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Executive Summary

Soy production has rapidly expanded in Latin America in the last two decades. From 1990 to 2007, soy production increased from 16 to 61 million tonnes in Brazil and from 12 to 47 million tonnes in Argentina. Also Paraguay and Bolivia have started large-scale soy production. Soy in Latin America is primarily grown for export, with China and the EU being the worlds' largest importers of soy products. Between 1997 and 2007, the share of genetically modified (GM) soy in the total soy production increased from 23% to 95% in Argentina and from 2% to about 66% in Brazil. The only GM soy currently commercially grown in Latin America is soy with a trait leading to tolerance to the herbicide glyphosate. This GM soy line is also known as Roundup Ready® or RR soy.

The use of RR soy has raised much discussion in debates about the socio-economic and environmental consequences of soy production. Many claims on RR soy have been made by various stakeholders, but they often lack science based evidence. To support stakeholders to engage in effective debates on GM soy, an overview of the scientific literature about the agro-ecological sustainability of the cultivation of GM soy in Brazil and Argentina is provided in this report. While socio-economic and institutional matters are evidently of great importance, they have not been within the scope of this study. In addition, almost all our data relate to the cultivation of RR soy. As all new GM events that will be commercially released in Latin America in the near future also relate to the use of broad-spectrum herbicides, the principles, practices and our findings related to RR soy may apply to a large extent to those events as well. Only when it concerns Bt soy, other issues need to be dealt with, which have not been extensively elaborated here.

The development of GM soy deviated from conventional breeding because the desired trait was incorporated in the soy through biotechnological methods rather than the conventional process of crossing plants or using mutation breeding. RR soy was obtained through the direct incorporation of a specific DNA construct, containing a gene originating from Agrobacterium, resulting in the RR trait. By now, the RR trait has been incorporated, through conventional breeding, into a wide range of receiver varieties adapted to local conditions. Therefore the genetic diversity of GM soy is not necessarily different from conventional soy.

No evidence was found that yields of GM soy differ consistently from yields of conventional soy. Differences that have been reported, either lower or higher yields of RR soy, are usually related to the genetic background of the GM varieties, and specific climatic or managerial conditions. There is no experience in large-scale cultivation of RR2 soy to reject or confirm the higher yields claimed for this soy type that will be released shortly.

Co-existence of GM and conventional soy production chains is technically feasible if appropriate measures are taken to minimise cross pollination, herbicide drift and the admixture of GM and conventional soy during field operations and in various post-harvest steps. Co-existence in the field is easily achieved, because soy is a self-pollinator, with outcrossing levels on average in the order of 1%. This implies that adventitious GM presence due to outcrossing declines to close to zero at 2-5 meters from the GM field. The likelihood of GM soy traits dispersing and persisting outside agricultural fields is very small in Latin America.

Potentially, the cultivation of RR soy can assist in lowering the environmental impact from herbicides, relative to conventional soy. Based on data of herbicide use in soy in the main soy cropping areas of Argentina (North Buenos Aires - South Santa Fe), we found substantial differences in the environmental impact from herbicides between conventional and zero tillage systems. Within a tillage system, we found a higher herbicide impact associated with RR soy, relative to conventional soy, primarily due to higher application rates of glyphosate in RR soy. We do not know how generally applicable this finding is, as another study found no such effect of GM soy across all production areas in Argentina. Nevertheless, the results warrant further research on actual herbicide use in GM and conventional soy. Various reasons could explain why the environmental impact from herbicide appears to have increased in RR soy in areas of Argentina. One of them is that the built up of resistance by weeds to glyphosate over time has stimulated farmers to increase glyphosate rates in RR soy to achieve acceptable weed control. The positive interaction between RR soy and the implementation of zero tillage practices may have further stimulated the use of herbicides in RR soy.

It should be noted that most factors that could lead to increased herbicide application rates in GM soy also apply to conventional crops. Broad-spectrum herbicides, especially glyphosate, used as pre-emergence herbicides make up an important component of the weed management in conventional soy. Weeds can also develop herbicide resistance in conventional crops and in zero tillage practices that were introduced in large parts of Brazil and Argentina independent from GM crops.

Zero tillage practices have been successfully introduced in Latin America to reduce soil erosion, to sustain or enhance soil quality and improve soil water balances. Moreover, zero tillage practices can save machinery, labour, time, and inputs, with the exception of herbicide use. A major difficulty associated with this practice is the control of weeds. Without tillage, weeds are not mechanically controlled anymore and other alternative control tools, especially chemical weed control, become more important. The availability of (broad-spectrum) herbicides has been at the base of the widespread adoption of zero tillage worldwide. Before the introduction of GM crops, broad-spectrum herbicides were used as pre-emergence herbicides at a large scale in zero tillage systems. In RR soy, glyphosate can also be applied post-emergence without risking crop damage, which has further eased weed control. While zero tillage techniques were already widely adopted in Latin America before the introduction of RR soy, the characteristics of RR soy have most likely facilitated the expansion of zero tillage practices.

The recent increase in the scale of soy farming in Latin America has been driven by the need to benefit from economies of scale required to export grain bulk products at competitive prizes. The availability of vast areas of new lands at the agricultural frontiers, suitable farm machinery, and appropriate field management techniques facilitated the expansion of large scale operations. The characteristics of RR soy fitted well in these developments. The flexible timing of application of glyphosate as a post-emergence herbicide in RR soy, as well as the implementation of zero tillage techniques, which on its turn may have been facilitated by RR soy, likely aided an enlargement of the scale of farming. However, we found no evidence that the availability of RR soy was an essential or decisive factor in this process. Grain cultivation has always been large scale in Argentina, and scale enlargement in the soy cultivation in Argentina and Brazil started well before the introduction of GM soy.

Monocropping soy or other crops may lead to agronomic difficulties in the long term. Whether or not additional crops are introduced in a crop rotation depends on opportunity costs. When income will be foregone because of lower margins of the alternative crop, the stimulant to rotate will be small. If the net benefits made from RR soy would be higher than those from conventional soy, the stimulant to cultivate soy as a monocrop would be higher in RR soy than in conventional soy. As with the scale farming, it is unlikely that the availability of RR soy has been an essential or decisive factor in allowing farmers to monocrop soy. Other (conventional) crops such as wheat and maize were widely cultivated as monocrops in the past in Argentina.

Based on our assessments of the agro-ecological performance of RR soy and conventional soy in Argentina and Brazil, we recommend stakeholders in the debates about GM and conventional soy to put little emphasis on issues related to the scale or type of cultivation practices (i.e. monocropping, large scale cultivation) or the expansion of soy production into areas which are environmentally sensitive, because these issues can not be unambiguously associated with GM soy. Notwithstanding, these issues are highly relevant for the discussion on sustainable soy production in general. Also the environmental effects of the GM construct itself appear to have little for the debate on the ecological impact of GM soy, while the co-existence of GM and conventional soy production chains can be achieved if appropriate measures are taken. We recommend to focus the GM soy discussion on the use of herbicides in GM and conventional farming systems and the environmental impact from these herbicides in the long term, specifically as related to the build-up of herbicide resistance in weeds.

1. Introduction

1.1 The international dialogue

Soy is a versatile crop that is used for very many purposes. The main driver of soy production is the demand for feed for the production of chicken and pork, primarily in Europe and China. Soy is also used for human consumption. Soy oil is an important ingredient in many processed food items. Soy is a major source for the chemical industry for the production of an array of bio-based products. Recently, soy oil has also become the main feedstock for the production of bio-diesel in Latin America. As a result of these developments, the production of soy has dramatically increased in the last 10 years and will continue to do so in the future (Van Berkum & Bindraban, 2008). Bindraban & Zuurbier (2007) showed that such a volumetric increase cannot be obtained by increasing yield only, necessitating the expansion of the cultivation area. Most of the expansion is expected to occur in Latin American countries such as Brazil, Argentina and Paraguay, because of the relative abundance of productive land and fresh water, and opportunities for large scale, economically competitive production.

It is the expansion of the soy acreage in Latin America that raises a great deal of concern among actors in the soy chain and consumers of soy products. Overexploitation of the enormous biomes in Latin American countries, most notably the Amazon, the Cerrado, the Pampa and the Chaco, would not only affect the economy and ecology of those countries, but of the world as a whole (e.g. Santilli *et al.*, 2005). Other aspects of the cultivation practices of soy also raise consumers' concern, such as the large scale of the operations, the pollution due to the use of agrochemicals, and the social implications for local people. The concern is expressed as the question: is soy production sustainable?

Phrased in more general terms, sustainability is commonly accepted to encompass social, economic and ecological dimensions that should be well balanced. Defining sustainable soy is highly complex, because of the international dimension where soy producing and consuming countries are thousands of kilometres apart. The desires and objectives of societies differ greatly between these countries because of differences in development stages and strategies, resource base, education, institutional capabilities and the like, leading to different perceptions on sustainability.

These contrasting objectives combined with a strong interdependence implies that global platforms are needed for actors to negotiate their desires. The negotiations can only be resolved if the desires can be transformed into sets of criteria that can be monitored through indicators that, in turn, can be implemented in real life by the actors involved in the production chain. Dialogues about these concerns on soy have lead to the installation of the Round Table on Responsible Soy (RTRS) to secure that future expansion of soy production is carried out within a sustainability framework by promoting the use of a responsible standard of soy production, processing and trade. The RTRS (2009) describes the current issues in the production of soy in Latin American countries as follows:

'Soy production and consumption grow at a rhythm without precedents. They demand more land, water, agrochemicals and fuel than ever. This expansion entails a series of economic, ecological and social impacts - from conflicts over land rights to pollution, from soil erosion to labour issues. Land clearing for monocultural plantations removes forests and savannas, destroys most of the local biodiversity and demands wide-scale use of artificial fertilizer and agrochemicals, which menace the ground and surface water systems. Plus, soy production generates few jobs per area due to the intense use of mechanization.'

1.2 The research framework and the objectives

In the RTRS discussion, the distinction between genetically modified soy (GM soy) and conventional soy (conventional soy) has been sidelined so far, as it was deemed too complicated by members of the RTRS. However, given the fierce global debates about the acceptability of GM organisms in the food and feed chains in general, this dimension of soy should be explicitly addressed by the RTRS. It is within this context that an initiative has been undertaken to realize a constructive debate on the benefits and drawbacks of GM soy (Global Connections, 2009).

Debates on GM crops usually touches upon a wide range of topics. These may relate to cultivation practices, such as pollution due to the use of agro-chemicals, effects on non-target organisms, admixture of conventional plants, the nature of practice, e.g. small or large scale farming operations, and the like. Discussions on GM crops also deal with intellectual property rights, the power relations between farmers and private companies that supply seeds, health risks, etcetera. A complete evaluation of the social, economic and environmental dimensions of sustainability of GM and conventional soybean should include this myriad of complex and interrelated issues. Within he framework of this study, it was not feasible however to include such a complete overview of all these issues and dimensions.

It was therefore decided by the project group (see section 1.3) that the scope of this study should be constrained to the (agro-)ecological dimension of the GM and conventional soy production systems in Latin America. This delineation does not imply that other aspects, such as the socio-economic impacts, are found less relevant for the GM soy debate. Rather, these could be considered in future research.

The aim of this report is to provide stakeholders of the dialogue on GM soy with an overview of scientific information on the ecological sustainability of GM and conventional soy production systems in Latin America enabling to engage in informed debates.

The objectives are to:

- determine current and near future commercial application of GM-technology in soy production;
- collect and validate claimed impacts, risks and opportunities of current and near future application of GM-technology in soy production;
- assess existing sustainability criteria against existing and currently proposed (agronomic) practices for GM soy;
- recommend options to manage risks and opportunities of GM soy production.

1.3 Methodology

A project team comprising of Civil Society Organisations, private enterprises, government organisations and researchers has decided on the scope of the study. The project as a whole includes a research component, and a process designed to ensure close interaction between stakeholders through workshops, an advisory group to the research team composed of representatives from various stakeholder groups, and an interactive internet site (http://gmsoydebate.global-connections.nl/). The process has been guided by Aidenvironment (http://www.aidenvironment.org/). The research carried out and presented in this report is the full responsibility of the authors. Inputs, suggestions or interactions with stakeholders served as a guidance for the research issues to be dealt with. Conclusions are as much as possible based on scientific, peer-reviewed literature. An overview of the activities in the project and the process is provided in Figure 1.1.

