 2006.
Coexistence rules and regulations in the European Union. American Journal of Agricultural Economics 88: 1193-1199.

Bellon, M.R. & J. Berthaud, 2006.
Traditional Mexican Agricultural Systems and the potential impacts of transgenenic varieties on maize diversity. Agriculture and Human Values 23: 3-14.

Benbrook, C., 2009.
Impacts of genetically engineered crops on pesticide use in the United States: The first thirteen years. Critical Issue Report. The Organic Center, Boulder, p VI + 62.

Bennett, R.M., Y. Ismael, U. Kambhampati & S. Morse, 2004a.
Economic impact of genetically modified cotton in India. AgBioForum 7: 96-100.

Bennett, R., Y. Ismael, S. Morse & B. Shankar, 2004b.
Reductions in insecticide use from adoption of Bt cotton in South Africa: impacts on economic performance and toxic load to the environment. Journal of Agricultural Science 142: 665-674.

Bennett, R., U. Kambhampati, S. Morse & Y. Ismael, 2006.
Farm-level economic performance of genetically modified cotton in Maharashtra, India. Review of Agricultural Economics 28: 59-71.

Bennett, R., S. Morse & Y. Ismael, 2003.
Bt cotton, pesticides, labour and health: A case study of smallholder farmers in the Makhathini Flats, Republic of South Africa. Outlook on Agriculture 32: 123–128.

Bernoux, M., C.C. Cerri, C.E.P. Cerri, M.S. Neto, A. Metay, A.S. Perrin, E. Scopel, T. Razafimbelo, D. Blavet, M.D. Piccolo, M. Pavei & E. Milne, 2006.
Cropping systems, carbon sequestration and erosion in Brazil, a review. Agronomy for Sustainable Development 26: 1-8.

Bindraban, P.S., A.C. Franke, D.O. Ferrar, C.M. Ghersa, L.A.P. Lotz, A. Nepomuceno, M.J.M. Smulders & C.C.M. van de Wiel, 2009.
GM-related sustainability: agro-ecological impacts, risks and opportunities of soy production in Argentina and Brazil. PRI report 259. Plant Research International, Wageningen UR, Wageningen, the Netherlands, 50 pp.

Binimelis, R., 2008.
Coexistence of plants and coexistence of farmers: Is an individual choice possible? Journal of Agricultural & Environmental Ethics 21: 437-457.

Bitocchi, E., L. Nanni, M. Rossi, D. Rau, E. Bellucci, A. Giardini, A. Buonamici, G.G. Vendramin & R. Pap, 2009.
Introgression from modern hybrid varieties into landrace populations of maize (*Zea mays* ssp. *mays* L.) in central Italy. Molecular Ecology 18: 603-621.

Blanco-Canqui, H. & R. Lal, 2008.
No-tillage and soil-profile carbon sequestration: An on-farm assessment. Soil Science Society of America Journal 72: 693-701.

Bockstaller, C., L. Guichard, D. Makowski, A. Aveline, P. Girardin & S. Plantureux, 2008.
Agri-environmental indicators to assess cropping and farming systems: a review. Agronomy for Sustainable Development 28: 139-149.

Boddey, R.M., D.F. Xavier, B.J.R. Alves & S. Urquiaga, 2003.
Brazilian agriculture: the transition to sustainability. Journal of Crop Production 9: 593-621.

Bohm, G.M.B., B.J.R. Alves, S. Urquiaga, R.M. Boddey, G.R. Xavier, F. Hax & C.V. Rombaldi, 2009.
Glyphosate- and imazethapyr-induced effects on yield, nodule mass and biological nitrogen fixation in field-grown glyphosate-resistant soybean. Soil Biology & Biochemistry 41: 420-422.

Bolliger, A., J. Magid, T.J.C. Amado, F.S. Neto, M.D.D. Ribeiro, A. Calegari, R. Ralisch & A. de Neergaard. 2006.
Taking stock of the Brazilian 'zero-till revolution': A review of landmark research and farmers' practice. Advances in Agronomy 91: 47-110.

Bonny, S., 2008.
Genetically modified glyphosate-tolerant soybean in the USA: adoption factors, impacts and prospects. A review. Agronomy for Sustainable Development 28: 21-32.

Bouxin, A., 2009.
Feed & food. Statistical yearbook 2009. FEFAC, Brussels, 84 pp. http://www.fefac.org/file.pdf?FileID=24622.

Brethour, C., A. Mussell, H. Mayer & L. Martin, 2002.
Agronomic, economic and environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario. Guelph, ON: George Morris Centre.

Brianezi, T., 2009.
Rodovia BR-158 desponta como vetor de expansão da soja. Repórter Brasil 15/4/2009. http://www.reporterbrasil.org.br/exibe.php?id=1555.

Brookes, G., 2002.
The farm level impact of using Bt maize in Spain. PG Economics Ltd. www.pgeconomics.co.uk/pdf/bt_maize_in spain.pdf.

Brookes, G., 2005.
The farm-level impact of herbicide-tolerant soybeans in Romania. AgBioForum 8: 235-241.

Brookes, G. 2008.
Economic impacts of low level presence of not yet approved GMOs on the EU food sector. Briefing document. GBC Ltd, UK, 40 pp. http://www.agrodigital.com/images/estudio.pdf.

Brookes, G. & P. Barfoot, 2008.
Global impact of biotech crops: socio-economic and environmental effects, 1996-2006. AgBioForum 11: 21-38.

Brookes, G. & P. Barfoot, 2009. Global impact of biotech crops: income and production effects, 1996-2007. AgBioForum 12: 184-208.

Brookes, G. & P. Barfoot, 2009.
GM crops: global socio-economic and environmental impacts 1996-2007. PG Economics Ltd, UK, Dorchester, UK, 128 pp.

Brookes, G. & P. Barfoot, 2010.
GM crops: global socio-economicand environmental impacts 1996-2008. PG Economics ltd, Dorchester, UK. 165 pp.

Brookes, G., T.H. Yu, S. Tokgoz & A. Elobeid, 2010.
The production and price impact of biotech corn, canola, and soybean crops. AgBioForum 13: 25-52.

Bunte, F.H.J., Y. Dijkxhoorn, R.E. Groeneveld, G.J. Hofstede, J.L. Top, J.G.A.J. van der Vorst & J. Wolfert, 2009.
Thought for food; the impact of ICT on agribusiness. LEI Report / Research area 3. Consumers and supply chains 2009-29. LEI Wageningen UR, The Hague, 67 pp.

Buschiazzo, D.E., J.L. Panigatti & P.W. Unger, 1998.
Tillage effects on soil properties and crop production in the subhumid and semiarid Argentinean Pampas. Soil & Tillage Research 49: 105-116.

Busse, M. & S. Braun, 2002.
Trade and investment effects of forced labour: An empirical assessment. HWVA discussion paper 200, Hamburg Institute of International Economics, 24 pp. http://www.econstor.eu/bitstream/10419/19361/1/200.pdf.

Byrne, P.F. & S. Fromherz, 2003.
Can GM and non-GM crops coexist? Setting a precedent in Boulder County, Colorado, USA. Journal of Food, Agriculture and Environment 1: 258-261.

CAPOMA, La Soja Mata, Chaya Communicación, 2009.
Soy and agribusiness expansion in Northwest Argentina. Legalized deforestation and community resistance. 45 pp. http://lasojamata.iskra.net/files/Soy_Expansion_Northwest_Argentina.pdf.

Carley, P., 1989.
The price of the plan. Perceptions of cotton and health in Uzbekistan and Turkmenistan. Central Asian Survey, 8: 1-38.

Carpenter, J., A. Felsot, T. Goode, M. Hammig, D. Onstad & S. Sankula, 2002.
Comparative Environmental Impacts of Biotechnology-derived and Traditional Soybean, Corn, and Cotton Crops. Council for Agricultural Science and Technology, Ames, USA. 189 pp.

Castiglioni, P., D. Warner, R.J. Bensen, D.C. Anstrom, J. Harrison, M. Stoecker, M. Abad, G. Kumar, S. Salvador, R. D'Ordine, S. Navarro, S. Back, M. Fernandes, J. Targolli, S. Dasgupta, C. Bonin, M.H. Luethy & J.E. Heard, 2008.
Bacterial RNA chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water-limited conditions. *Plant Physiology* 147: 446-455.

CBS, 2009.
http://www.cbs.nl/nl-NL/menu/cijfers/default.htm April 2009.

Cerdeira, A.L. & S.O. Duke, 2006.
The current status and environmental impacts of glyphosate-resistant crops: A review. Journal of Environmental Quality 35: 1633-1658.