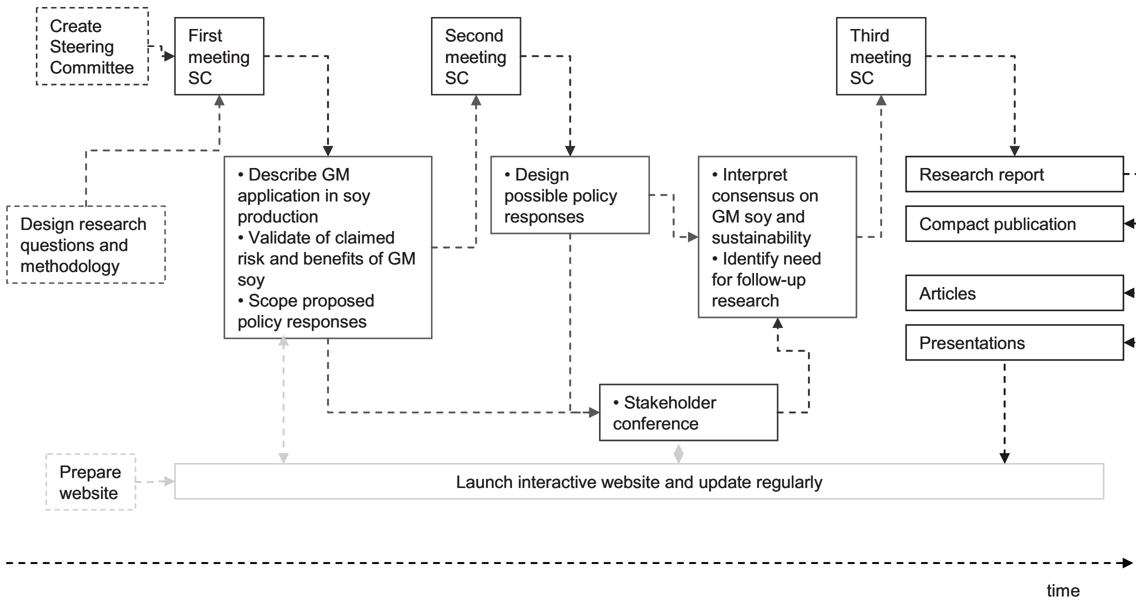

Figure 1.1. *Flow chart of activities ad interactions between involved stakeholders in the project.*

This report presents research findings that are based on scientific literature and information from scientists in Latin America. A characteristic of scientific information is its reproducibility. Peer reviewed literature scrutinizes information on this basis and therefore warrants this quality or reproducibility. In addition, much information is available at universities and research institutions in the form of 'grey literature', i.e. non peer-reviewed research findings, though scrutinized by the responsible institutions on their scientific merits. Information provided by governing bodies, such as the United Nations and national institutions that set conditions and criteria based on scientific knowledge and consensus building among stakeholders has also been used, but only as general information to set the scene. Statistical information provided by such organisations have been used as well. Finally, private companies and Civil Society Organisations also provide information that may be valuable in evaluating the issues reviewed in this study, but may lack a scientific scrutiny. Without criticizing the validity of this information, we have used this type of information only to present the views, perceptions and strategies of these stakeholders. Company websites and other internet sites providing overviews of the registration process of GM crops submitted for regulatory approval have been used to generate information about current and anticipated GM soy lines and their approval status.

When finalising the document, compiled recommendations from the steering committee have been considered and incorporated whenever felt relevant and necessary by the research team. Responses as to how we have dealt with each recommendation were provided to the committee.

How to read this report

This report starts with an overview of the commercially available and anticipated GM soy lines in Latin America (Chapter 2), as well as a description of the soy production systems in Latin America (Chapter 3). In describing these systems, a production ecological perspective has been adopted as a starting point (Figure 1.2). The scientific information is presented in three different ways. First, the scientific information on the sustainability of the GM and conventional soy the production systems is described in Chapter 4. Subsequently, claims made by stakeholders about GM soy in Latin America have been gathered by searching the internet and through feedback from workshops and the internet debate. These claims have been validated using the scientific information gathered on GM soy (Chapter 5). Chapter 6 provides a summary of the results and recommendations that came from this work.

A consequence of the structure of this report is that some information has been repeated in different sections. The section presenting the scientific information on the sustainability of the GM and conventional soy the production systems (Chapter 4) contains the complete set of information used to evaluate the claims and the RTRS criteria.

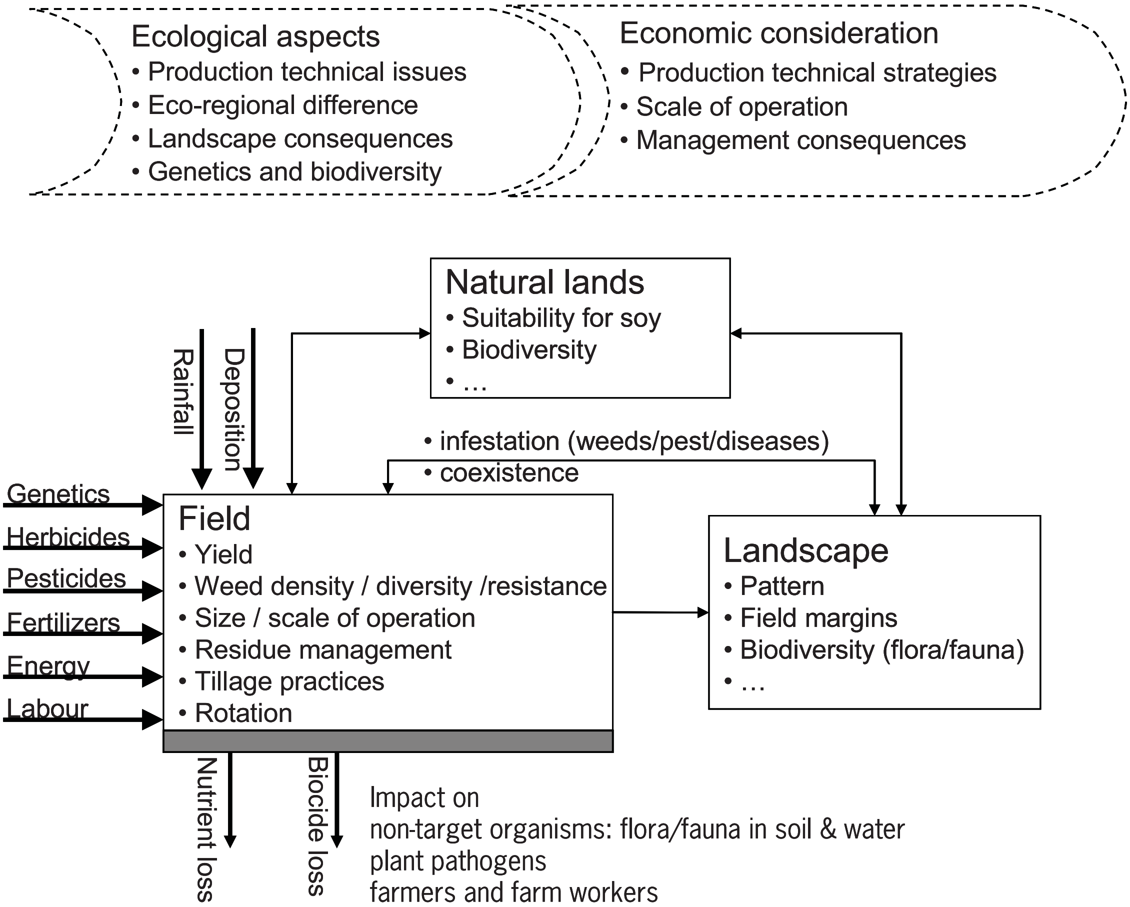

Figure 1.2. *Overview of relevant components of soy cultivation used to assess the agro-ecological sustainability of GM and conventional soy.*

2. Current cultivation and near-future commercial GM soy lines in Latin America

Soy production rapidly expanded in Latin America in the last two decades. From 1990 to 2007, soy production increased from 16 to 61 million tonnes in Brazil and from 12 to 47 million tonnes in Argentina (Soy Stats, 2008; based on USDA data). In 2007, Brazil, the second largest soy producer in the world had a share of 28% in the world soy production, while Argentina and Paraguay accounted for 21% and 3%, respectively. The world's largest soy producer, the USA, had a share of 32%. Also Bolivia has recently started large-scale soy production. Based on foreseen developments in the demand for soy, the sector will maintain a high growth rate in the near future. Soy in Latin America is primarily grown for export, with China and the EU being the world's largest importers of soy products. The EU imports about 40 million tons of soy products (beans, meal and oil) annually, predominantly used to feed livestock with smaller amounts of soy oil and beans used in the food industry (GMO Compass, 2009a).

The share of genetically modified soy (GM soy) in the soy production of Latin America has rapidly increased in recent years. Between 1997 and 2007, it increased in Argentina from 23% to 95% and in Brazil from 2% to 66% (55-63% according to WWF Brazil) (Soy Stats, 2008; based on USDA data). In 2007, the total acreage of GM soy equalled 16 million ha in Argentina and 14.5 million ha in Brazil. In the USA, 91% of the cultivated soy in 2007 was GM, up from 0% in 1995. GM soy accounts for more than half of the world acreage of GM crops and is the most widely grown GM crop (GMO Compass, 2009a).

GM soy follows a conventional breeding pathway in the sense that the desired transgenic trait is bred in a range of conventional varieties. The methodology how this trait was originally incorporated in the crop species differs from conventional breeding techniques. In a conventional breeding program, a desired trait is incorporated through crossing plants by means of controlled pollination and consecutive back-crossing over 5 to 7 generations to arrive at variety that inherits all the good qualities of the receiver variety and as much as possible, only the desired trait from the donor variety. This process is basically a time consuming numbers game that can be accelerated, among others, through advanced breeding techniques. GM soy was obtained through the direct incorporation of isolated genes that determine the desired trait in the receiver variety through laboratory methods of transfer of specific DNA constructs. The *EPSPS* gene in the construct used for introducing the RR trait entailing resistance to the herbicide glyphosate originated from *Agrobacterium*. The RR gene was incorporated in a wide range of receiver varieties adapted to local conditions, which implies that the genetic diversity of GM soy need not differ from conventional soy (Sneller, 2003).

The only GM trait in soy currently released in Latin America leads to tolerance to the non-selective herbicide glyphosate. The RR trait has been bred into a range of varieties adapted to local farming systems and market demands. All registered GM soy varieties commercially grown in Latin America in 2008 have this single GM trait. This type of soy is collectively called 'Roundup Ready®', or RR soy hereafter. Thus, Roundup Ready is a trade mark and 'RR soy' is a collection of varieties that have this GM trait in common. Monsanto Company and a number of companies licensed by Monsanto Company are the producers of RR soy seed (Monsanto Company, 2009). Glyphosate belongs to the herbicide group of the glycines, which inhibit the plant enzyme 5-enolpyruvylshikimate 3-phosphate (EPSP) synthase in the shikimate pathway towards the biosynthesis of aromatic amino acids (Duke & Powles, 2008). When this essential gene is blocked by the herbicide, the plant will die. RR soy still has its own, sensitive, forms of the enzyme but contains an extra gene coding for a glyphosate-insensitive form of this enzyme, obtained from Agrobacterium sp. strain CP4. This insensitive form, so-called CP4 EPSP synthase, remains active after glyphosate treatment of the plants, leading to continued synthesis of aromatic amino acids. Interestingly, the glyphosate sensitivity of this insensitive form can be restored by a single amino acid change (alanine to glycine) in the active site of the enzyme (Funke *et al.*, 2006).

Soy lines with one or more new GM traits that are currently being tested or have been submitted somewhere in Latin America for national regulatory approval include the following.

A GM soy with tolerance to the non-selective herbicide ammonium-glufosinate, the so-called 'LibertyLink®' or LL soy, has been patented by Bayer CropScience (Bayer CropScience, 2009). LL soy is primarily promoted as an alternative for RR soy for farmers that face weed control problems due to the development of glyphosate resistance among weeds (Powles, 2008). Ammonium-glufosinate falls into the herbicide class of the PPO inhibitors, which contains herbicide that inhibit the protoporphyrinogen oxidase enzyme which is involved in the chlorophyl synthesis pathway. LL soy has been registered for production in the USA and production is expected to start in 2009, while the commercial introduction in Argentina and Brazil is still under investigation. In Brazil, the decision whether to approve commercial production of LL soy is expected early 2009. In the EU, LL soy has recently been approved for import as food and feed.

A second generation of RR soy (RR2 soy) will be released in the USA and Canada by Monsanto Company by 2009. RR2 soy offers the same glyphosate tolerance trait as the original RR soy lines, but the trait has been inserted into the crop using a different method based on the use of Agrobacterium. According to Monsanto Company (2009), this method causes less disruption of the genome than the original insertion method. Monsanto Company does not specify on its website in which sense the new method causes less disruption. The gene encoding glyphosate tolerance in RR2 has been inserted into an area of the genome that encodes for a high yield potential. Thus, when this line is used in further crossings to produce other RR2 varieties for e.g. specific uses or regions, genes for high yield potential will accompany the RR2 trait selected for in the production of these varieties. Monsanto company claims on its website that RR2 soy provides 7-11% higher yield, compared to the same type of varieties with the original RR trait. In the EFSA document (GMO Compass, 2009b) accompanying the EU registration process, the company claims a yield increase of 4-7% only. The actual yield increase will probably depend on environmental conditions as well and has not been tested in independent large scale field trials. In Brazil, Monsanto aims to release RR2 soy stacked with a Bt gene (cryA1c) which codes for resistance against certain Lepidoptera species. This Bt gene is already widely used in other GM crops such as Bt cotton and is based on a gene from the bacterium *Bacillus thuringiensis*. It is still uncertain when RR2 - Bt soy will be released in Brazil, as the registration process has not been initiated yet. In Argentina, it is anticipated that Monsanto company will not apply for registration of RR2 soy due to intellectual property issues. RR2 soy has recently been approved for import as food and feed in the EU.

In Brazil, Embrapa, the Brazilian Agricultural Research Corporation, together with the BASF Group has developed a soy line with tolerance to imidazolines herbicides, such as imazethapyr, imazapyr and imazapic. These herbicides fall into the class of ALS-inhibitors, which inhibit the plant enzyme acetolactate synthase which is involved in the synthesis of branched-chain amino acids (Devine *et al.*, 1993). This so-called cultivance soy (CV soy) has been created through a patented transformation process using a gene from a plant species *Arabidopsis thaliana*. The developers of CV soy (Embrapa / BASF Group) expect a commercial launch of this GM line in 2010/2011.

Pioneer Hi-Bred / Dupont plans to release a GM soy variety with tolerance to the herbicide glyphosate, as well as to the ALS-inhibitors chlorimuron and thifensulfuron (Pioneer, 2009). Pioneer Hi-Bred currently sells the GM trait encoding for glyphosate tolerance under the license of Monsanto company. However, the GM trait of the varieties in the pipeline has been patented by Pioneer Hi-Bred itself. According to the company website (Pioneer, 2009), a commercial launch of this product is expected in the USA by 2011. This soy line is marketed under the name of 'Optimum® GAT®', hereafter referred to as Optimum GAT soy. Optimum GAT soy has been approved for cultivation in the USA. Optimum GAT was submitted for regulatory approval by EFSA in the EU in 2007 and is currently still under review. Optimum GAT soy was tested in a number of field experiments in Brazil, but this soy line has not been submitted for approval for commercial production yet. It is uncertain when Optimum GAT soy will be released in Brazil or other Latin American countries.

Other GM soy lines with traits affecting soy production methods are in the pipeline, but are not expected to be released before 2011, as they are still in the early stages of development, and have yet to start the process of regulatory approval.

- Work is ongoing by Monsanto Company to incorporate tolerance against the herbicide Dicamba in soy (Behrens *et al.*, 2007). Dicamba is a broad-spectrum herbicide with a working mechanism different from glyphosate, ammonium-glufosinate and ALS-inhibitors. Dicamba applications can assist in controlling troublesome weeds that have become resistant to the herbicides used in conjunction with GM herbicide tolerant

crops. Dicamba is an auxin-type herbicide that mimics the effects of excess quantities of the natural plant hormone indole-3-acetic acid (IAA) and controls most broadleaf weeds.
- Seed companies also aim to release GM soy varieties with traits that create crops with drought tolerance or a better nutrient use efficiency. It will take 5 years before such traits could become commercially available according to the main seed companies (Monsanto Company, 2009; Pioneer, 2009). Given the complex plant physiological processes involved in these traits, it may also take more time.

Other GM soy technologies in the pipeline focus on grain quality traits in response to demands from consumers and the industry, rather than on agronomic traits beneficial to soy producers.
- Several GM soy varieties in the pipeline have traits leading to an increased or altered lipid (fat) content. These varieties may facilitate the use of soy as a provider of biofuel, improve the storage of soy oil, or make soy oil healthier for human consumption. Soy oil for human consumption may, for instance, be improved by reducing the fraction of saturated fats (Pioneer, 2009) or by adding new, health-promoting fatty acids, such as Omega-3 types, to soy (Monsanto, 2009).
- Work is ongoing to change the protein quality of soy feed with GM and thereby reduce the need for amino-acids supplements in livestock feed.

It may still take several years before varieties with specific grain quality traits will be released, with the exception of soy with a high oleic oil and a lower trans-fat content (Pioneer, 2009), which may be launched commercially in North America in 2009. In Latin America, these GM traits are currently not being tested and they will probably not be commercially released within the next couple of years.

As this study aims to asses the impact of GM traits in soy on the sustainability of farming in Latin America, it is particularly relevant to study the impact of GM soy traits that directly affect the production methods. Therefore, GM traits with a focus on grain quality are excluded from our assessment. GM soy with traits directly affecting production methods that are currently cultivated or expected to be commercially available from 2009-2011 include:
- RR soy (tolerant to glyphosate);
- LL soy (tolerant to ammonium-glufosinate);
- RR2 - Bt soy (tolerant to glyphosate and Lepidoptera pests);
- CV soy (tolerant to ALS inhibitors);
- Optimum GAT soy (tolerant to glyphosate and ALS inhibitors).

3. Description of soy production systems in Latin American countries

3.1 Soy in Brazil

In Brazil, the cultivation of soy was traditionally concentrated in the southern states. When soy varieties adapted to lower latitudes were developed in the 1970s, soy production expanded in the central Cerrado region of Brazil (Goedert, 1983). Currently, 60% of the soy is produced in the Cerrado region, where vast areas of originally grass and scrub savannah have been converted into arable lands. While the southern states are characterised by a variety of small- and large-holder farms, the central states are characterised by large holdings with high levels of mechanisation (Bolliger *et al.*, 2006; Van Berkum *et al.*, 2006). Most recently, soy expansion has taken place in the northern states of Brazil, where much of the soy production is taking place on more recently deforested lands, including the Amazon forest. While the actual share of this region in the total soy production is small, the production is rapidly expanding here (Cerri *et al.*, 2005). In the southern states, soy mostly replaced other arable crops, rather than occupying new, previously uncultivated lands. The recent expansion of soy production in the Cerrado region and the Amazon has also come at the expense of grazing lands and natural areas (Van Berkum *et al.*, 2006; Kessler *et al.*, 2007). Especially in the Cerrado, large areas of natural or extensively managed scrub savannah have been converted to arable land for soy farming. Indirectly, the expanding soy cultivation probably had an impact on natural areas as well. As pastures were converted into arable land for soy cropping, livestock keepers converted natural areas into pastures to compensate for the loss of grazing lands elsewhere (Van Berkum & Bindraban, 2008). Soy in Brazil is grown in monocropping systems or in rotation with maize, wheat or other crops. Growing soy in rotation with other crops is slightly more common in the southern states than in the central or northern states. Zero tillage systems have been rapidly adopted in soy-based cropping systems of Brazil from the 1980s onwards in response to severe problems with soil erosion (Goedert, 1983). Input cost savings from less fuel, machine and labour use became strong drivers for farmers to adopt zero tillage. In 2007, it was estimated that more than 6 million ha were under zero tillage in the Brazilian Cerrados, which is almost half the arable area of the Cerrado (Federaçã Brasileira de Plantio Direto, 2009). The commercial cultivation of GM soy (RR soy) was approved in 2003 and 2004 based on two Presidential decrees, followed by a registration of RR soy within a legal framework in 2005. Since then, the share of GM soy in the total soy area increased to 66% in 2007. Before the approval of GM soy in Brazil, RR soy was presumably already cultivated in Brazil as a result of illegal seed imports from Argentina (Schnepf, 2003).

3.2 Soy in Argentina

In the Pampas ecosystems, the main growing region of soy in Argentina, major structural and functional changes in farming have occurred in the last two centuries. Rapid agricultural expansion took place at the end of the 19th century and by the first decades of the twentieth century, when the area of land ploughed for annual crops covered more than 10 million hectares. By the 1960s, maize dominated the more humid arable systems of the Pampas and in vast areas, maize was cultivated as a monoculture. Progressively, agricultural land use was intensified and in the 1970s, mixed cropping-grazing systems almost disappeared, as wheat-soy double cropping expanded throughout the region, increasing the amount of soil cultivation as well as soil degradation. At the end of the 20th century, zero tillage techniques were widely adopted because it improved water use efficiency by the crop and reduced the labour required for cropping as well as soil degradation (Buschiazzo *et al.*, 1998). In little more than a decade, a large proportion of the cropped soils of the Pampas became permanently under zero tillage. Simultaneously, soy cultivation in monocultures or in wheat-soy double cropping systems became dominant in vast areas of the Pampas. Outside the Pampas, soy cultivation also rapidly expanded in that period (Figure 3.1). Since 1996, the area sown with maize, sunflowers and wheat remained stable or fell in Argentina, while that with soy more than doubled. Of the approximately 25 million hectares currently planted in Argentina with annual crops, 52% has been allocated to soy (Satorre, 2005).

In the more temperate and highly fertile Pampas, cropping has been a form of dominant land use for a long time and here, the area under soy has primarily expanded at the expense of other crops. Outside the Pampas however, the large increase in soy production has also come at the expense of grasslands and natural areas, especially in the northern regions (e.g. Grau *et al.*, 2005 & 2008). As in Brazil, soy cultivation in Argentina also indirectly contributed to the loss of natural areas, as the expanding soy cultivation forced cattle rangers to take natural areas into use.

RR soy has been released in Argentina in 1996. In the 2001/2002 growing season, already 90% of the soy acreage was planted with RR soy (Trigo & Cap, 2003). The introduction of RR soy has been followed by a dramatic increase in the area under soy cultivation, and also the expansion rate of the area under soy increased when RR soy was introduced. During the expansion of RR soy, the Argentinean economy experienced great changes, mainly associated with free-market policies that favoured the concentration of agriculture production and management (Manuel-Navarrete *et al.*, 2008). According to Argentina's National Institute of Statistics and Census, changes in land tenure between 1988 and 2002 showed a strong concentration in the Pampas, with the average area of a production unit increasing from 400 ha to 533 ha (SAGYPA, 2007). These changes in the economic system played an important role in the growth rate of the area cropped with soy, as well as changes in soy productivity and the production system. The concentration of soy production and management facilitated the adoption of input-oriented (machinery, fertilizers, pesticides), and process-oriented (management systems with a high emphasis on information and knowledge, e.g. precision agriculture) farming methods (Manuel-Navarrete *et al.*, 2008).

3.3 Soy in Paraguay

Paraguay has also recently expanded large-scale, export-oriented soy production. In 2007, Paraguay produced 7 million tons of soy, equal to 3% of the world production (Soystats 2008, 2009) and soy was by far Paraguay's most important export commodity contributing to about 60-70% of its total (agricultural and non-agricultural) export. Soy expansion has come at the expense of other crops, such as cotton, as well as pastures and natural areas such as the Atlantic forests. Conflicts about lands between large-scale soy producers and subsistence farmers are being reported by non-governmental organisations as the value of arable land greatly increased. Expansion of soybean area has been estimated at 1 million hectares over the coming decade to reach 4 million hectares in total (FAPRI, 2008).

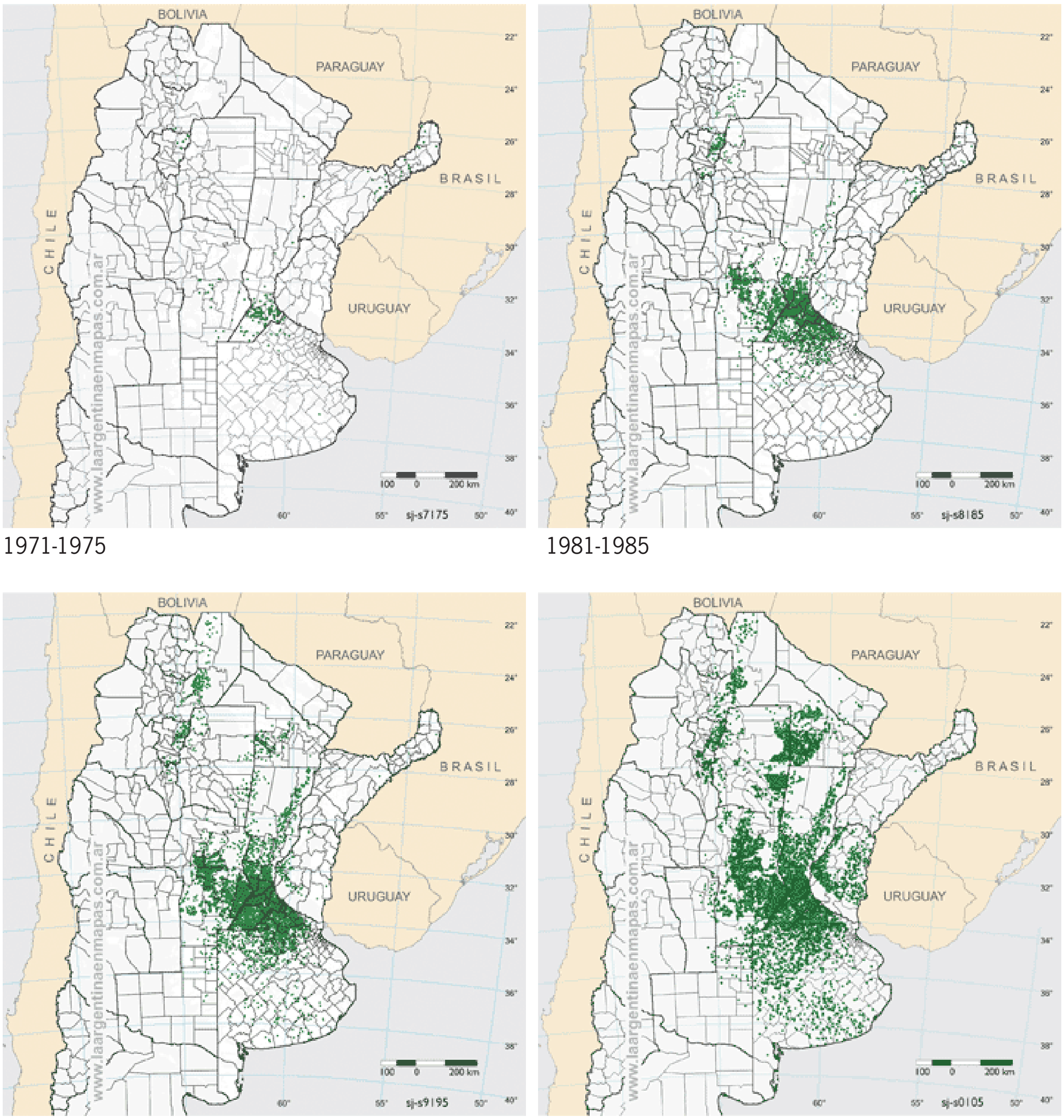

Figure 3.1. *Evolution of the area cultivated with soy in northern Argentina from 1971-1975 to 2001-2005, one dot represents 1000 ha (source: Argentina on maps, 2009).*

4. Agronomic and ecological impacts of GM soy in Argentina and Brazil

4.1 Introduction

The prime difference between the RR soy and conventional soy is the RR genetic trait leading to glyphosate tolerance in plants. RR soy plants withstand the application of the non-selective, broad-spectrum herbicide glyphosate. Weed control in conventional soy requires the use of more selective herbicides and/or non-chemical control methods. The use of broad-spectrum herbicides in crops generally makes weed control for farmers easier, more flexible, and sometimes cheaper. Many of the GM soy lines in the pipeline also have traits that make soy plants tolerant to broad-spectrum herbicides such as ALS inhibitors or ammonium-glufosinate (a PPO-inhibitor). The anticipated RR2 - Bt soy has, besides glyphosate tolerance, tolerance to certain Lepidoptera pests which is likely to affect pest management. The ecological impacts of the current and near-future GM soy lines on the agro-ecosystem are primarily through changes in weed and pest management. These impacts may be direct, e.g. changing herbicide use affecting the environmental impact from these herbicides, or indirect, e.g. weed management may facilitate or discourage certain agricultural practices. Below we give an overview of the scientific information available on the possible direct and indirect impacts of GM soy in comparison with conventional soy, as far as these are related to the production system. Sustainability indicators such as the use of crop protection agents, energy consumption, tillage techniques, biodiversity, yield, etcetera, in relation to GM and conventional soy are discussed. Within each indicator item, we try to integrate the various types of information. However, we do not aim to weigh the diverse sustainability indicators against each other.