Cerdeira, A.L., D.L.P. Gazziero, S.O. Duke, M.B. Matallo & C.A. Spadotto, 2007.
Review of potential environmental impacts of transgenic glyphosate-resistant soybean in Brazil. Journal of Environmental Science and Health Part B 42: 539-549.

Champion, G.T., M.J. May, S. Bennett, D.R. Brooks, S.J. Clark, R.E. Daniels, L.G. Firbank, A.J. Haughton, C. Hawes, M.S. Heard, J.N. Perry, Z. Randle, M.J. Rossall, P. Rothery, M.P. Skellern, R.J. Scott, G.R. Squire & M.R. Thomas, 2003.
Crop management and agronomic context of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. Philosophical Transactions of the Royal Society of London B Biological Sciences 358: 1801-1818.

Chapagain, A.K., A.Y. Hoekstra, H.H.G. Savenije & R. Gautam, 2006.
The water footprint of cotton consumption: an assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60: 186-203.

Christoffoleti, P.J., A.J.B. Galli, S.J.P. Carvalho, M.S. Moreira, M. Nicolai, L.L. Foloni, B.A.B. Martin & D.N. Ribeiro, 2008.
Glyphosate sustainability in South American cropping systems. Pest Management Science 64: 422-427.

CEC, 2004.
Maize and Biodiversity, the effects of transgenic maize in Mexico, Key findings and Recommendations. Commission for Environmental Cooperation of North America, Quebec, 38 pp.
http://www.cec.org/Storage/56/4837_Maize-and-Biodiversity_en.pdf

Co-Extra, 2009.
GM and non-GM supply chains: their CO-EXistence and TRAceability. Final activity report-publishable executive summary of EU project Co-Extra, Sixth Framework Programme, Priority 5 Food quality and safety, Contract No. 007158, 77 pp.

Commission of the European Communities, 2003.
Commission recommendation of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming (2003/556/EC). Official Journal of the European Union L 189: 36-47.

Commission of the European Communities, 2006.
Report on the implementation of national measures on the coexistence of genetically modified crops with conventional and organic farming, Communication from the Commission to the Council and the European parliament, COM(2006) 104, Brussels, 76 pp.

Cotton Australia, 2009.
http://www.cottonaustralia.com.au/ April 2009.

Credit & Finance Risk Analysis, 2010.
Soybean commodity market. http://credfinrisk.com/soybean.html

CREM, 2009.
Sustainable Cotton on the shelves, a handbook for the mainstream retail. 35 pp.

Crost, B., B. Shankar, R. Bennett & S. Morse, 2007. I
Bias from farmer self-selection in genetically modified crop productivity estimates: evidence from Indian data. Journal of Agricultural Economics 58: 24-36.

CTNBio, 2009.
Technical Opinion no. 2236/2009 - Commercial Release of Genetically Modified Soybean, Tolerant to Herbicides of Chemical Class Imidazolinones - Soybean CV127, Event BPS-CV127-9. http://www.ctnbio.gov.br/index.php/content/view/14924.html.

d'Engelbronner-Kolff, F.M., 2001.
A web of legal cultures, dispute resolution processes amongst the Sambyu of Northern Namibia. Shaker Publishing BV, Maastricht.

Davis, V.M., K.D. Gibson, T.T. Bauman, S.C. Weller & W.G. Johnson, 2009.
Influence of weed management practices and crop rotation on glyphosate-resistant horseweed (*Conyza canadensis*) population dynamics and crop yield-years III and IV. Weed Science 57: 417-426.

De Barros, R.P., R. Henriques & R. Mendonça, 2001.
A estabilidade inaceitável: Desigualdade e pobreza no Brasil. Texto para discussão Nº 800. IPEA, Rio de Janeiro, 24 pp.

De Groote, H., S. Mugo, D. Bergvinson & B. Odhiambo, 2005.
Assessing the benefits and risks of GE crops: evidence from the Insect Resistance Maize for Africa project. ISB News Report February 2005: 7-9.

De la Fuente, E.B., S.A. Suárez & C.M. Ghersa, 2006.
Soybean weed community composition and richness between 1995 and 2003 in the Rolling Pampas (Argentina). Agriculture, Ecosystems and Environment 115: 229-236.

De Souza Ferreira Filho, J.B. & M. Horridge, 2009.
Would trade liberalization help the poor of Brazil? Agricultural Distortions Working Paper 52795, World Bank, 15 pp.

Deese, W. & J. Reeder, 2007.
Export taxes on agricultural products: Recent history and economic modelling of soybean export taxes in Argentina. US International Trade Commission Journal of International Commerce and Economics, September 2007, 29 pp.

Defra/FSA, 2009.
GM crops and foods: follow-up to the *Food Matters* report by Defra and the FSA. Department for Environment Food and Rural affairs and Food Standards Agency, UK. 24 pp.

Delgado, O., 2007.
The soya route in North West Argentina. In: Rulli, J. (ed.) The United Soy Republics: the truth about soy in South America, p. 132-159. http://lasojamata.iskra.net/files/soy_republic/Chapt06SoyRouteNWArgentina.pdf.

Demont, M., M. Cerovska, W. Daems, K. Dillen, J. Fogarasi, E. Mathijs, F. Muška, J. Soukup & E. Tollens, 2008.
Ex ante impact assessment under imperfect information: Biotechnology in new member states of the EU. Journal of Agricultural Economics 59: 463-486.

Demont, M. & Y. Devos, 2008.
Regulating coexistence of GM and non-GM crops without jeopardizing economic incentives. Trends in Biotechnology 26: 353-358.

Demont, M. & E. Tollens, 2004.
First impact of biotechnology in the EU: Bt maize adoption in Spain. Annals of Applied Biology 145: 197-207.

Devos, Y., M. Demont, K. Dillen, D. Reheul, M. Kaiser & O. Sanvido, 2009.
Coexistence of genetically modified (GM) and non-GM crops in the European Union. A review. Agronomy for Sustainable Development 29: 11-30.

Dewar, A.M., M.J. May, I.P. Woiwod, L.A. Haylock, G.T. Champion, B.H. Garner, R.J.N. Sands, A. Qi & J.D. Pidgeon, 2003.
A novel approach to the use of genetically modified herbicide tolerant crops for environmental benefit. Proceedings of the Royal Society of London Series B, Biological Sciences 270: 335-340.

Dillen, K., P.D. Mitchell, T. Van Looy & E. Tollens, 2010.
The western corn rootworm, a new threat to European agriculture: opportunities for biotechnology? Pest Management Science 66: 956-966.

Doran, K., 2006.
Can we ban child labor without harming household welfare? An answer from schooling experiments. Unpublished paper Princeton University, Princeton, NJ.

Duke, S.O. & S.B. Powles, 2008.
Glyphosate: a once-in-a-century herbicide. Pest Management Science 64: 319-325.

Duke S.O. & S.B. Powles, 2009.
Glyphosate-resistant crops and weeds: now and in the future. AgBioForum 12: 346-357.

Dyer, G.A., J.A. Serratos-Hernández, H.R. Perales, P. Gepts, A. Piñeyro-Nelson, A. Chávez, N. Salinas-Arreortua, A. Yúnez-Naude, J.E. Taylor & E.R. Alvarez-Buylla, 2009.
Dispersal of transgenes through maize seed systems in Mexico. PLoS ONE 4: e5734.

Dyer, G.A. & J.E. Taylor, 2008.
A crop population perspective on maize seed systems in Mexico. Proceedings of the National Academy of Sciences of the United States of America 105: 470-475.

EJF (Environmental Justice Foundation), 2007.
The children behind our cotton. London, UK, 25 pp.

Elbehri, A. & S. Macdonald, 2004.
Estmating the impact of transgenic Bt cotton on West and Central Africa: A general equilibrium approach. World Development 32: 2049 -2064.

Ervin, D., L.L. Glenna & R.A. Jussaume Jr, 2010.
Are biotechnology and sustainable agriculture compatible? Renewable Agriculture and Food Systems 25: 143-157.

EuropaBio, 2010.
Joint Spanish, Romanian and Portuguese delegation calls for fairer access to GM Crops and technologies. Press release Brussels, 12 July 2010.
http://www.europabio.org/PressReleases/general/PR_2010-07-12_Event_Spain_Romania_Portugal.pdf.

EUROSTAT, 2010.
http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/. December 2010.

FAO, 2008.
Opportunities and challenges of biofuel production for food security and the environment in Latin America and the Caribbean. FAO thirtieth regional conference for Latin America and the Caribbean, Brasilia, Brazil, April 2008. LARC/08/4, 7 pp.

FAOSTAT, 2010.
http://faostat.fao.org/default.aspx December 2010.