4.2 Crop protection in GM and conventional soy

When farmers replace conventional soy with GM soy varieties with tolerance to broad spectrum herbicides, their herbicide use changes drastically. Changing from conventional soy to RR soy production coincides with a strong increase in the use of glyphosate, and a strong decrease in the use of other herbicides used in conventional soy. This has been well documented in the USA. See Figure 4.1 presenting the total herbicide use (kg active ingredients) in soy in the USA, in 1995-2005, a period in which the contribution of RR soy to the total soy acreage increased from 0 to 85%. Overall, total herbicide use did not clearly increase or decrease in the period when RR soy almost entirely replaced conventional soy.

The use of crop protection agents in GM and conventional soy in Latin America has been documented rather poorly. While national statistics on the use of crop protection agents are available for many countries in Latin America, the application rates in a specific GM and conventional crop is generally unknown. We retrieved data on agro-chemical application rates in RR and conventional soy in the main soy cropping area of Argentina (North Buenos Aires - South Santa Fe). We were not able to obtain similar data for other countries in Latin America. In Table 4.1, the main differences in use of crop protection agents between RR and conventional soy in two tillage systems in the main soy cropping area of Argentina are shown. These data are based on management profiles described in AGROMERCADO (AGROMERCADO, 2009). This journal monthly calculates the net and gross margin of each crop in the main agricultural areas of Argentina. In order to calculate those indexes, the common pesticide, herbicide and tillage management is assessed on-farm by extension agents. It is important to note that almost all soy in Argentina is of the RR type nowadays, and data on conventional soy are from 2001, while data on RR soy is an average from 2001-2007. Researchers from the University of Buenos Aires and extension workers from the area reckon that conventional soy would not be managed very differently nowadays than in 2001. These data from AGROMERCADO have not been published in a scientific journal up to now.

Table 4.1 presents input rates separate for zero tillage and conventional tillage as these tillage practices lead to important differences in other management practices. For more information on zero tillage and its relationship with GM soy, see section 4.5.

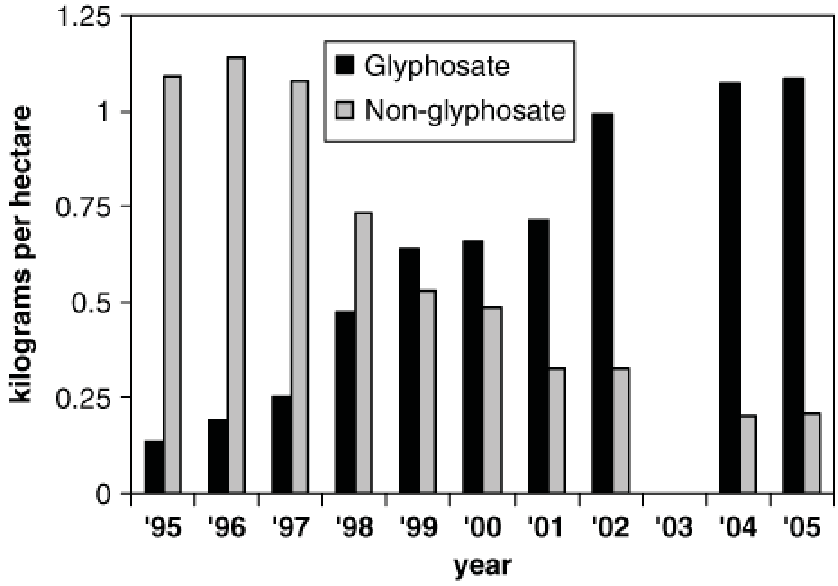

Figure 4.1. *Herbicide use in soy in the USA, average active ingredient per area treated with herbicides, 1995-2005. Data from NASS (2006). From: Kleter et al. (2007).*

Differences in the use of crop protection agents between RR and conventional soy are caused by a replacement of several herbicides, e.g. imidazolinones for broad-leaf weeds, and soil-incorporated triazines for grass species, by glyphosate in RR soy (Table 4.1). However, despite the use of glyphosate in RR soy, some weed problems remain in RR soy systems and therefore, glyphosate is used in conjunction with other herbicides. Glyphosate is not solely applied in RR soy, as it is also commonly used in conventional soy grown in zero tillage systems. In conventional soy, glyphosate is used almost exclusively as a pre-emergence herbicide at the beginning of the growing season. Unlike the USA data in Figure 4.1, the Argentinean data in Table 4.1 suggest that the total herbicide use (accumulated amount of active ingredients) is higher RR soy than in conventional soy in Argentina. An increase in the application rate of glyphosate in RR soy is only partly compensated by a reduction in the use of other herbicides in RR soy, relative to conventional soy. Furthermore, the data suggest that the use of crop protection agents is higher in zero tillage systems than in conventional systems, irrespective of the type of soy that is cultivated. In zero tillage, mechanical weed control is often replaced by chemical control, increasing the reliance on herbicides for weed control. In RR soy / high input fungicides are used whereas they are not in the other rotations. We found no evidence that RR soy is more susceptible to fungi than conventional soy and expect the fungicide use to be related to changes in the farming system over time unrelated to the GM event. The impact of fungicide use on the environmental impact assessment (see below) is very small.

Note that the quantity of crop protection agents applied in the field does not entirely reflect the environmental impact from these applications. This topic is discussed in more detail in the following section.

Table 4.1. Typical application rates of crop protection agents in the main soy cropping area of Argentina (Northern Buenos Aires - South Santa Fe) for a modal and high input level and for fields under zero tillage and conventional tillage. Data for conventional soy corresponds to production systems before they were replaced by RR soy from 2001. Application rates in kg active ingredients ha^{-1}.

Brand Name	Active ingredient	Herbicide class	Type of crop protection agent	Zero tillage		Conventional tillage	
				Conventional soy	RR soy	Conventional soy	RR soy
Modal input level							
GALANT	Haloxyfop	Aryloxyphenoxy acid	Herbicide	0.096	0	0.096	0
2-4 D	2-4 D	Chlorophenoxy acid	Herbicide	0.3	0.3	0	0
PIVOT	Imazetapyr	Imidazolinones	Herbicide	0.1	0	0.1	0
ROUND UP	Glyphosate	Phosphonic acid	Herbicide	1.92	3.36	0	2.4
CIPERMETRINA	Cypermethirin	Pyrethroid	Insecticide	0.025	0.025	0.025	0.025
LORSBAN	Chlorpyrifos	Organophosphate	Insecticide	0.288	0.288	0.288	0.288
High input level							
SPHERE	Trifloxistrobin	Estrobiruline	Fungicide	0	0.065	0	0.065
	Cyproconazole	Triazol	Fungicide	0	0.025	0	0.025
GALANT	Haloxyfop	Aryloxyphenoxy acid	Herbicide	0.096	0	0.096	0
	Metsulphuron	Sulfonylurea	Herbicide	0.042	0	0.042	0
MISIL	Dicamba	Benzoic acid	Herbicide	0.057	0	0.057	0
2-4 D	2-4 D	Chlorophenoxy acid	Herbicide	0.3	0.3	0	0
PIVOT	Imazetapyr	Imidazolinones	Herbicide	0.1	0	0.1	0
ROUND UP	Glyphosate	Phosphonic acid	Herbicide	1.92	3.84	0	2.88
SENCOREX	Metribuzin	Triazinone	Herbicide	0.36	0	0.36	0
CIPERMETRINA	Cypermethirin	Pyrethroid	Insecticide	0.075	0.075	0.075	0.075
LORSBAN	Chlorpyrifos	Organophosphate	Insecticide	0.288	0.288	0.288	0.288
THIODAN	Endosulfan	Chlorinated hydro-carbon	Insecticide	0.21	0.21	0.21	0.21

4.3 Environmental impact from crop protection agents in GM and conventional soy

The quantity of crop protection agents applied in the field does not necessarily reflect the ecological impact from these applications. Also the toxicity of crop protection agents should be taken into account when assessing the ecological impact. Different crop protection agents have a different toxicity per amount of active ingredient, as well as a different environmental burden. Moreover, the surfactants used to apply crop protection agents could affect the ecological impact. Since applications of crop protection agents may impact the environment in various ways, their impact can only be compared with each other if the various impacts are somehow quantified and weighed. We used two methods to compare the environmental impact from crop protection agents in Argentina: the Environmental Impact Quotient (Kovach *et al.*, 2008) and a fuzzy logic system (Ferraro *et al.*, 2003).

The Environmental Impact Quotient (EIQ) is a universal and widely used indicator to assess and compare the environmental impact from the application of crop protection agents (Kovach *et al.*, 2008). The EIQ is calculated with an equation containing various components that estimate the impact of crop protection agents on farm workers, consumers and ecology, i.e. impact on fish, birds, honey bees and beneficial insects. The index contains the following elements: dermal and chronic toxicity to mammals, fish toxicity, leaching potential, surface loss potential, bird toxicity, soil half-life, bee toxicity, beneficial arthropod toxicity and plant surface half-life. An EIQ value is assigned to an active ingredient that is part of a pesticide formulation. To obtain a *field* EIQ, the application rate of each ingredient in the applied agent is multiplied by the EIQ. The EIQ of many crop protection agents has been assessed and is updated regularly based on data from the USA (Kovach *et al.*, 2008). The EIQ values associated with agro-chemicals applied in Latin America may be slightly different from those applied in the USA, as rural landscapes, farming practices and climates differ. In tropical climates, higher temperatures accelerate microbial activities and the decomposition of crop protection agents, relative to temperate climates, reducing the long-term environmental impact from crop protection agents (Racke *et al.*, 1997). It was concluded that crop protection agents in tropical environments, and Latin America in particular, do not show any unique behaviour in comparison to those in temperate climates (Racke *et al.*, 1997; Solomon *et al.*, 2007). Since we did not find information on EIQ values from Latin American production systems, we used EIQ values from the USA in our assessments (Kovach *et al.*, 2008). No EIQ value was available for the herbicide Haloxyfop. This active ingredient is not registered in the USA and several EU countries anymore (CTGB, 2009), presumably due to its toxicity. We assumed an average EIQ value for Haloxyfop in our calculations, which may be an underestimation of its actual impact. However, the contribution of the field EIQ of haloxyfop to the total field EIQ was modest, even when a much higher EIQ value of haloxyfop was assumed.

Field EIQ values for the different soy production systems in Argentina are presented in Table 4.1. Among the crop protection agents used in the Argentinean soy, the EIQ value of glyphosate is lowest while that of chlorpyrifos, an organophosphate insecticide, is highest (Table 4.2). As the application rate of glyphosate in RR soy and in conventional soy under zero tillage is very high, compared to the application rates of other agro-chemicals (Table 4.1), the *field* EIQ of glyphosate is also high, making glyphosate the largest contributor to the total field EIQ value (Table 4.2).

Table 4.2. EIQ values of agro-chemicals applied in soy production systems of Argentina (Table 4.1), the field EIQ value, and the accumulated field EIQ value.

Active ingredient	EIQ value [1]	Field EIQ			
		Zero tillage		Conventional tillage	
		Conventional soy	RR soy	Conventional soy	RR soy
Modal input					
Haloxyfop	25 [2]	2.4	0	2.4	0
2-4 D	23	6.8	6.8	0	0
Imazetapyr	27	2.7	0	2.7	0
Glyphosate	15	29.4	51.5	0	36.8
Cypermethirin	18	0.4	0.4	0.4	0.4
Chlorpyrifos	44	12.5	12.5	12.5	12.5
Accumulated field EIQ		*54.3*	*71.3*	*18.1*	*49.8*
High input					
Trifloxistrobin	31	0	2.0	0	2.0
Cyproconazole	37	0	0.9	0	0.9
Haloxyfop	25 [2]	2.4	0	2.4	0
Metsulphuron	17	0.7	0	0.7	0
Dicamba	28	1.6	0	1.6	0
2-4 D	23	6.8	6.8	0	0
Imazetapyr	27	2.7	0	2.7	0
Glyphosate	15	29.4	58.9	0	44.2
Metribuzin	23	8.2	0	8.2	0
Cypermethirin	18	1.3	1.3	1.3	1.3
Chlorpyrifos	44	12.5	12.5	12.5	12.5
Endosulfan	42	8.8	8.8	8.8	8.8
Accumulated field EIQ		*74.6*	*91.3*	*38.4*	*69.8*

[1] *Based on Kovach et al. (2008).*

[2] *No EIQ value was available for haloxyfop, an average value for herbicides was taken.*

As a result, the cropping systems in which glyphosate is applied (RR soy and conventional soy under zero tillage) has a high accumulated field EIQ. Moreover, it can be observed that the implementation of zero tillage systems coincided with an increase in the accumulated field EIQ, irrespective of the type of soy cultivated.

An alternative way to asses the environmental impact from agro-chemicals is the use of fuzzy logic systems. The fuzzy logic system used to assess the environmental impact from agro-chemicals was developed by Ferraro *et al.* (2003) to evaluate the environmental sustainability of cropping systems in Argentina. In this study, the environmental impact of energy consumption and tillage impact on soil were also included in a fuzzy logic system. In the present report, only the impact from agro-chemicals is assessed.

A fuzzy logic system has all the assumptions, rules of inference and decision criteria mathematically defined. In the present fuzzy logic system, these criteria were based on the following. For each product application (insecticides, herbicides and fungicides), a value on a dimensionless scale between 0 (totally unacceptable impact) and 1 (totally acceptable impact) was calculated. This value was calculated according to decision rules expressed through mathematical functions. These mathematical functions defined the fuzzy nature of the indicators describing the degree to which an event occurs, but not whether it occurred. Mathematical functions could take any value from the interval [0, 1] and they were defined by setting the corresponding scores for unacceptable (0) and acceptable (1) values for each of the input variables. The unacceptable and acceptable scores for the input variables and the shape of the mathematical functions reflected the knowledge available in the literature on the influence of the use of crop protection agents on the environment. The indicator of crop protection agents' impact used three input variables that describe the toxicity and the amount of active ingredients utilized in each field: (1) oral acute lethal dose 50 for rats (mg active ingredient/1000 g rat weight), (2) contact acute lethal dose 50 for bees (g active ingredient/bee) and (3) the dose applied (g active ingredient/ha) for each pesticide application.

The outcomes of the fuzzy logic system applied to the agro-chemical use in Argentinean soy production systems suggest that the use of the insecticide chlorpyriphos, an organophosphate, has a strong impact on the mammal, insect and the overall index with index values being zero or close to zero (Table 4.3).

Table 4.3 Outcome of the fuzzy logic system applied to agro-chemical use in Argentinean soy production systems (Table 4.1), on a relative scale where 0 corresponds to the highest environmental impact and 1 to the lowest environmental impact.

	Zero tillage		Conventional tillage	
	Conventional soy	RR soy	Conventional soy	RR soy
Modal input				
Mammal index [1]	0.147	0.121	0.366	0.278
Insect index [2]	0.000	0.000	0.000	0.000
Overall index	0.015	0.012	0.037	0.028
Overall index without chlorpyriphos	0.714	0.683	0.939	0.841
High input				
Mammal index (M)[1]	0.000	0.000	0.000	0.000
Insect index (I)[2]	0.000	0.000	0.000	0.000
Overall index (P)	0.000	0.000	0.000	0.000
Overall index without chlorpyriphos	0.685	0.646	0.907	0.704

[1] *0=highest impact (toxicity equivalent to an applied dose equal to 200 g a.i./ha of Monocrotophos - an organophosphate insecticide with a very high toxicity to birds and mammals); 1=lower impact (no agro-chemicals applied).*

[2] *0=highest impact (toxicity equivalent to an applied dose equal to 234 g a.i./ha of Chlorpyriphos - an organophosphate insecticide with a very high toxicity to insects):, 1=lower impact (no agro-chemicals applied).*

An index value of zero suggests a very high environmental impact. When the impact from chlorpyriphos is excluded from the analysis, the overall index of all systems is closer to 1, indicating a lower environmental impact. The overall index without chlorpyriphos is lower for RR soy than for conventional soy and is lower for fields under zero tillage than for fields under conventional tillage.

The outcomes from the EIQ approach and the fuzzy logic system are comparable with each other in the sense that both approaches suggest that a change from conventional to zero tillage and a change from conventional to RR soy increases the environmental impact from herbicides. Moreover, both approaches suggest that a change from conventional to zero tillage has a bigger effect on the environmental impact from crop protection agents than a change from conventional to RR soy.

The differences in outcomes between the EIQ approach and the fuzzy logic system are related to differences in the mathematical relations and pesticide toxicity input values. The EIQ approach is more sensitive to application rate than the fuzzy logic system, resulting in very high field EIQ values associated with the agent that is applied in the highest quantity (glyphosate). The fuzzy logic system uses high toxicity input values for organophosphates (chlorpyriphos), causing the environmental impact from insecticides to be much higher than that from herbicides. Also the environmental impact from agents is assessed differently in the two approaches. EIQ assesses not only acute toxicity for insect and mammals (as the fuzzy logic system does) but also includes potential effects on beneficial arthropods, birds, consumers, and farm workers.

Brookes & Barfoot (2006) conducted a similar assessment for RR and conventional soy in Argentina using the EIQ approach. While their study also acknowledges the increase in herbicide use and associated field EIQ due to the implementation of zero tillage systems, their comparison between the environmental impact from RR soy and conventional soy suggests a small decrease in field EIQ when RR soy is adopted. This is in contrast with the results described above. While the field EIQ values of herbicide use in conventional soy in the current data are comparable with the values found by Brookes & Barfoot, the current data suggest higher field EIQ values associated with RR soy than Brookes & Barfoot. The main reason for this is that Brookes & Barfoot use lower glyphosate and 2,4 D application rates in their EIQ assessment. The sources of the input data used by Brookes and Barfoot (Kynetic, AAPRESID and Monsanto Argentina) are different. Moreover, the data from Brookes & Barfoot are supposedly valid for all soy growing areas of Argentina, while the current data were collected solely in the main soy cropping area of Argentina where farming is generally more intense with higher input rates.

The toxicity of glyphosate

The EIQ value of glyphosate is low compared to other crop protection agents used in soy (Table 4.2). Among the 130 herbicides for which the EIQ value has been assessed by Kovach *et al.* (2008), glyphosate ranks 110th in terms of EIQ value, suggesting a low environmental impact per amount of active ingredient in comparison with most other herbicides. This relatively low EIQ value is reflected by studies demonstrating that glyphosate has a low toxicity to fish, birds, mammals and invertebrates, as well as a low persistence in soils and on plants (Henry *et al.*, 1994; Freedman, 1991; Grossbard & Atkinson, 1985), in comparison to other crop protection agents. Glyphosate-exposed herbicide applicators in the USA were not found to have any higher chance of cancer (De Roos *et al.*, 2005). The outcome of a review on the human health impacts of glyphosate by Williams *et al.* (2000) was there are no indications that glyphosate poses a risk to human health under normal conditions of use. The major breakdown product of glyphosate, aminomethylphosphonic acid (AMPA) is less toxic than glyphosate. In the Netherlands therefore, no thresholds for concentrations of AMPA in groundwater or surface water exist (CTGB, 2009).

A number of scientific studies nevertheless report a damaging effect of glyphosate on the ecology or mammals. For example, glyphosate and its surfactants applied at recommended rates can reduce the growth of particular earthworms (*Aporrectodea caliginosa*) in the soil (Springett & Gray, 1992). Applications of maximum recommended rates of commercial formulations of glyphosate on surface waters was found to strongly reduce the survival of amphibians (tadpoles and frogs) (Relyea, 2005). Rats orally treated with glyphosate produced foetuses with skeletal alterations (Dallegrave *et al.*, 2003). Glyphosate formulations can induce necrosis in human cells (Benachour & Séralini, 2009). Many more studies on the toxicological impact of glyphosate, its surfactants and AMPA have been published. We do not intend to review all these studies, since this would be laborious and a review would only useful for the purpose of this study if the impact of glyphosate is compared with similar studies on the impact of other crop protection agents used in conjunction with GM and conventional soy. The toxicity of most herbicides has been less extensively studied than that of glyphosate.

4.4 Herbicide resistant weed biotypes in soy

The high adoption of GM glyphosate-tolerant crops (soy, cotton, maize and sugar beet) in certain regions of the USA resulted in an almost exclusive use of glyphosate for weed control over large areas. Consequently, in regions where glyphosate-tolerant crops dominate, prominent weeds evolved glyphosate resistance (Powles, 2008). Also in Latin America, a range of weed biotypes developed resistance against glyphosate since the introduction of RR crops in Latin America (Table 4.4). These include prominent weeds that are difficult to control, such as *Sorghum halepense* in Argentina, *Lolium multiflorum* in both Brazil and Argentina (Christoffoleti *et al.*, 2008), and *Euphorbia heterophylla* in Brazil which exhibits multiple resistance to glyphosate and ALS-inhibitors or PPO-inhibitors. It is anticipated that glyphosate-resistant biotypes of other prominent weeds will evolve as well over the next years, as glyphosate-tolerant crops will remain popular with farmers in Latin America (Puricelli & Tuesca, 2005; Powles, 2008). The development of herbicide-resistant weed biotypes can lead to higher herbicide application rates. There is a tendency among Brazilian farmers, and presumably also among other farmers in Latin America, to increase glyphosate application rates in response to weed resistance (Cerdeira *et al.*, 2007). This tendency will exacerbate the environmental impact from glyphosate applied in GM soy. It is well possible that the relatively high glyphosate application rates observed in RR soy in Argentina (Table 4.1) are related to the development of glyphosate resistance among weeds.

Weed biotypes may also develop resistance against the herbicides used in conjunction with the anticipated new GM soy lines. Resistance against ALS inhibiting herbicides is already a common phenomenon among weeds of Latin America because of the use of ALS-inhibitors in conventional crops in the past (Table 4.4). Worldwide, many weeds have shown an ability to develop resistance against ALS-inhibitors (Heap, 2008). Weeds evolving resistance against PPO inhibitors (e.g. the herbicide ammonium-glufosinate, inhibiting the plant enzyme protoporphyrinogen oxidase) are still rare in Latin America, but in the USA several ammonium-glufosinate resistant weed biotypes have been recorded (Heap, 2008). Herbicide-resistant weed biotypes have often evolved in conventional cropping systems as well (Heap, 2008). Herbicide resistance among weeds is not related to the GM trait in crops as such, but to the frequent use of herbicides with a similar mode of action.

As weeds develop resistance to glyphosate applications, the agronomic advantage of cultivating RR soy can vanish. In that case, farmers are likely to apply weed control methods as in conventional soy, or adopt one of the anticipated new GM soy lines with tolerance to a herbicide other than glyphosate. The development of glyphosate resistant weed biotypes is therefore seen as a major threat to the continued use of RR soy in Latin America (Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2007). The development of herbicide-resistant weed biotypes also limits the number of chemical weed control options available to both GM and conventional farmers. For instance, glyphosate-resistant weed biotypes can make the use of glyphosate as a pre-emergence herbicide in conventional soy ineffective. Herbicides losing their effectiveness is a worrying phenomenon, as herbicides with a new working mechanism are rarely released, while the move towards zero tillage practices in Latin America has increased the reliance on chemicals for weed control.

The key to avoid or manage weed biotypes resistant to particular herbicides is diversification of weed management. The cultivation of conventional soy is associated with a herbicide application regime different from that of RR soy and could thus contribute to a diversification of weed management and the control of glyphosate resistant weeds. With the release of LL, Optimum GAT and CV soy lines with tolerance to herbicides other than glyphosate, new opportunities arise to rotate herbicide use in soy. The inclusion of alternative non-chemical weed control methods, such as mechanical weed control, could also contribute to a diversification of weed management. However, mechanical weed control conflicts directly with the aim to practice zero tillage. Rotating soy with other crops usually results in a drastic diversification of weed management. Crop rotations also contribute to the sustainability of farming in other ways.

Table 4.4. Weed species with resistant biotypes against glyphosate, ALS inhibitors or PPO inhibitors in Argentina, Brazil and Paraguay (Heap, 2008; Vila-Aiub, 2008).

Herbicide	Argentina	Brazil	Paraguay
Glyphosate	*Lolium multiflorum* *Sorghum halepense*	*Conyza canadensis* *Conyza bonariensis* *Digitaria insularis* *Euphorbia heterophylla* [1] *Lolium mulitflorum*	*Digitaria insularis*
ALS inhibitors	*Amaranthus quitensis*	*Bidens pilosa* *Bidens subalternans* *Cyperus difformis* *Euphorbia heterophylla* [1] *Fimbristylis miliacea* *Parthenium hysterophorus* *Raphanus sativus* *Sagittaria montevidensis*	*Euphorbia heterophylla*
PPO inhibitors (e.g. ammonium-glufosinate)		*Euphorbia heterophylla* [1]	

[1] *Also includes multiple resistant biotypes.*

4.5 GM soy and tillage practices

The use of GM soy with tolerance to broad-spectrum herbicides is frequently linked to the application of conservation tillage. Conservation tillage is a generic term for farming techniques involving the application of reduced or zero tillage techniques combined with a greater soil cover by plant residues. Conservation tillage practices have been successfully adopted in many parts of the world, especially in grain-based systems in areas sensitive to soil erosion. In certain soils and crops however, tillage appears to be a necessity to soil compaction. Conservation tillage is associated with numerous agronomic, environmental and economic benefits. Conservation tillage usually substantially reduces soil erosion from water and wind. Soil erosion does not only degrade agricultural lands on-farm, but also entails very high off-farm environmental and human health costs (Pimentel, 2006). Conservation tillage often has a positive impact on the soil moisture balance and it can improve the soil physical structure as well as soil biota (Bolliger *et al.*, 2006; Holland, 2004; Kladivko, 2001; Benckiser, 1997). Moreover, the application of conservation tillage techniques usually saves machinery, labour and fuel inputs, which is a strong incentive to farmers to adopt these techniques.