FAPRI, 2009.
World oilseeds and products. FAPRI Agricultural outlook, Iowa State University, US, pp. 219-281.
http://www.fapri.iastate.edu/outlook.

Farmlandgrab.org, 2009.
Pakistan: Government asked to stop land deals with foreigners. Article from The News, 9 August 2009, on Farmlandgrab website by GRAIN. http://farmlandgrab.org/6932.

Fawcett, R. & D. Towery, 2002.
Conservation tillage and biotechnology. How new technologies can improve the environment by reducing the need to plow. Conservation Technology Information Center (CTIC), West Lafayette, US, 20 pp.

Fediol, 2009.
http://www.fediol.be/. April 2009.

Fernandez-Cornejo, J., 2004.
The seed industry in U.S. agriculture: an exploration of data and information on crop seed markets, regulation, industry structure, and research and development. USDA Economic Research Service, Agriculture Information Bulletin No. AIB786, 81 pp.

Fernandez-Cornejo, J. & M. Caswell, 2006.
The first decade of genetically engineered crops in United States. USDA Economic Research Service, Economic Information Bulletin No. 11, 30 pp.

Fernandez-Cornejo, J., C. Hendricks & A. Mishra, 2005.
Technology adoption and off-farm household income. Journal of Agricultural and Applied Economics 37: 549-564.

Fernandez-Cornejo, J. & D. Schimmelpfennig, 2004.
Have seed industry changes affected research effort? USDA Economic Research Service, Amber Waves February 2004, 19 pp.

Firbank, L.G., M.S. Heard, I.P. Woiwod, C. Hawes, A.J. Haughton, G.T. Champion, R.J. Scott, M.O. Hill, A.M. Dewar, G.R. Squire, M.J. May, D.R. Brooks, D.A. Bohan, R.E. Daniels, J.L. Osborne, D.B. Roy, H.I.J. Black, P. Rothery & J.N. Perry, 2003.
An introduction to the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. Journal of Applied Ecology 40: 2-16.

Fitting, E., 2006.
Importing corn, exporting labor: The neoliberal corn regime, GMOs, and the erosion of Mexican biodiversity. Agriculture and Human Values 23: 15-26.

Fluck, R.C., 1992.
Energy in farm production. Energy in World Agriculture, Vol. 6, Elsevier, Amsterdam, 367 pp.

Follett, R.F., 2001.
Soil management concepts and carbon sequestration in cropland soils. Soil & Tillage Research 61: 77-92.

Franke, A.C., F.M. Greco, M.Y. Noordam, P. Roza, D.J.F. Eaton, P.S. Bindraban & L.A.P. Lotz, 2009.
The institutional and legal environment for GM soy in Brazil. Plant Research International Report 297, Wageningen, 42 pp.

Frisvold, G.B., T.M. Hurley & P.D. Mitchell, 2009.
Adoption of best management practices to control weed resistance by corn, cotton, and soybean growers. AgBioForum 12: 370-381.

Frisvold, G.B., J.M. Reeves & R. Tronstad, 2006.
Bt cotton adoption in the United States and China: international trade and welfare effects. AgBioForum 9: 69-78.

Fulton, M. & K. Giannakas, 2004.
Inserting GM products into the food chain: the market and welfare effects of different labeling and regulatory regimes. American Journal of Agricultural Economics 86: 42-60.

Furlaneto, F.P.B., P.C. Reco, R.A.D. Kanthack, M.S.T. Esperancini & A.L.R.O. Ojima, 2008.
Transgenic versus conventional soybean: estimative of the operational production costs in the Middle Paranapanema, São Paulo State. Ciência e Agrotecnologia 32: 1935-1940.

Gardner, J.G. & C.H. Nelson, 2007.
Genetically modified crops and labor savings in US crop production. Annual Meeting of the Southern Agricultural Economics Association, Mobile, AL, February 2007, 20 pp.

Gardner, J.G., R.F. Nehring & C.H. Nelson, 2009.
Genetically modified crops and household labor savings in US crop production. AgBioForum 12: 303-312.

Gent, C. & P. Braithwaite, 2006.
Cotton and cotton textiles. Unpicking the threads: Conclusions of a value chain analysis. 2nd International colloquium on fair trade and sustainable development, La Chaire de responsabilité sociale et de développement durable, École des Sciences de la Gestion (ESG), Université du Quebec a Montréal (UQAM), 21 pp.

Ghersa, C.M. & M.A. Martinez-Ghersa, 2000.
Ecological correlates of weed seed size and persistence in the soil under different tilling systems: implications for weed management. Field Crops Research 67: 141-148.

Gianessi, L.P., 2008.
Review: Economic impacts of glyphosate crops. Pest Management Science 64: 346–352.

Gianessi, L., S. Sankula & N. Reigner, 2003.
Plant biotechnology: Potential impact for improving pest management in European agriculture The National Center for Food and Agricultural Policy, Washington, DC, 15 pp.

GMO Compass, 2010.
http://www.gmo-compass.org/eng/home/ December 2010.

Gomes, M., A. Biondi, T. Brianezi & V. Glass, 2009.
Brazil of biofuels: impacts of crops on land, environment and society - soybean and castor bean. Biofuel Watch Center, Repórter Brasil, 58 pp. http://www.reporterbrasil.org.br/documentos/brazil_of_biofuels_v4.pdf.

Gómez-Barbero, M., J. Berbel & E. Rodríguez-Cerezo, 2008.
Adoption and performance of the first GM crop introduced in EU agriculture: Bt maize in Spain (EUR 22778 EN). European Commission, Joint Research Centre and Institute for Prospective Technological Studies, Seville, Spain, 55 pp.

Gómez-Barbero, M., J. Berbel & E. Rodríguez-Cerezo, 2008.
Bt corn in Spain - the performance of the EU's first GM crop. Nature Biotechnology 26: 384-386.

Gómez-Barbero, M. & E. Rodríguez-Cerezo, 2006.
Economic impact of dominant GM crops worldwide: a review (EUR 22547 EN). European Commission, Joint Research Centre and Institute for Prospective Technological Studies Seville, Spain, 43 pp.

Gordon, B., 2007.
Manganese nutrition of glyphosate-resistant and conventional soybeans. Better Crops 91: 12-13.

Gouse, M., 2009.
Ten years of Bt cotton in South Africa: Putting the smallholder experience into context. In: Tripp, R. (ed.) Biotechnology and agricultural development, transgenic cotton, rural institutions and resource-poor farmers. Routledge, Oxon, p. 200-224.

Gouse, M., P. Carl, D. Schimmelpfennig & J. Kirsten, 2006.
Three seasons of subsistence insect-resistant maize in South Africa: Have smallholders benefited? AgBioForum 9: 15-22.

Gouse, M., J. Kirsten, B. Shankar & C. Thirtle, 2005a.
Bt cotton in KwaZulu Natal: Technological triumph but institutional failure. AgBiotechNet 7, ABN 134, 7pp.

Gouse, M., J. Piesse, C. Thirtle & C. Poulton, 2009.
Assessing the performance of GM maize amongst smallholders in Kwa-Zulu Natal, South Africa. AgBioForum 12: 78-89.

Gouse, M., C.E. Pray, J. Kirsten & D. Schimmelpfennig, 2005b.
A GM subsistence crop in Africa: the case of Bt white maize in South Africa. International Journal of Biotechnology 7: 84–94.

Gouse, M., C. Pray & D. Schimmelpfennig, 2004.
The distribution of benefits from Bt cotton adoption in South Africa. AgBioForum 7: 187-194.

Govereh, J. & T.S. Jayne, 2002.
Cash cropping and food crop productivity: synergies or trade-offs? Agricultural Economics 28: 39-50.

Grau, H.R., N.I. Gasparri & T.M. Aide, 2005.
Agriculture expansion and deforestation in seasonally dry forests of north-west Argentina. Environmental Conservation 32: 140-148.

Grau, H.R., N.I. Gasparri & T.M. Aide, 2008.
Balancing food production and nature conservation in the Neotropical dry forests of northern Argentina. Global Change Biology 14: 985-997.

Greenpeace, 2004.
Manifesto 'Defend our maize, care for life'.
http://weblog.greenpeace.org/ge/archives/Oaxaca%20MANIFIESTO.pdf.

Grigg, D.B., 1995.
An introduction to agricultural geography. Routledge, New York, 2nd edition, 217 pp.

Grigsby, W.J., 2002.
Subsistence and land tenure in the Sahel. Agriculture and Human Values 19: 151 -164.

Gruère, G., A. Bouët & S. Mevel, 2007.
Genetically modified food and international trade. The case of India, Bangladesh, Indonesia, and the Philippines. International Food Policy Research Institute (IFPRI) Discussion Paper 00740. IFPRI, Washington DC, USA, 48 pp.