Conservation tillage has been claimed to assist in maintaining or increasing soil organic matter levels. The International Panel on Climate Change (IPCC) estimates that the conversion from conventional tillage to zero tillage systems stores on average 300 kg carbon ha^{-1} annually, while the conversion from conventional tillage to reduced tillage stores 100 kg carbon ha^{-1} annually. Some scientists question the benefits of conservation tillage for carbon sequestration carbon when carbon dynamics in the deeper soil layers (> 30 cm) are also accounted for (Baker *et al.*, 2007; Blanco-Canqui & Lal, 2008). These benefits are likely to depend on soil properties, climatic conditions and land use. Soil carbon levels in cropping systems are in most cases well below those in natural areas and grasslands and the gains in soil carbon storage (or reduced soil carbon losses) that can be made by a conversion from conventional to conservation tillage are rapidly lost when soils are ploughed conventionally again (Follet, 2001).

Also in Latin America, conservation tillage is seen as a key method to achieve more sustainable farming systems and has been applied in a wide range of biophysical and socio-economic environments (Calegari *et al.*, 2008; Jantalia *et al.*, 2007; Bolliger *et al.*, 2006; Goedert, 1983). Zero tillage is the main form of conservation tillage practiced in Latin America. Grain-based systems (e.g. including soy, wheat or maize) appear to be particularly suitable for the implementation of zero tillage systems. From the 1980s, zero tillage systems have been rapidly adopted in cropping systems of Brazil in response to severe problems with soil erosion (Goedert, 1983). Input cost savings from less fuel, machinery and labour use became strong drivers for farmers to adopt zero tillage. Through the 1970s and 1980s, the use of zero tillage spread through the southern States of Brazil. In the 1990s, also the Cerrado region experienced a very rapid adoption of zero tillage (Bolliger *et al.*, 2006). In 2006, it was estimated that more than 6 million ha were under zero tillage in the Brazilian Cerrados, which is almost half the arable area of the Cerrado (Federaçã Brasileira de Plantio Direto, 2009). In the whole of Brazil, 25.5 million ha were under zero tillage in 2006 (Federaçã Brasileira de Plantio Direto, 2009). In Argentina, the first experiences with zero tillage started in the 1960s (Panigatti, 1998). Since the introduction of RR soy, the growth of zero tillage in the Pampas has been driven by technical as well as economic factors. 13.2 million ha of soy was under zero tillage in Argentina in 2005, which equalled 87% of the total soy acreage (Brookes & Barfoot, 2006).

The agronomic and environmental benefits of zero tillage techniques observed worldwide (erosion control, improved water balance, savings of fuel and machinery) also apply for Latin America in general (Micucci & Tabaoda, 2006; Bolliger *et al.*, 2006; Jantalia *et al.*, 2007). Differences in soy grain yield between fields under zero tillage and conventional tillage tend to be small (Puricelli & Tuesca, 2005). Only when water availability is low, soybean under zero tillage tends to give higher yields (Buschiazzo *et al.*, 1999). The available soil water at sowing for soybean does not usually match soil full storage capacity (Sinclair *et al.*, 2007). Zero tillage reduces evaporation by eliminating soil surface rugosity (evaporation surface) caused by tillage and by residue accumulation, which also reduces runoff and increases water infiltration. A large body of Brazilian literature, reviewed by Bolliger *et al.* (2006), indeed indicates that soil carbon levels in soils under zero tillage are above that of conventionally tilled soils. For example, on typical Cerrado soils of Brazil, 10 tonnes of carbon were lost in the upper 100 cm of the soil over a period of 20 years when the land was converted from native vegetation to cropped land under zero tillage; 30 tonnes of carbon were lost when the land was converted using conventional tillage (Jantalia *et al.*, 2007). In other words, 20 tonnes of carbon was saved from oxidation and remained in the soil when zero tillage was applied.

Zero tillage does not only have positive impacts on the sustainability of farming. Zero tillage in Brazil has been associated with 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 (Bolliger *et al.*, 2006). Depending on soil type, climate and land use, these drawbacks are more or less relevant. 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. Zero tillage may thus enhance the cultivation of previously natural lands. 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.

The rapid adoption of RR soy has frequently been linked to the simultaneously increased implementation of zero tillage systems in soy in Latin America (Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2007; Cerdeira & Duke, 2006; Brookes & Barfoot, 2006; Trigo & Cap, 2003). RR soy facilitates the implementation of zero tillage systems as glyphosate applications associated with RR crops reduce the need for mechanical weed control and are easy to integrate in a system that requires a greater soil coverage with plant residues. This is also true for the GM soy lines in the pipeline with tolerances to other broad-spectrum herbicides. In Argentina, in 2005, 13.2 (or 87%) of the total of 15.2 million hectares of soy was cultivated with RR soy using zero tillage, whereas in 1996, when virtually no RR soy was grown yet, only 36% of the soy area was under zero tillage (Brookes & Barfoot, 2006, adapted from Benbrook and Trigo). The link between zero tillage and RR soy is also supported by survey data from Argentina, 2001, in which 42% of the conventional soy growers were found to apply zero tillage practices, whereas 80% of the RR soy growers used zero tillage (Qaim & Traxler, 2005).

However, the large-scale adoption of zero tillage in Latin America started well before the introduction of GM crops, indicating that in many cases weeds can also be managed in a zero-tillage system with conventional soy. Moreover, the various benefits from zero tillage practices are also relevant for conventional crops.

4.6 Energy use in GM and conventional soy

Energy consumption is an indicator of the sustainability of a cropping system. Below we assess the energy consumption of different soy cropping systems in Argentina based on input use and tillage and other operations. Input use includes the use of crop protection agents as well as fertilizer applications. The data on fertilizer input and type of farm operations (Table 4.5) originate from the same source (AGROMERCADO, 2009) as the herbicide application rates and are based on extension agents' observations of the actual farm management in the main soy production area of Argentina (Northern Buenos Aires - South Santa Fe). Zero tillage requires less farm operations than conventional tillage. Fertilizer application rates are slightly higher in fields under zero tillage because soil nutrient release directly after planting is somewhat slower in fields that are not tilled. The energy consumption required for tillage and other farm operations and for the production of crop protection agents was retrieved from scientific literature (Table 4.6).

The amount of energy required for farm operations is substantially reduced by the implementation of zero tillage (Table 4.7). However, the amount of energy required to produce crop protection agents and fertilizer is higher in zero tillage systems than in conventional tillage systems. The accumulated energy consumption still suggests that soy produced with zero tillage requires on average some 20% less energy than soy produced with conventional tillage. Furthermore, the data suggest that the production of RR soy requires more energy than the production of conventional soy which is due to a higher consumption of energy for the production of crop protection agents (primarily glyphosate) in RR soy.

We did not take into account the energy costs to produce agricultural machinery, as it is difficult to attribute these energy costs to specific operations. Fields under zero tillage generally requires less inputs from agricultural machinery than fields under conventional tillage.

Table 4.5. Type of operations and fertilizer applications in soy production systems of Argentina.

	Zero tillage		Conventional tillage	
	Conventional soy	RR soy	Conventional soy	RR soy
Operations				
Tandem Disk Harrows			X	X
Tandem Disk Harrows + cultipacker			X	X
Chisel plow			X	X
Drill	X	X	X	X
Agro-chemical applications / Fertilizer application	X	X	X	X
Fertilizer application				
Diammonium phosphate (kg ha^{-1})	80	80	75	75

Table 4.6. Energy consumption required for the production of agro-chemicals and for various tillage operations applied in soy production systems.

Active ingredient (a.i.)	MJ per kg active ingredient	Reference
Haloxyfop	385	Nagy (1999)
2-4 D	98	Green (1987)
Clorpiriphos	255	Nagy (1999)
Cypermethirin	579	Ferraro (2003)
Dicamba	336	Green (1987)
Cyproconazole	196	Green (1987)
Endosulfan	417	Nagy (1999)
Glyphosate	511	Green (1987)
Haloxyfop	385	Nagy (1999)
Imazetapyr	298	Johnston (1997)
Metribuzin	200	Nagy (1999)
Metsulphuron	337	Johnston (1997)
Trifloxistrobin	196	Green (1987)
Tillage operation	MJ per tillage operation per ha	
Tandem disk harrows	394	Kalk & Hülsbergen (1996)
Pesticide sprayer/Fertilizer application	97	Kalk & Hülsbergen (1996)
Drill	480	Lobb (1989)
Chisel	416	Lobb (1989)
Cultipacker	131	Lobb (1989)

Table 4.7. Energy consumption in different soy production systems of Argentina (MJ ha^{-1}).

	Conservation agriculture		Conventional agriculture	
	Conventional soy	RR soy	Conventional soy	RR soy
Modal input				
Crop protection agents	1165	1834	155	1314
Farm operations	771	771	2299	2299
Fertiliser	1554	1554	1457	1457
Total	*3490*	*4159*	*3911*	*5070*
High input				
Crop protection agents	1374	2214	364	1694
Farm operations	771	771	2299	2299
Fertiliser	1554	1554	1457	1457
Total	*3699*	*4539*	*4120*	*5450*

4.7 GM soy and water

Herbicides have an impact on water ecosystems. This impact is already included in the assessment of the field EIQ values above. More detailed information on the ways the main herbicide used in GM soy, glyphosate, can enter water systems is provided in this section.

The risks of glyphosate leaching to the groundwater is very limited in most soils compared to 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 pronounced preferential flow, glyphosate can move to the groundwater more readily (Kjaer *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 (Kjaer *et al.*, 2005). As the risks of water contamination through glyphosate volatilisation 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 in that case an important factor determining the amount of drift deposits ending up in water systems. Spraying equipment, weather conditions during spraying, operator's skills, spray-free buffer zones, etcetera, all influence the amount of drift from the application of crop protection agents (Nuyttens *et al.*, 2006 a & b).

4.8 GM soy and soil biota

The potential effects of GM soy, relative to conventional soy, on soil biota include direct effects of applications of crop protection agents, changes in the amount and composition of root exudates, and effects of management practices associated with GM soy other than those from the applications of crop protection agents. Cerdeira and Duke (2006), Motavalli *et al.* (2004), Kowalchuk *et al.* (2003) and Bruinsma *et al.* (2003) all reviewed the impact of RR crops or GM crops in general on soil biota and stated that there is no conclusive evidence that the cultivation of currently released GM crops is causing significant changes in soil microbial populations. Changes occur when GM crops are grown, but these are minor in comparison with other sources of variation. These changes are usually not long-lasting and are often not being observed in subsequent years. For example, glyphosate is toxic to many soil microorganisms, but there is little or no measurable impact of glyphosate applications on soil microorganisms after weeks or months after application. Moreover, these changes in soil microbial communities due to the cultivation of GM crops can be negative, neutral or positive for agroecosystem functioning. Furthermore, the impact of glyphosate is usually not compared with the impact from other herbicides that are used in conjunction with conventional crops. The reviews have identified knowledge gaps that hinder an objective assessment of the impact of GM crop on soil microbiota.

4.9 Effects of crop protection agents on pathogen pressure in GM soy

The application of herbicide or pesticides may affect the crop disease pressure. In particular, the application of agro-chemicals may affect the crop's susceptibility to pathogens, the occurrence or virulence of plant pathogens, the occurrence of antagonistic microbiota, and the availability of substrate for plant pathogens (Termorshuizen & Lotz, 2002). Indirect impacts of changing weed populations (e.g. as a result of broad-spectrum herbicide applications in GM crops) on the crop pathogen pressure are discussed below.

Theoretically, the application of a broad-spectrum herbicide against which a GM crop is tolerant should not affect the disease susceptibility of the crop. However, in certain tissues or under certain environmental conditions the RR trait could affect plant's disease resistance mechanisms (Cerdeira *et al.*, 2007) and make the crop more susceptible to diseases. Termorshuizen and Lotz (2002) published a literature review on the effects of glyphosate and glufosinate ammonium on soil borne pathogens highlighting the following. In vitro, glyphosate and glufosinate ammonium were shown to inhibit the growth and development of certain pathogens (e.g. *Septoria nodorum*, *Rhizoctonia solana*, *Sclerotinia sclerotium*, *Calonectria crotalariae*), while enhancing the pathogenicity and virulence of others (e.g. *Fusarium solani*). Similarly, the activities of antagonistic microbial populations may be reduced (e.g. *Trichoderma* spp. against *Fusarium oxysporum*, and *Pythium aphanidermatum* and *Pseudomonas fluorescens* against *Pythium aphanidermatum*). However, the authors question whether any of these direct impacts of glyphosate or glufosinate ammonium applications is of significance given the low persistence of these herbicides in soils.

A well known side effect of glyphosate and glufosinate ammonium is the emergence of so-called herbicide-synergists, which are opportunistic root pathogens accelerating the killing of plant roots that are herbicide sensitive (Termorshuizen & Lotz, 2002). These opportunistic plant pathogens may also affect the roots of herbicide-tolerant GM crops. As the application of broad-spectrum herbicides in GM crops is often done at later crop stages than in conventional crops, weeds in GM crops are controlled at a larger plant size, which may enhance the activities of the opportunistic root pathogens. In this case, rather than the direct impact from the herbicides used in GM crops, it may be the stage at which weed control is conducted that has the largest effect on the activities of crop pathogens.

Aboveground, the application of glyphosate in RR soy in a greenhouse was found to have preventative or curative properties on soybean rust (Feng *et al.*, 2005). Soybean rust is one of the most important fungal diseases in soybean in Brazil, requiring frequent spraying with fungicides.

4.10 GM soy and grain yield

The focus of current and anticipated GM soy varieties is facilitating weed and pest management and not enhancing grain yield, with the exception of the RR2 - Bt soy, which gives, according to Monsanto Company, a yield increase of 4-11% in comparison with similar conventional varieties. Generally, the yield performance of RR soy is reported to be similar on average to conventional soy in Canada, the USA and Argentina. Also in the data from AGROMERCADO (2009), used in this report to assess the environmental impact and energy budget of RR and conventional soy, no yield difference between RR and conventional soy in Argentina was reported. For Mexico, an increase of 9.1% was reported by Brookes & Barfoot (2008) based on info from Monsanto Company. Lower yields have also been reported for field trials in comparison with conventional soy varieties. Lower yields reported for RR soy are sometimes attributed to the use of older or poorly adapted germplasm for the production of RR varieties. Experimental data on the yield of soy cultivars between 1984 and 2001 (Santos *et al.*, 2000), showed a significant trade-off between the RR trait and yield in the early introduced RR soy cultivars (i.e. 1996-1997) in Argentina. However, the yield gap was overcome in cultivars released in 2000-2001. Keller & Fontanetto (1998) reported that reduced yields of the early RR soy cultivars primarily occurred in years when water availability was low.

4.11 GM soy and biodiversity in and around fields

The weed management system associated with RR soy and expected new GM soy lines with traits leading to herbicide-tolerance could result in a loss of biodiversity in and around fields:

1. If GM soy enhances large scale farming, this could lead to the disappearance of field margins and a reduction in landscape complexity. Field margins and other landscape elements can play an important role as refugia for functional biodiversity in rural landscapes (Marshall & Moonen, 2002; Roschewitz *et al.*, 2005). Moreover, large scale farming may stimulate particular farming practices, such as the application of herbicides with airplanes leading to high amounts of drift, that can lead to a reduction of the quality of field margins. In Brazil there are sometimes legal obligations to set aside a certain part of the farm land for nature. As this percentage of land reserved for nature is fixed and independent of farm size, the size of farming may in this case have little impact on the biodiversity. The link between GM soy and the ongoing enlargement of the scale of soy farming is further discussed in section 4.15.

2. An efficient weed control enabled by GM crops can reduce the biodiversity associated with weeds. This is especially relevant if the species affected by weeds have an impact on agro-ecosystem functioning or include rare species. This type of biota may be referred to as functional biodiversity. For instance, in the UK, seed rain

from weeds known to be important in the diets of granivorous farmland birds was significantly reduced in particular herbicide-tolerant GM crops, relative to conventional crops (Moorcroft *et al.*, 2002; Gibbons *et al.*, 2006). It is important to note that this was not directly the result of the presence of the GM trait, but of the more efficient weed control enabled by the GM trait. Beneficial organisms, e.g. earthworms, carabid beetles, microbial communities with an antagonist role, may be enhanced by the presence of a large and varied weed community. On the other hand, weed plants and their seeds may also host microbial communities pathogenic to crops and function as a reservoir of crop pathogens when a suitable host crop is absent (Franke *et al.*, 2009; Marshall *et al.*, 2003). In this case, biota enhanced by weeds have a negative impact on agroecosystem functioning. It is not possible to state whether the overall impact of a greater functional biodiversity effected by weed communities is in general positive or negative for agro-ecosystem functioning. RR soy in Argentina tend to have a lower weed density and species diversity than conventional soy (Puricelli & Tuesca, 2005). It is thus likely that the cultivation of herbicide tolerant GM soy will lead to a reduction in the functional biodiversity dependent on weeds in the field, which could work out positive or negative for soy production and agro-ecosystem functioning in general.

On the other hand, zero tillage often increases soil biodiversity and an increased soil coverage in zero tillage systems may benefit aboveground biodiversity as well (Holland, 2004; Kladivko, 2001; Benckiser, 1997). If GM soy enhances the implementation of zero tillage techniques (see section 4.5), GM soy could stimulate the biodiversity in and around fields through a change in tillage practices.

4.12 Rotating soy with other crops

GM and conventional soy in Latin America are grown in rotation with other summer crops (e.g. maize) or in more intensively cultivated systems containing a summer crop (e.g. soy) as well as a winter crop (e.g. wheat). Soy is often grown in rotation with cereals, as soy and cereals are complementary in terms of their impacts on soil fertility and structure. Monocropping soy, i.e. growing solely soy for consecutive years on the same plot, is also common in many parts of Latin America (Tanaka *et al.*, 2006). Monocropping in general is considered a threat to the agronomic and economic sustainability of farming, as it can enhance the occurrence of pests, diseases and weeds, reduce soil fertility (Zimdahl, 1980) and may result in high fluctuations in farm income. It is widely recognised that crop rotation should be an integral aspect of sustainable farming systems. A lack of agronomically or economically suitable alternative crops for soy is likely to be the main reason for soy monocropping.

RR soy and the expected new soy lines with tolerance to broad-spectrum herbicides could facilitate soy monocropping in the following ways:

1. As weed control is relatively easy in RR soy, problems with an increased weed pressure in soy monocropping are less likely to occur in the short term in RR soy than in conventional soy. This is likely to change on the long term if glyphosate-resistant weeds impair these benefits.

2. If the net benefits from growing RR soy are higher than those from growing conventional soy, as suggested by Qaim & Traxler (2005), and thus also higher than other crops suitable for rotation, this could stimulate the cultivation of RR soy in a monoculture. In general, the higher the net benefit of a particular crop relative to other crops, the higher the opportunity costs of adding an alternative crop to the crop rotation.

Apart from the issue of weed control, the production methods associated with RR soy appear equally suitable for monocropping as that of conventional soy. It is unlikely that the type of weed control enabled by the RR trait was a decisive factor in allowing farmers to monocrop soy. Prior to introduction of RR soy in Brazil, large scale operations and monocropping soy already expanded rapidly. Also in Argentina, monocropping soy and other (conventional) crops was common before the introduction of RR soy.

4.13 Co-existence of GM and conventional soy and the dispersal of GM traits outside agricultural fields

Co-existence refers to the ability of farmers, businesses and consumers to make a choice between GM and conventional crop production, processing and consumption, in compliance with the legal obligations for labelling and/or purity criteria (European Commission, 2009). Perfect segregation of the different agricultural production types is not possible, e.g. in seed production various measures have been implemented to keep impurities below a certain level. Likewise, mixing GM with conventional can be kept below a threshold level. In the EU, this threshold has been set at 0.9%, which implies that agricultural products that contain more than 0.9% ingredients from GM origin should be labelled as a GM-containing product.

Co-existence of GM and conventional soy in the field can be relatively easily achieved. GM soy plants are by large self-pollinators with outcrossing levels on average in the order of 1%. This implies that co-existence measures in the field can be relatively easy. Experiments in Brazil indeed revealed a maximum of 1.3% outcrossing at 0.5 m, lowering to 0% after 2.3 m (Andrade Pereira *et al.*, 2007) Other Brazilian experiments found 0.6% at 1 m to 0.2% at 5 m in the Southern Brazilian state of Paraná (Schuster *et al.,* 2007) or 0.5% at 1 m to 0% at 10 m in the Cerrado biome region (Abud *et al.*, 2007). The fertilization of conventional soy fields by adjacent GM soy fields, is therefore likely to be minimal, certainly so if fields are situated more than 10 meters apart.

The drift of herbicides between fields should always be avoided as much as possible. This is even more urgent when crops in a neighbouring field are highly susceptible to the applied herbicide, which is the case when glyphosate is applied nearby a field cultivated with conventional soy. The amount of drift can be minimised to levels where no crop damage occurs if appropriate measures are taken (e.g. correct spraying equipment, training of the operator, the use of spray-free buffer zones, etcetera) (Van de Zande *et al.*, 2008).

Admixture of GM and conventional soy is more likely to occur during field operations and in various post-harvest steps. Attention should be paid to keeping production chains separate, i.e. ensuring that sowing or harvesting machinery shared between farms is thoroughly cleaned. Otherwise, separate machinery for GM and conventional operations can be used. During transport of GM soy, grain losses that can end up in conventional soy fields should be avoided as much as possible. Also, flows of products should be kept separated throughout the production chain (maintaining segregated chains) if differentiated GM and conventional markets are to be served.

The likelihood of GM soy traits spreading and persisting outside agricultural fields is very small in Latin America. Soy originates from East Asia where wild relatives are still present. No wild species that can somehow cross-fertilise naturally with soy exists in Latin America (Anonymous, 2000). The occurrence of cross-fertilisation between GM soy and wild plants can thus be excluded in Latin America. Soy seeds are not dormant and soy seeds are unlikely to form a persistent seed bank in the soil. Due to its nutritious content, soy seeds are also highly predated. In many parts of Latin America, soy can only grow and produce seeds in particular seasons of the year. In the more tropical parts of Latin America, soy can grow all year round, but predation and weed pressure appears to be too high for soy seeds to produce a persistent population outside agricultural fields. It

4.14 GM soy production and the loss of natural areas

The expansion of soy production in Latin America has come with a reduction in the cultivation of other crops and an intensification of existing arable farming systems. Moreover, natural areas and pastures have been converted into arable land for soy production. The conversion of pastures into arable fields has stimulated livestock keepers to start farming in previously natural areas. The large soy expansion has resulted in biodiversity losses in Latin America and substantial additional emissions of green house gasses due to the loss of forests and grass lands. The question can be posed whether GM soy contributes more to the loss of natural areas than conventional soy production.

The RR trait in soy makes weed control easier and more flexible, and other GM soy lines with tolerance to broad-spectrum herbicides will have a similar effect. Weed pressure in arable fields is particularly high, for instance, in the humid tropics, where weeds tend to grow faster and complete more lifecycles per year than in temperate climates. Weed control could be one of the factor limiting the expansion of soy into particular areas such as the humid tropics. The relatively easy weed management associated with RR soy could thus facilitate the expansion of soy in those areas. Weed control characteristics in RR soy could also be particularly suitable for the conversion of (degraded) pastures into arable lands. This conversion is also hindered by a high weed pressure. The expansion of the soy cropping area through the recuperation of degraded pastures can be seen as a relatively environmentally friendly was of expanding the arable lands.

Figure 4.2. Land use in the triple border region (Argentina-Brazil-Paraguay) in 1973 and 2003.

In Argentina specifically, the increase in soy production in the temperate and highly fertile Rolling, Inland and Southern Pampas, where cropping for cash crops has been the predominant form of land use for more than hundred years, occurred at the expense of pastures and areas with cultivation of maize and not of natural areas. In other parts of Argentina, soy cultivation directly and indirectly contributed to the loss of natural areas. These areas are mainly in the northeast and northwest of Argentina (Yungas, Chaco and Espinal regions). This has been relatively well documented for the northern region of the Chaco (Grau *et al.*, 2005 & 2008). Also, for instance, the change of land use in the tri-border area of Argentina, Paraguay and Brazil between 1973 and 2003 (Figure 4.2) clearly shows that soy expansion has taken place at the expense of natural areas. The relative area covered by soy since the RR introduction has risen more rapidly in extra-Pampean region than in the Pampean region itself (Figure 4.3). As soy production was already important in the Pampean area when RR soy was introduced, but absent in the northern regions, part of this difference may be seen as catching up (non-soy crops to GM soy in the northern regions, conventional soy to GM soy in the pampean area). However, RR soy probably did facilitate the soy expansion in the extra-pampean area due to easier weed control in RR soy systems, in the early years after conversion of natural areas into farmland.

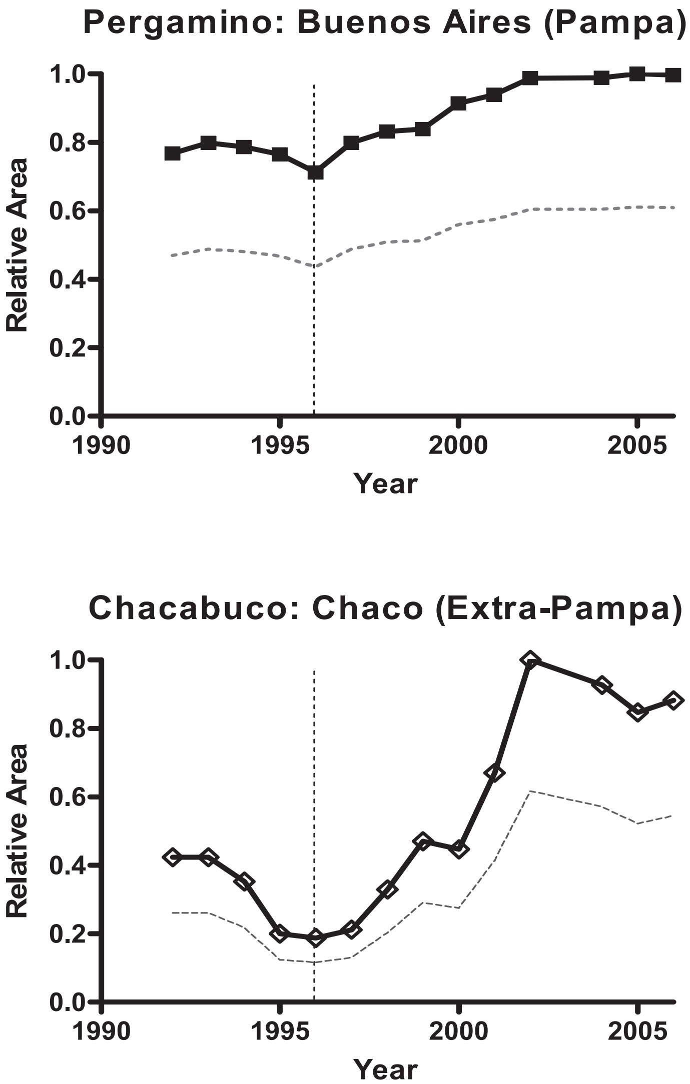

Figure 4.3. *Relative area of soy cropping in a Pampean and an extra-Pampean region. Solid lines show the soy area relative to the maximum area under soy (180,000 ha for Pergamino, 85,000 ha for Chacabuco) in each place. Dotted lines show the soy area relative to the total area (295,000 ha for Pergamino, 137,800 ha for Chacabuco) in each place. The vertical dotted line shows the year of RR soy introduction.*

4.15 GM soy and the scale of farming

An enlargement of the scale of soy production can lead to a loss of biodiversity in and around agricultural fields, reduced on-farm employment opportunities and a loss of livelihoods for small-scale farmers whose land is taken over by expanding farmers. Scale enlargement can also contribute to economically more efficient production systems reducing the price of soy and its products, stimulating the competitiveness of the soy sector and creating additional economic activities elsewhere in the soy production chain.