Gruère, G., P. Mehta-Bhatt & D. Sengupta, 2008.
Bt cotton and farmer suicides in India. Reviewing the evidence. International Food Policy Research Institute (IFPRI) Discussion Paper 00808. IFPRI, Washington DC, USA, 55 pp.

Grupo Semillas, 2010.
Social human rights in Colombia: GMO's and the human rights of indigenous people of Colombia. Parallel report to the Fifth State Report by the Republic of Colombia concerning the realization of the International Covenant on Economic, Social and Cultural Rights. Grupo Semillas, Bogotá, Colombia, 34 pp.

Gurian-Sherman, D., 2009.
Failure to yield. Evaluating the performance of genetically engineered crops. Union of Concerned Scientists, Cambridge, MA, USA, 43 pp.

Hammar, A., 2001.
'The day of burning': Eviction and reinvention in the margins of northwest Zimbabwe. Journal of Agrarian Change 1: 550–574.

Hart, M.M., J.R. Powell, R.H. Gulden, K.E. Dunfield, K.P. Pauls, C.J. Swanton, J.N. Klironomos, P.M. Antunes, A.M. Koch & J.T. Trevors, 2009.
Separating the effect of crop from herbicide on soil microbial communities in glyphosate-resistant corn. Pedobiologia 52: 253-262.

Harwood, J., V. Heifner, K. Coble, J. Perry & A. Somwaru, 1999.
Managing risk in farming: Concepts, research, and analysis. USDA Economic Research Service, Agricultural Economic Report No. 774, 125 pp. http://www.ers.usda.gov/publications/aer774/aer774.pdf.

Haughton, A.J., G.T. Champion, C. Hawes, M.S. Heard, D.R. Brooks, D.A. Bohan, S.J. Clark, A.M. Dewar, L.G. Firbank, J.L. Osborne, J.N. Perry, P. Rothery, D.B. Roy, R.J. Scott, I.P. Woiwod, C. Birchall, M.P. Skellern, J.H. Walker, P. Baker, E.L. Browne, A.J.G. Dewar, B.H. Garner, L.A. Haylock, S.L. Horne, N.S. Mason, R.J.N. Sands & M.J. Walker, 2003.
Invertebrate responses to the management of genetically modified herbicide-tolerant and conventional spring crops. II. Within-field epigeal and aerial arthropods. Philosophical Transactions of the Royal Society of London Series B-Biological Sciences 358: 1863-1877.

Haverkort, A.J., P.S. Bindraban, J.G. Conijn & F.J. de Ruijter, 2009.
A crop production ecology (CPE) approach to sustainable production of biomass for food, feed and fuel. Outlook on Agriculture 38: 249-258.

Hayley, J., 2006.
GMO traces pressure Spain's organic maize farmers. Planet Ark. http://www.planetark.com/dailynewsstory.cfm/newsid/38756/story.htm.

Head, G., W. Moar, M. Eubanks, B. Freeman, J. Ruberson, A. Hagerty & S. Turnipseed, 2005.
A multiyear, large-scale comparison of arthropod populations on commercially managed Bt and non-Bt cotton fields. Environmental Entomology 34: 1257-1266.

Head, G. & D. Ward, 2009.
Insect resistance in corn through biotechnology. In: Kriz, A.L. & B.A. Larkins (eds) Molecular genetic approaches to maize improvement. Biotechnology in agriculture and forestry Vol. 63. Springer, Berlin/Heidelberg, p. 31-40.

Heap, I., 2009.
The international survey of herbicide resistant weeds. www.weedscience.com. Accessed September 2009.

Heard, M.S., C. Hawes, G.T. Champion, S.J. Clark, L.G. Firbank, A.J. Haughton, A.M. Parish, J.N. Perry, P. Rothery, D.B. Roy, R.J. Scott, M.P. Skellern, G.R. Squire & M.O. Hill, 2003a.
Weeds in fields with contrasting conventional and genetically modified herb icide-tolerant crops. II. Effects on individual species. Philosophical Transactions of the Royal Society of London Series B-Biological Sciences 358: 1833-1846.

Heard, M.S., C. Hawes, G.T. Champion, S.J. Clark, L.G. Firbank, A.J. Haughton, A.M. Parish, J.N. Perry, P. Rothery, R.J. Scott, M.P. Skellern, G.R. Squire & M.O. Hill, 2003b.
Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. I. Effects on abundance and diversity. Philosophical Transactions of the Royal Society of London Series B-Biological Sciences 358: 1819-1832.

Helsel, Z.R., 2006.
Energy in pesticide production and use. In: Pimentel, D. (ed.) Encyclopedia of pest management, 1-1: 1-4. Taylor & Francis, London.

Herring, R.J., 2008.
Whose numbers count? Probing discrepant evidence on transgenic cotton in the Warangal district of India. International Journal of Multiple Research Approaches 2: 145-159.

Hoekstra, A.Y., A.K. Chapagain, M.M. Aldaya & M.M. Mekonnen, 2009.
Water footprint manual. State of the art 2009. Water Footprint Network, Enschede, the Netherlands, 127 pp.

Hofs, J.L., M. Fok & M. Vaissayre, 2006a.
Impact of Bt cotton adoption on pesticide use by smallholders: a 2-year survey in Makhathini Flats (South Africa). Crop Protection 25: 984-988.

Hofs, J.L., B. Hau & D. Marais, 2006b.
Boll distribution patterns in Bt and non-Bt cotton cultivars. I. Study on commercial irrigated farming systems in South Africa. Field Crops Research 98:203-209.

Hofs, J.L., B. Hau, D. Marais & M. Fok, 2006c.
Boll distribution patterns in Bt and non-Bt cotton cultivars. II. Study on small-scale farming systems in South Africa. Field Crops Research 98: 210-215.

Hofs, J.L., A.S. Schoeman & J. Pierre, 2008.
Diversity and adunbance of flower-visiting insects in Bt and non-Bt cotton fields of Maputaland (KwaZulu Natal Province, South Africa). International Journal of Tropical Insect Science 28: 211-219.

Hoisington, D. & R. Ortiz, 2008.
Research and field monitoring on transgenic crops by the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). Euphytica 164: 893-902.

Holland, J.M., 2004.
The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture Ecosystems & Environment 103: 1-25.

Hossain, F., C.E. Pray, Y. Lu, J. Huang, C. Fan & R. Hu, 2004.
Genetically modified cotton and farmers' health in China. International Journal of Occupational and Environmental Health 10: 296–303.

Hoste, R. & J. Bolhuis, 2010.
Sojaverbruik in Nederland. LEI report 2010-059. LEI-WUR, Den Haag, 32 pp.

Huang, J., R. Chen, J. Mi, R. Hu & E. Osir, 2009.
Farmers'seed and pest control management for Bt cotton in China. In: Tripp, R. (ed.) Biotechnology and agricultural development, transgenic cotton, rural institutions and resource-poor farmers. Routledge, Oxon, p. 105-134.

Huang, J., R. Hu, C. Fan, C.E. Pray & S. Rozelle, 2002.
Bt cotton benefits, costs, and impacts in China. AgBioForum 5: 153-166.

Huang, J., R. Hu, F. Qiao & S. Rozelle, 2003.
Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China. Agricultural Economics 29: 55-67.

Hülsbergen, K.J., B. Feil, S. Biermann, G.W. Rathke, W.D. Kalk & W. Diepenbrock, 2001.
A method of energy balancing in crop production and its application in a long-term fertilizer trial. Agriculture Ecosystems & Environment 86: 303-321

Hutchison, W.D., E.C. Burkness, P.D. Mitchell, R.D. Moon, T.W. Leslie, S.J. Fleischer, M. Abrahamson, K.L. Hamilton, K.L. Steffey, M.E. Gray, R.L. Hellmich, L.V. Kaster, T.E. Hunt, R.J. Wright, K. Pecinovsky, T.L. Rabaey, B.R. Flood & E.S. Raun, 2010.
Areawide suppression of European corn borer with Bt maize reaps savings to non-Bt maize growers. Science 330: 222-225.

Icoz, I., D. Saxena, D.A. Andow, C. Zwahlen & G. Stotzky, 2008.
Microbial populations and enzyme activities in soil in situ under transgenic corn expressing Cry proteins from *Bacillus thuringiensis.* Journal of Environmental Quality 37: 647-662.

IFA, 2002.
IFA statistics. http://www.fertilizer.org/ifa/Home-Page/STATISTICS.

ILO, 1989.
C169 Indigenous and tribal peoples convention. http://www.ilo.org/ilolex/cgi-lex/convde.pl?C169.

INTA (Instituto Nacional de Tecnología Agropecuaria), 2008.
Biodiesel production from soybean in Argentina. Doc IIR-BC-INF-09-08, 12 pp.
http://www.inta.gov.ar/info/bioenergia/boletines/bc-inf-09-08.pdf.

IPCC, 2007.
Climate change 2007: synthesis report. An assessment of the Intergovernmental Panel on Climate Change.
http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. Accessed February 2010.

Ismael, Y., R. Bennett & S. Morse, 2001.
Biotechnology in Africa: The adoption and economic impacts of Bt-cotton in the Makhathini flats, Republic of South Africa. Paper presented for AfricaBio Conference: Biotechnology Conference for sub-saharan Africa, 26th – 27th September 2001, Johannesburg, South Africa, 20 pp.
http://www.agbioworld.org/biotech-info/topics/dev-world/africa.pdf.

James, C., 2008.
Global status of commercialized biotech/GM crops: 2008. ISAAA Brief No 39, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY, 243 pp.
http://www.isaaa.org/resources/publications/briefs/39/download/isaaa-brief-39-2008.pdf.

James, C., 2009.
Global status of commercialized biotech/GM crops: 2009. ISAAA Brief No 41, International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY, 290 pp.
http://www.isaaa.org/resources/publications/briefs/41/download/isaaa-brief-41-2009.pdf.

Johnson, W.G., M.D.K. Owen, G.R. Kruger, B.G. Young, D.R. Shaw, R.G. Wilson, J.W. Wilcut, D.L. Jordan & S.C. Weller, 2009.
US farmer awareness of glyphosate-resistant weeds and resistance management strategies. Weed Technology 23: 308-312.

Kambhampati, U., S. Morse, R. Bennett & Y. Ismael, 2005.
Perceptions of the impacts of genetically modified cotton varieties: a case study of the cotton industry in Gujarat, India. AgBioForum 8: 161-171.

Kandiyoti, D., 2008.
Invisible to the world? Dynamics of forced child labour in the cotton sector of Uzbekistan. SOAS, University of London, 40 pp. http://www.soas.ac.uk/cccac/events/cotton-sector-in-central-asia-2005/file49842.pdf.

Karihaloo, J.L. & P.A. Kumar, 2009.
Bt cotton in India. A status report. Asia-Pacific Consortium on Agricultural Biotechnology (APCoAB), New Delhi, India, second edition, 48 pp. http://www.apcoab.org/uploads/files/1276753800bt_cotton2.pdf.

Kaskey, J., 2010.
Monsanto will let bio-crop patents expire. Bloomberg Businessweek January 21, 2010. http://www.businessweek.com/magazine/content/10_05/b4165019364939.htm Accessed February 2010.

Keetch, D.P., J.W. Webster, A. Ngqaka, R. Akanbi & P. Mahlanga, 2005.
Bt maize for small scale farmers: a case study. African Journal of Biotechnology 4: 1505-1509.

Keller, O.R. & H.M. Fontanetto, 1998.
Ensayo de cultivares de soja resistentes a glifosato y convencionales. In: INTA (ed.) Información Técnica para Productores 1997-1998. INTA, p. 164-167.

Kevane, M. & L. Gray, 1999.
A woman's field is made at night: gendered land rights and norms in Burkina Faso. Feminist Economics 5(3): 1-27.

Khandelwal, A., S. Katiyar & M. Vaishnav, 2008.
Child labour in cottonseed production – A case study of cottonseed farms in North Gujarat, Dakshini Rajasthan Mazdoor Union (DRMU).

Kim, E.J., 2008.
Mexico's bioenergy law enactment and energy-food conflict. Ewha Womans University, Department of Political Science and Diplomacy.

King, C.A., L.C. Purcell & E.D. Vories, 2001.
Plant growth and nitrogenase activity of glyphosate-tolerant soybean in resonse to foliar glyphosate applications. Agronomy Journal 93: 179-186.

Kjær, J., P. Olsen, M. Ullum & R. Grant, 2005.
Leaching of glyphosate and amino-methylphosphonic acid from Danish agricultural field sites. Journal of Environmental Quality 34: 608-620.

Kleter, G.A., R. Bhula, K. Bodnaruk, E. Carazo, A.S.Felsot, C.A. Harris, A. Katayama, H.A. Kuiper, K.D. Racke, B. Rubin, Y. Shevah, G.R. Stephenson, K. Tanaka, J. Unsworth, R.D. Wauchope & S.S. Wong, 2007.
Altered pesticide use on transgenic crops and the associated general impact from an environmental perspective. Pest Management Science 63: 1107-1115.

Kok, E.J., L.T. Colon, A.J. Smelt, O. Dolstra, J.J. de Vlieger, G.A.L. Meijer & A.H. Ipema, 2006.
Gegarandeerd GGO-vrije diervoederketens : knelpunten en oplossingsrichtingen. RIKILT, Instituut voor Voedselveiligheid, Wageningen, 87 pp.

Kooistra, K., R. Pyburn (chapter 5) & A. Termorshuizen, 2006.
The sustainability of cotton. Consequences for man and environment. Science Shop Wageningen University and Research Center Report No. 223, XVI + 60 pp.

Kostandini, G., B.F. Mills, S.W. Omamo & S. Wood, 2009.
Ex ante analysis of the benefits of transgenic drought tolerance research on cereal crops in low-income countries. Agricultural Economics 40: 477-492.

Kovach, J., C. Petzolt, J. Degnil & J. Tette, 2009.
A method to measure the environmental impact of pesticides.
http://nysipm.cornell.edu/publications/eiq/default.asp.

Kremer, R.J. & N.E. Means, 2009.
Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. European Journal of Agronomy 31: 153-161.

Kremer, R.J., N.E. Means & S. Kim, 2005.
Glyphosate affects soybean root exudation and rhizosphere micro-organisms. International Journal of Environmental Analytical Chemistry 85: 1165-1174.

Kruger, M., J.B.J. Van Rensburg & J. Van den Berg, 2009.
Perspective on the development of stem borer resistance to Bt maize and refuge compliance at the Vaalharts irrigation scheme in South Africa. Crop Protection 28: 684-689.

Lalitha, N., Bharat Ramaswami & P.K. Viswanathan, 2009.
India's experience with Bt cotton: Case studies from Gujarat and Maharashtra. In: Tripp, R. (ed.) Biotechnology and agricultural development, transgenic cotton, rural institutions and resource-poor farmers. Routledge, Oxon, p. 135-167.

Laursen, L., 2010.
How green biotech turned white and blue (news feature). Nature Biotechnology 28: 393-395.

Lemaux, P.G., 2009.
Genetically engineered plants and foods: a scientist's analysis of the issues (Part II). Annual Review of Plant Biology 60: 511-559.

Levidow, L. & K. Boschert, 2008.
Coexistence or contradiction? GM crops versus alternative agricultures in Europe. Geoforum 39: 174-190.

Locke, M.A., R.M. Zablotowicz & K.N. Reddy, 2008.
Integrating soil conservation practices and glyphosate-resistant crops: impacts on soil. Pest Management Science 64: 457-469.

Lotz, L.A.P., J.D.A. Wevers & R.Y. van der Weide, 1999.
My view. Weed Science 47: 479-480.

Louette, D., A. Charrier & J. Berthaud, 1997.
In situ conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. Economic Botany 51: 20-38.

Lu, Y., K. Wu, Y. Jiang, B. Xia, P. Li, H. Feng, K.A.G. Wyckhuys & Y. Guo, 2010.
Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. Science 328: 1151-1154.

Mankiw, N.G., 2009.
Macroeconomics. Worth Publishers, New York, Seventh Edition, XXXVII + 598 pp.

Marvier, M., C. McCreedy, J. Regetz & P. Kareiva, 2007.
A meta-analysis of effects of Bt cotton and maize on nontarget invertebrates. Science 316: 1475-1477.

Mascarenhas, M. & L. Busch, 2006.
Seeds of change: Intellectual property rights, genetically modified soybeans and seed saving in the United States. Sociologia Ruralis 46: 122-138.

Mathieu, P., M. Zongo & L. Paré, 2003.
Monetary land transactions in Western Burkina Faso: Commoditisation, papers and ambiguities. In: Benjaminsen, T.A. & C. Lund (eds) Securing land rights in Africa. Frank Cass, London, p. 109–128.

Meertens, H.C.C., L.J. Ndege & H.J. Enserink, 1995.
Dynamics in farming systems: Changes in time and space in Sukumaland, Tanzania. Royal Tropical Institute, Amsterdam, 96 pp.

Mello, E., 2004.
Brazil Oilseeds and Products. Brazil's 2004/05 Soybean Outlook 2004. USDA, GAIN Report number BR4629.

Messéan, A., F. Angevin, M. Gómez-Barbero, K. Menrad & E. Rodríguez-Cerezo, 2006.
New case studies on the coexistence of GM and non-GM crops in European agriculture (EUR 22102 EN). European Commission, Joint Research Centre and Institute for Prospective Technological Studies, Seville, Spain, 114 pp. http://ftp.jrc.es/EURdoc/eur22102en.pdf.

Mohanty, B., 2005.
We are like the living dead: famer suicides in Maharashtra, Western India. Journal of Peasant Studies 32: 243 -76.

Monti, M., 2008.
Retenciones móviles en los granos: impactos económicos en el Distrito de Rufino. Dirección de Extensión e Investigación Agropecuaria, Ministerio de la Producción, Provincia de Santa Fé, Argentina.

Morse, S., R. Bennett & Y. Ismael, 2005.
Comparing the performance of official and unofficial genetically modified cotton in India. AgBioforum 8: 1-6.

Morse, S., R. Bennett & Y. Ismael, 2006.
Environmental impact of genetically modified cotton in South Africa. Agriculture, Ecosystems & Environment 117: 277-289.

Morse, S., R. Bennett & Y. Ismael, 2007.
Inequality and GM crops: a case-study of Bt cotton in India. AgBioForum 10: 44-50.

Mungai, N.W., P.P. Motavalli, K.A. Nelson & R.J. Kremer, 2005.
Differences in yields, residue composition and N mineralization dynamics of Bt and non-Bt maize. Nutrient Cycling in Agroecosystems 73: 101-109.

Murugkar, M., B. Ramaswami & M. Shelar, 2007.
Competition and monopoly in Indian cotton seed market. Economic and Political Weekly 42: 3781-3789.

MVO, 2009.
Factsheet soy 2009. Product Board MVO, Rijswijk, 27 pp.
http://www.mvo.nl/Portals/0/statistiek/nieuws/2009/MVO_Factsheet_Soy_2009.pdf.

Mwangi, P.N. & A. Ely, 2001.
Assessing risks and benefits: Bt maize in Kenya. Biotechnology and Development Monitor No. 48: 6-9.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca & J. Kent. 2000.
Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Naranjo, S.E., 2009.
Impacts of Bt crops on non-target invertebrates and insecticide use patterns. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 4: 1-23.

Nehring, R., J. Fernandez-Cornejo & D. Banker, 2002.
Off-farm labor and the structure of U.S. agriculture: The case of corn/soybean farms. Presented at 2002 Annual meeting of American Agricultural Economics Association, July 28-31, Long Beach, CA, 26 pp.
http://ageconsearch.umn.edu/bitstream/19763/1/sp02fe03.pdf.

Nielsen, C.P. & K. Anderson, 2001.
Global market effects of alternative European responses to genetically modified organisms. Weltwirtschaftliches Archiv-Review of World Economics 137: 320-346.

OECD –FAO, 2006.
Agricultural Outlook 2006–2015. OECD, Paris, 190 pp.

Osaki, M. & M.O. Batalha, 2009.
Mudança do sistema de produção da soja com o ogm. Apresentação oral, Aministração Rural e Gestão do Agronegócio, Brazil, 18 pp. http://www.sober.org.br/palestra/6/1154.pdf.

Paarlberg, R., 2006.
Are genetically modified (GM) crops a commercial risk for Africa? International Journal of Technology and Globalisation 2: 81-92.

Parthasarathy, D, 2002.
Globalization, new agricultural technologies, and IPRs: Implications of modern biotechnology and genetic engineering for capabilities, exclusion, and livelihoods in developing countries. Paper presented at the 9th Biennial Conference of the International Association for the Study of Common Property, Victoria Falls, Zimbabwe, 17-21 June 2002.

Pemsl, D., H. Waibel & A.P. Gutierrez, 2005.
Why do some Bt-cotton farmers in china continue to use high levels of pesticides? International Journal of Agricultural Sustainability 3: 44-56.

Pengue, W., 2005.
Transgenic crops in Argentina, the ecological and social debt. Bulletin of Science, Technology and Society 25: 314-322.

Peters, P.E., 2004.
Inequality and social conflict over land in Africa. Journal of Agrarian Change 4: 269-314.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saaouri & R. Blair, 1995.
Environmental and economic costs of soil erosion and conservation benefits. Science 24: 1117-1123.

Piñeyro-Nelson, A., J. Van Heerwaarden, H.R. Perales, J.A. Serratos-Hernández, A. Rangel, M.B. Hufford, P. Gepts, A. Garay-Arroyo, R. Rivera-Bustamante & E.R. Álvarez-Buylla, 2009.
Transgenes in Mexican maize: molecular evidence and methodological considerations for GMO detection in landrace populations. Molecular Ecology 18: 750-761.

Powell, J.R., D.J. Levy-Booth, R.H. Gulden, W.L. Asbil, R.G. Campbell, K.E. Dunfield, A.S. Hamill, M.M. Hart, S. Lerat, R.E. Nurse, K.P. Pauls, P.H. Sikkema, C.J. Swanton, J.T. Trevors & J.N. Klironomos, 2009.
Effects of genetically modified, herbicide-tolerant crops and their management on soil food web properties and crop litter decomposition. Journal of Applied Ecology 46: 388-396.

Powles, S., 2008.
Evolved glyphosate-resistant weeds around the world: lessons to be learnt. Pest Management Science 64: 360-365.

Pray, C.E., P. Bengali & B. Ramaswami, 2005.
The cost of biosafety regulations: the Indian experience. Quarterly Journal of International Agriculture 44: 267–289.

Pray, C.E., J. Huang, R. Hu & S. Rozelle, 2002.
Five years of Bt cotton in China - the benefits continue. Plant Journal 31: 423-430.

Pray, C.E., D. Ma, J. Huang & F. Qiao, 2001.
Impact of Bt Cotton in China. World Development 29: 813-825.

Pray, C.E. & A. Naseem, 2007.
Supplying crop biotechnology to the poor: opportunities and constraints. Journal of Development Studies, 43: 192-217.

Price, G.K., W. Lin, J.B. Falck-Zepeda & J. Fernandez-Cornejo, 2003.
Size and distribution of market benefits from adopting biotech crops. USDA Economic Research Service, Technical Bulletin No. 1906, 44 pp.

Prihoda, K.R. & J.R. Coats, 2008.
Fate of *Bacillus thuringiensis* (Bt) Cry3Bb1 protein in a soil microcosm. Chemosphere 73: 1102-1107.

Pschorn-Strauss, E., 2005.
Bt-cotton in South-africa: the case of the Makhathini farmers, Seedling (GRAIN) April 2005: 13-24. http://www.grain.org/seedling/?id=330.

Puricelli, E. & D. Tuesca, 2005.
Weed density and diversity under glyphosate-resistant crop sequences. Crop Protection 24: 533-542.

Qaim, M., 2009.
The economics of genetically modified crops. Annual Review of Resource Economics 1: 665–693.

Qaim, M., E.J. Cap & A. de Janvry, 2003.
Agronomics and sustainability of transgenic cotton in Argentina. AgBioForum 6: 41-47.

Qaim, M. & A. de Janvry, 2003.
Genetically modified crops, corporate pricing strategies, and farmers' adoption: the case of Bt cotton in Argentina. American Journal of Agricultural Economics 85: 814-828.

Qaim, M., C.E. Pray & D. Zilberman, 2008.
Economic and social considerations in the adoption of *Bt* crops. In: Romeis, J., A.M. Shelton & G.G. Kennedy (eds), Integration of insect-resistant genetically modified crops within IPM programs. Springer, Dordrecht, p. 329-356.

Qaim, M., A. Subramanian, G. Naik & D. Zilberman, 2006.
Adoption of Bt cotton and impact variability: insights from India. Review of Agricultural Economics 28: 48–58.

Qaim, M. & G. Traxler, 2005.
Roundup Ready soybeans in Argentina: farm level and aggregate welfare effects. Agricultural Economics 32: 73-86.

Quist, D. & I.H. Chapela, 2001.
Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. Nature 414: 541-543.

Ramessar, K., T. Capell, R.M. Twyman & P. Christou, 2010.
Going to ridiculous lengths-European coexistence regulations for GM crops (commentary). Nature Biotechnology 28: 133-136.

Raney, T., 2006.
Economic impact of transgenic crops in developing countries. Current Opinion in Biotechnology 17: 174–178.

Rangasamy, N. & K. Elumalai, 2009.
Market opportunities and challenges for agri-biotech products in India. Agricultural Economics Research Review 22: 471-481

Reddy, K.N. & R.M. Zablotowicz, 2003. Glyphosate-resistant soybean response to various salts of glyphosate and glyphosate accumulation in soybean nodules. Weed Science 51: 496-502.

Romeis, J., M. Meissle & F. Bigler, 2006.
Transgenic crops expressing *Bacillus thuringiensis* toxins and biological control. Nature Biotechnology 24: 63-71.

Romig, S., 2010.
Argentina court blocks glyphosate spraying near rural town. Dow Jones News Wires, March 21, 2010. http://axisoflogic.com/artman/publish/Article_59002.shtml.

Roy, D.B., D.A. Bohan, A.J. Haughton, M.O. Hill, J.L. Osborne, S.J. Clark, J.N. Perry, P. Rothery, R.J. Scott, D.R. Brooks, G.T. Champion, C. Hawes, M.S. Heard & L.G. Firbank, 2003.
Invertebrates and vegetation of field margins adjacent to crops subject to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. Philosophical Transactions of the Royal Society of London B Biological Sciences 358: 1879-1898.

RTRS, 2010.
Round Table for Responsible Soy. http://www.responsiblesoy.org.

Sadashivappa, P. & M. Qaim, 2009.
Bt cotton in India: development of benefits and the role of government seed price interventions. AgBioForum 12: 172-183.

Sankula, S., 2006.
Quantification of the impacts on US Agriculture of biotechnology-derived crops planted in 2005. National Center for Food and Agricultural Policy, Washington, 90pp.
http://www.researchtriangle.org/uploads/Reports/2005biotechimpacts-finalversion.pdf.

Santos, D.J., V.O. Sadras & F.H. Andrade, 2000.
Genetically modified soybean in Argentina: a yield-glyphosate tolerance trade off? VII World Soybean Research Conference, February 29-March 5, 2004. Embrapa, Foz do Iguassu, PR, Brazil: p. 110.

Sanvido, O., J. Romeis & F. Bigler, 2007.
Ecological impacts of genetically modified crops: ten years of field research and commercial cultivation. In: Fiechter, A. & C. Sautter (eds), Green gene technology. Research in an area of social conflict. Advances in Biochemical Engineering/Biotechnology 107: 235-278.

Schimmelpfennig, D.E., C.E. Pray & M.F. Brennan, 2004.
The impact of seed industry concentration on innovation: a study of US biotech market leaders. Agricultural Economics 30: 157-167.

Schumpeter, J.A., 1942.
Capitalism, socialism and democracy. Harper & Brothers Publishers, New York.

Scott, M.P. & L.M. Pollak, 2005.
Transgenic maize. *Starch/Stärke* 57: 187-195.

SDPI (Sustainable Policy Development institute), 2008.
Draft national employment policy: challenging unemployment and creating decent work for all. SDPI Research and News Bulletin 15, No. 1:12.
http://www.sdpi.org/help/research_and_news_bulletin/jan_march_08/bulletin.pdf.

Serratos-Hernández, J.A., J.L. Gómez-Olivares, N. Salinas-Arreortua, E. Buendía-Rodríguez, F. Islas-Gutiérrez & A. de-Ita, 2007.
Transgenic proteins in maize in the Soil Conservation area of Federal District, Mexico. Frontiers in Ecology and the Environment 5: 247-252.

Shen, R.F., H. Cai & W.H. Gong, 2006.
Transgenic Bt cotton has no apparent effect on enzymatic activities or functional diversity of microbial communities in rhizosphere soil. Plant Soil 285: 149-159.

Sheridan, C., 2010.
Report blames GM crops for herbicide spike, downplays pesticide reductions (news feature). Nature Biotechnology 28: 112-113.

Shi, G., J.-P. Chavas & K.W. Stiegert, 2009.
Pricing of herbicide-tolerant soybean seeds: a market-structure approach. AgBioForum 12: 326-333.

Siegmann, K.A., 2004.
Cotton pickers after the quota expiry: bitter harvest. SDPI (Sustainable Development Policy Insitute) Research and News Bulletin 13, No. 1:6-7.
http://www.sdpi.org/help/research_and_news_bulletin/jan_feb_06/bulletin.pdf.

SIMPOC (Statistical Information and Monitoring Programme on Child Labour), 2001.
Brazil. International Programme on the Elimination of Child Labour (IPEC), International Labour Organisation, Switzerland. http://www.ilo.org/dyn/clsurvey/lfsurvey.list?p_lang=en.

Sisterson, M.S., R.W. Biggs, N.M. Manhardt, Y. Carrière, T.J. Dennehy & B.E. Tabashnik, 2007.
Effects of transgenic cotton on insecticide use and abundance of two generalist predators. Entomologia Experimentalis et Applicata 124: 305-311.

Slater, K., 2003.
Environmental impact of textiles. Production, processes and protection. Woodhead Publishing, Cambridge, UK, 240 pp.

Smale, M., P. Zambrano & M. Cartel, 2006.
Bales and balance: a review of the methods used to assess the economic impact of Bt cotton on farmers in developing economies. AgBioForum 9: 195-212.

Smale, M., P. Zambrano, G. Gruère, J. Falck-Zepeda, I. Matuschke, D. Horna, L. Nagarajan, I. Yerramareddy & H. Jones, 2009.
Measuring the economic impacts of transgenic crops in developing agriculture during the first decade. Approaches, findings, and future directions. IFPRI Food Policy Review 10. International Food Policy Research Institute, Washington DC, 107 pp.

Smyth, S. & A. McHughen, 2008.
Regulating innovative crop technologies in Canada: the case of regulating genetically modified crops. Plant Biotechnology Journal 6: 213-225.

Sobolevsky, A., G. Moschini & H. Lapan, 2005.
Genetically modified crops and product differentiation: Trade and welfare effects in the soybean complex. American Journal of Agricultural Economics 87: 621-644.

Soleri, D., D.A. Cleveland, F. Aragón Cuevas, L.M.R. Fuentes, L.H. Ríos & S.H. Sweeney, 2005.
Understanding the potential impact of transgenic crops in traditional agriculture: maize farmers' perspectives in Cuba, Guatemala and Mexico. Environmental Biosafety Research 4: 141-166.

Soleri, D., D.A. Cleveland, G. Glasgow, S.H. Sweeney, F. Aragón Cuevas, M.R. Fuentes & H. Ríos, 2008.
Testing assumptions underlying economic research on transgenic food crops for Third World farmers: Evidence from Cuba, Guatemala and Mexico. Ecological Economics 67: 667-682.

Spoor, M., 2007.
Ten propositions on rural poverty and agrarian transition in Central Eurasia. IBEI Working Papers 2007/10. IBEI, Barcelona, 44 pp. http://www.recercat.net/bitstream/2072/4479/1/WP_IBEI_10.pdf.

Squire, G.R., C. Hawes, G.S. Begg & M.W. Young, 2009.
Cumulative impact of GM herbicide-tolerant cropping on arable plants assessed through species-based and functional taxonomies. Environmental Science and Pollution Research 16: 85-94.

Stein, A.J. & E. Rodríguez-Cerezo, 2009.
The global pipeline of new GM crops. Implications of asynchronous approval for international trade. JRC Scientific and Technical Reports, European Commission, Joint Research Centre, JRC51799. IPTS-JRC, Sevilla, 113 pp. http://ftp.jrc.es/EURdoc/JRC51799.pdf.

Stone, G.D., 2002.
Biotechnology and suicide in India (commentary). Anthropology News 43(5):5.

Stone, G.D., 2007.
Agricultural deskilling and the spread of genetically modified cotton in Warangal. Current Anthropology 48: 67-103.

Storer, N.P., J.M. Babcock, M. Schlenz, T. Meade, G.D. Thompson, J.W. Bing & R.M. Huckaba, 2010.
Discovery and characterization of field resistance to Bt maize: *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Puerto Rico. Journal of Economic Entomology 103: 1031-1038.

Subramanian, A., K. Kirwan, D. Pink & M. Qaim, 2010.
GM crops and gender issues. Nature Biotechnology 28: 404-406.

Subramanian, A. & M. Qaim, 2009.
Village-wide effects of agricultural biotechnology: the case of Bt cotton in India. World Development 37: 256-267.

Subramanian, A. & M. Qaim, 2010.
The impact of Bt cotton on poor households in rural India. Journal of Development Studies 46: 295-311.

Sundstrom, F.J., J. Williams, A. Van Deynze & K.J. Bradford, 2002.
Identity preservation of agricultural commodities. Agricultural Biotechnology in California Series Publication 8077, University of California, Davis, 15 pp. http://anrcatalog.ucdavis.edu/pdf/8077.pdf.

Sweet, J.B. & P.J.W. Lutman, 2006.
A commentary on the BRIGHT programme on herbicide tolerant crops and the implications of the BRIGHT and Farm Scale Evaluation programmes for the development of herbicide tolerant crops in Europe. Outlooks on Pest Management 17: 249-254.

Sweet, J.B., E. Simpson, J. Law, P. Lutman, K. Berry, R. Payne, G. Champion, M. May, K. Walker, P. Wightman & M. Lainsbury, 2004.
Botanical and rotational implications of genetically modified herbicide tolerance in winter oilseed rape and sugar beet (BRIGHT Project). HGCA, London, 265 pp.

Tabashnik, B.E., J.B.J. van Rensburg & Y. Carrière, 2009.
Field-evolved insect resistance to Bt crops: definition, theory and data. Journal of Economic Entomology 102: 2011-2025.

Thirtle, C., L. Beyers, Y. Ismael & J. Piesse, 2003.
Can GM-technologies help the poor? The impact of Bt cotton in Makhathini Flats, KwaZulu-Natal. World Development 31: 717-732.

Tomei, J. & P. Upham, 2009.
Argentinean soy-based biodiesel: An introduction to production and impacts. Energy Policy 37: 3890-3898.

Torres, J. & J.R. Ruberson, 2005.
Canopy- and ground-dwelling predatory arthropods in commercial Bt and non-Bt cotton fields: patterns and mechanisms. Environmental Entomology 34: 1242-1256.

Traxler, G. & S. Godoy-Avila, 2004.
Transgenic cotton in Mexico. AgBioForum 7: 57-62.

Trigo, E.J. & E.J. Cap, 2006.
Ten years of genetically modified crops in Argentine agriculture. Argentine Council for Information and Development of Biotechnology (ArgenBio), 52 pp.
http://www.efb-central.org/images/uploads/Ten_Years_GM_Crops_in_Argentine_Agric.pdf.

Trigo, E., E. Cap, V. Malach & F. Vilarreal, 2009.
The case of zero-tillage technology in Argentina. IFPRI Discussion Paper 00915. International Food Policy Research Institute, Washington DC, 32 pp.
http://www.ifpri.org/sites/default/files/publications/ifpridp00915.pdf.

Trigona, M., 2009.
The Soy Republic of Argentina. Toward Freedom September 8, 2009.
http://mobile.zcommunications.org/the-soy-republic-of-argentina-by-marie-trigona.

Tripp (ed), 2009.
Biotechnology and Agricultural development. transgenic cotton, rural institutions and resource-poor farmers. Routledge, Oxon, 274 pp.

UNDP (United Nations Development Programme), 2006.
Country Programme Document for Brazil 2007 – 2011.
http://www.undp.org/latinamerica/country-docs/CPD-Brazil.pdf.

UNPFII, 2007.
Declaration on the Rights of Indigenous People. http://www.un.org/esa/socdev/unpfii/en/declaration.html.

US Cotton Board, 2009.
http://www.cottonboard.org/ April 2009.

US Department of State, 2009.
Country Reports on Human Rights Practices, see http://www.state.gov/g/drl/rls/hrrpt/2009/index.htm.

USDA/FAS, 2010.
US States Department of Agriculture / Foreign Agriculture Service. http://www.fas.usda.gov/ Accessed February 2010.

Van Asseldonk, M.A.P.M. & R.B.M. Huirne, 2006.
Coexistence risk analysis. IRMA, Wageningen, 21 pp.

Van Bol, V., S. Claeys, P. Debongnie, J. Godfriaux, L. Pussemier, W. Steurbaut & H. Maraite, 2003.
Pesticide indicators. Pesticide Outlook 14: 159-163.

Van de Wiel, C.C.M. & L.A.P. Lotz, 2006.
Outcrossing and coexistence of genetically modified with (genetically) unmodified crops: a case study of the situation in the Netherlands. NJAS Wageningen Journal of Life Sciences 54: 17-35.

Van Gelder, J.W. & A. Herder, 2009.
Soja Barometer 2009. Een onderzoeksrapport voor de Nederlandse Sojacoalitie. Profundo, Amsterdam, 50 pp.
http://commodityplatform.org/wp/wp-content/uploads/2009/12/achtergrond-soja-barometer-2009-nsc.pdf (in Dutch, translated summary Soy Barometer 2009:
http://commodityplatform.org/wp/wp-content/uploads/2010/06/soybarometerfinal1.pdf.

Van Meijl, H. & F. van Tongeren, 2004.
International diffusion of gains from biotechnology and the European Union's Common Agricultural Policy. Agricultural Economics 31: 307-316.

Van Rie, J. & J. Ferré, 2000.
Insect resistance to *Bacillus thuringiensis* insecticidal crystal proteins. In: Charles, J.-F., A. Delécluse & C. Nielsen-Le Roux (eds) Entomopathogenic bacteria: from laboratory to field application. Kluwer Academic Publishers, Dordrecht, the Netherlands, p. 219-236.

Vanloqueren, G. & P.V. Baret, 2009.
How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. Research Policy 38: 971-983.

Venkateswarlu, D., 2007.
Child bondage continues in Indian cotton supply chain. More than 400,000 children in India involved in hybrid cottonseed cultivation. Study jointly commissioned by OECD Watch, Deutsche Welthungerhilfe (DWHH), India Committee of the Netherlands (ICN), Eine Welt Netz NRW (EWN NRW) and International Labor rights Forum (ILRF), 39 pp. http://www.indianet.nl/pdf/childbondagecotton.pdf.

Venkateswarlu, D., 2010.
Seeds of child labour. Signs of hope. Child and adult labour in cottonseed production in India. Study jointly commissioned by International labour Rights Forum (ILRF), India Committee of the Netherlands (ICN) and Stop Child Labour - School is the Best Place to Work, 31 pp. http://www.indianet.nl/pdf/signsofhope.pdf.

Venkateshwarlu, D. & L. da Corta, 2001.
Transformations in the age and gender of unfree workers on hybrid cotton seed farms in Andhra Pradesh. Journal of Peasant studies 28(3): 1-36.

Venkateswarlu, D. & L. da Corta, 2005.
The price of childhood. On the link between prices paid to farmers and the use of child labour in cottonseed production in Andhra Pradesh, India. Study jointly commissioned by India Committee of the Netherlands, International Labor Rights Fund and Eine Welt Netz NRW, 39 pp.
http://www.indianet.nl/PriceOfChildhood2005_Final.pdf.

Verner, D., 2006.
Labor markets and income generation in rural Argentina. World Bank Policy Research Working Paper 4095, The World Bank, 35 pp. http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2006/12/13/000016406_20061213135909/Rendered/PDF/wps4095.pdf.

Waltz, E., 2009.
Battlefield (news feature). Nature 461: 27-32.

Wang, Z., H. Lin, J. Huang, R. Hu, S. Rozelle & C. Pray, 2009.
Bt cotton in China: are secondary insect infestations offsetting the benefits in farmer fields? Agricultural Sciences in China 8: 83-90.

Williams, G.M., R. Kroes & I.C. Munro, 2000.
Safety evaluation and risk assessment of the herbicide Roundup and its active ingredient, glyphosate, for humans. Regulatory Toxicology and Pharmacology 31: 117-165.

Wise, T.A., 2007.
Policy space for Mexican maize: protecting agro-biodiversity by promoting rural livelihoods. Global Development and Environment Institute Working Paper No. 07-01,Tufts University, Medford, Massachusetts, USA, 22 pp. http://www.ase.tufts.edu/gdae/Pubs/wp/07-01MexicanMaize.pdf.

Wolfenbarger, L.L., S.E. Naranjo, J.G. Lundgren, R.L. Bitzer & L.S. Watrud, 2008.
Bt crop effects on functional guilds of non-target arthropods: a meta-analysis. PLoS ONE 3:e2118.

Wolson, R.A., 2007.
Assessing the prospects for the adoption of biofortified crops in South Africa. AgBioForum 10: 184-191.

WWF, 2010.
http://www.panda.org/ March 2010.

Yorobe, J.M. (Jr.) & C.B. Quicoy, 2006.
Economic impact of Bt corn in the Philippines. Philippine Agricultural Scientist 89: 258-267.

Zambrano, P., L.A. Fonseca, I. Cardona & E. Magalhaes, 2009.
The socio-economic impact of transgenic cotton in Colombia. In: Tripp, R. (ed.) Biotechnology and agricultural development, transgenic cotton, rural institutions and resource-poor farmers. Routledge, Oxon, p. 168-199.

Zilberman, D., H. Ameden & M. Qaim, 2007.
The impact of agricultural biotechnology on yields, risks, and biodiversity in low-income countries. Journal of Development Studies 43: 63–78.