The scale of soy farming has increased in Brazil and Argentina in recent years. The expansion of the soy production area has been realised through the establishment of new large-scale farms. Moreover, a consolidation of farms has occurred in the traditional soy producing areas. The increase in the scale of soy farming in Brazil and Argentina has been driven by the need to benefit from economies of scale required to export grain bulk products at competitive prizes. The availability of vast areas of new lands at the agricultural frontiers, suitable farm machinery, and appropriate field management techniques facilitated the expansion of large scale operations. Soy cultivation can be highly mechanised and conducted on a large scale with a minimum of labour. In Argentina, large-scale soy farming generates one job per 200 hectares, whereas typical smallholder farm operations require one job per eight hectares (Verner, 2005).

RR soy fitted in this move towards an enlargement of the scale of farming. The flexible timing of application of glyphosate as a post-emergence herbicide in RR soy, as well as soil zero tillage practices associated with GM soy, require less labour for weeding than conventional tillage in conventional soy. Labour extensive cultivation methods can facilitate an enlargement of the scale of farming, as labour extensive systems are usually mechanised knowledge-intensively, and tend to succeed in lowering the production costs per hectare as farm size increases.

In Brazil, the development of large-scale soy production started well before the (official) introduction of RR soy, which indicates that RR soy was not a main driver of enlargement in scale. In Argentina on the other hand, the enlargement of the scale of soy production did coincide with the adoption of RR soy. Simultaneous with the RR soy introduction (1996/1997) other changes occurred, such as the introduction of free-market policies, the concentration of farm management, and the introduction of external economic actors in the agricultural sector. While RR soy fitted in the move toward large scale farming, these changes in scale probably would have occurred as well without the availability of RR soy.

4.16 Anticipated changes due to soy varieties with new GM traits

Soy lines with new agronomic GM traits that are expected to be available and cultivated commercially within the next few years in Latin America include:

- LL soy (tolerant to ammonium-glufosinate);
- RR2 - Bt soy (tolerant to glyphosate and Lepidoptera pests);
- CV soy (tolerant to ALS inhibitors);
- Optimum GAT soy (tolerant to glyphosate and ALS inhibitors).

The LL soy, CV soy and Optimum GAT soy all have traits that make soy plants tolerant to broad-spectrum herbicides, similar to RR soy. These new GM soy lines offer the benefit of increasing the number of options available to control weeds chemically, which can assist in slowing down or coping with the development of glyphosate-resistant weed biotypes. However, if weed control is insufficiently diversified, weeds are also likely to develop resistance against the herbicides that are used in conjunction with these new GM soy lines.

As field management in the anticipated GM soy lines is unknown, we cannot state whether their introduction will lead to an increase or decrease in the use of crop protection agents, compared to RR or conventional soy. The EIQ value (per kg active ingredient) of the herbicides used in conjunction with the new GM soy lines is generally higher than that of glyphosate (Table 4.8), but that does not necessarily mean that the field EIQ associated with the new GM lines will be higher than that of RR soy, as the field EIQ also depends on the rates of application in the field.

Table 4.8. EIQ values of herbicides used in conjunction with RR and new GM soy lines (Kovach et al., 2009).

Herbicide	EIQ value
Glyphosate	15
Ammonium-glufosinate	28
Some ALS-inhibitors:	
Imzethapyr	27
Imizapic	30
Imazapyr	18
Sulfonylurea	27

Apart from the environmental impact from herbicide applications, the consequences of the introduction of new GM soy lines with tolerance to broad-spectrum herbicides on the production system and the environment could be comparable to those of RR soy. With regard to coexistence, crop yield, tillage practices, crop rotations, biodiversity, and the scale of farming, there are no indications these new GM soy lines have an impact that is very distinct from that of RR soy.

The anticipated RR2 - Bt soy line is different from the other expected GM soy lines as it has a Bt gene providing soy plants with proteins that are toxic to certain Lepidoptera pests (e.g. caterpillars of certain butterflies and moths). The use of Bt genes in soy is new. Bt genes have been frequently inserted into maize and cotton lines and Bt cotton and Bt maize have been planted worldwide on a large scale. Different Bt genes lead to tolerance to different groups of pest insects. Literature on the impact of Bt crops on pesticide use generally points towards a reduction in the use of pesticides on Bt crops and an improvement in the associated EIQ values, relative to their conventional counterparts with normal pesticide treatments, if Bt crops are planted in an area with a relevant pest problem (Brookes & Barfoot, 2006; Kleter *et al.*, 2007). Pesticide use (active ingredients) in Bt maize and Bt cotton in 1996-2004 was estimated to decline globally with 3.7 and 14.7%, respectively, while the EIQ declined with 4.4% for Bt maize and 17.4% for Bt cotton (Brookes & Barfoot, 2005). As no Bt soy lines have been released commercially yet, the actual impact of Bt soy on pesticide use is unknown.

Pest insects can develop resistance against the toxins produced by Bt crops. The first case of insect resistance to the Bt trait was recorded in the USA in 2007. So far, the number of cases of insects developing resistance to Bt traits in crops has been very limited. The legal obligation to mix small amounts of non-Bt, insect-susceptible crop seed with Bt seed in the USA and elsewhere (the so-called high dosage/refuge strategy) probably slowed down the evolution of Bt-resistant pest insects.

The RR2 - Bt soy was also bred for genes that, according to Monsanto Company, lead to an increase in soy grain yields of 4-11%. A higher yield with a similar input use leads to a more sustainable farming system, as fewer resources (e.g. land, inputs) are required to produce a certain amount of food. Since the genes that are responsible for the higher grain yields have not been obtained through GM, it is well possible that similar yield gains can be achieved with conventional soy.

5. Collecting and validating claimed impacts of GM-technology in soy production

5.1 Collecting claimed impacts

The following claims were collected based on information in literature and from organisations that have a stake in soy production in Latin America.

1. GM soy yield is different from that of conventional soy
2. GM soy changes the use of crop protection agents in soy and the environmental impact from these agents
3. GM soy stimulates the development of herbicide resistance among weeds
4. GM soy aggravates problems with the control of volunteer soybean in subsequent crops
5. GM soy facilitates zero tillage
6. GM soy facilitates monocropping
7. GM soy has an impact on biodiversity in and around agricultural fields
8. GM soy is a threat to nearby farms that want to cultivate GM-free soybean
9. GM traits in soy can spread and persist outside agricultural fields
10. GM soy facilitates the expansion of soy production into natural areas
11. GM soy affects the genetic diversity of soy varieties in Latin America
12. GM soy changes the scale of soy farming in Latin America

5.2 Validating claimed impacts

5.2.1 GM soy yield is different from that of conventional soy

The focus of current and anticipated GM soy varieties is facilitating weed and pest management and not enhancing grain yield, with the exception of the RR2 - Bt soy, which gives, according to Monsanto Company, a yield increase of 4-11% in comparison with similar conventional varieties. Generally, the yield performance of RR soy is reported to be similar on average to conventional soy in Canada, the USA and Argentina. For Mexico, an increase of 9.1% was reported by Brookes & Barfoot (2008) based on info from Monsanto Company. Lower yields have also been reported for field trials in comparison with conventional soy varieties. Lower yields reported for RR soy are sometimes attributed to the use of older or poorly adapted germplasm for the production of RR varieties. Experimental data on the yield of soy cultivars between 1984 and 2001 (Santos *et al.*, 2000), showed a significant trade-off between the RR trait and yield in the early introduced RR soy cultivars (i.e. 1996-1997) in Argentina. However, the yield gap was overcome in cultivars released in 2000-2001. Keller & Fontanetto (1998) reported that reduced yields of the early RR soy cultivars primarily occurred in years when water availability was low.

Differences in yield between RR soy and conventional soy are usually small. There is no evidence that RR soy produces yields that are structurally different from those of conventional soy.

5.2.2 GM soy changes the use of crop protection agents in soy and the environmental impact from these agents

For an extensive overview of the environmental impact of crop protection agents used in conjunction with RR and conventional soy, see sections 4.2, 4.3 and 4.8 of this report. RR soy cultivation comes with a strong increase in the use of glyphosate, and a strong decrease in the use of other herbicides. Data from the main soy growing area of Argentina suggests that the total use of crop protection agents, as well as the environmental impact from these agents, is higher in RR soy than in conventional soy. Two different approaches were used to value the environmental impact from crop protection agents used in soy, the Environmental Impact Quotient (EIQ) (Kovach *et al.*, 2008) and a fuzzy logic system (Ferraro *et al.*, 2003). Although the two approaches produced slightly different results, both suggest that a change from conventional tillage to zero tillage has a larger impact on the environmental impact that a change from conventional to GM soy. Both approaches also suggest that RR soy has a higher environmental impact than conventional soy.

Brookes & Barfoot (2006) conducted a similar assessment for RR and conventional soy in Argentina using the EIQ approach. While their study also acknowledges the increase in herbicide use and associated field EIQ due to the implementation of zero tillage systems, their comparison between the environmental impact from RR soy and conventional soy suggests a small decrease in field EIQ when RR soy is adopted. This is in contrast with the results described above. While the field EIQ values of herbicide use in conventional soy in the current data are comparable with the values found by Brookes & Barfoot, the current data suggest higher field EIQ values associated with RR soy than Brookes & Barfoot. The main reason for this is that Brookes & Barfoot use lower glyphosate and 2,4 D application rates in their EIQ assessment. The sources of the input data used by Brookes and Barfoot (Kynetic, AAPRESID and Monsanto Argentina) are different. Moreover, the data from Brookes & Barfoot are supposedly valid for all soy growing areas of Argentina, while the current data were collected solely in the main soy cropping area of Argentina where farming is generally more intense with higher input rates.

GM soy has a strong impact on the use of crop protection agents, especially on herbicides. The environmental impact from the crop protection agents used in GM soy is probably comparable to or higher than the impact from agents used in conventional soy.

5.2.3 GM soy stimulates the development of herbicide resistance among weeds

For a more detailed discussion of the impact of GM soy on the development of herbicide resistance among weeds, see section 4.4. In Latin America, a range of weed biotypes has developed resistance against glyphosate since the introduction of RR crops in Latin America. These include prominent weeds that are difficult to control, such as *Sorghum halepense* in Argentina, *Lolium multiflorum* in both Brazil and Argentina (Christoffoleti *et al.*, 2008), and *Euphorbia heterophylla* in Brazil which exhibits multiple resistance to glyphosate and ALS-inhibitors or PPO-inhibitors. It is anticipated that glyphosate-resistant biotypes of other prominent weeds will evolve as well over the next couple of years, as glyphosate-tolerant crops will remain popular with farmers in Latin America (Puricelli & Tuesca, 2005; Powles, 2008). As weeds develop resistance to glyphosate applications, the agronomic advantage of cultivating RR soy can vanish. In that case, farmers are likely to either apply weed control methods as in conventional soy, or adopt one of the anticipated new GM soy lines with tolerance to a herbicide other than glyphosate. The development of glyphosate resistant weed biotypes is therefore seen as a major threat to the continued use of RR soy in Latin America (Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2007).

Weed biotypes may also develop resistance against the herbicides used in conjunction with the anticipated new GM soy lines. Resistance against ALS inhibiting herbicides is already a common phenomenon among weeds of Latin America because of the use of ALS-inhibitors in conventional crops in the past. Weeds evolving resistance against PPO inhibitors (e.g. the herbicide ammonium-glufosinate) are still fairly rare in Latin America, but in the USA, several ammonium-glufosinate resistant weed biotypes have been recorded (Heap, 2008). Herbicide resistance among weeds is not related to the GM trait as such, but to the frequent use of herbicides with a similar mode of action. Herbicide-resistant weed biotypes also frequently evolved in conventional cropping systems in the past (Heap, 2008).

The introduction of RR soy very likely contributed to the development of glyphosate resistant weed biotypes in Brazil and Argentina.

5.2.4 GM soy aggravates problems with the control of volunteer soybean in subsequent crops

Generally there are no problems with volunteers in soy. Soy seeds are not dormant and soy seeds are unlikely to form a persistent seed bank in the soil. Due to its nutritious content, soy seeds are also highly predated. In many parts of Latin America, soy can only grow in particular seasons of the year. In the more tropical parts of Latin America, soy could grow all year round. Here it is possible that GM soy grains left on the field or lost during transport sprout and grow in a field with conventional crops. We found no evidence that this actually happens and causes problems in the control of volunteer crops.

5.2.5 GM soy facilitates the application of soil zero tillage in Latin America

The rapid adoption of RR soy has frequently been linked to the simultaneously increased implementation of zero tillage systems in soy in Latin America (Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2007; Cerdeira & Duke, 2006; Brookes & Barfoot, 2006; Trigo & Cap, 2003). Zero tillage has numerous advantages for the sustainability of farming, especially in relation to soil degradation and soil moisture conservation, as discussed in more detail in section 4.5 of this report.

RR soy facilitates the implementation of zero tillage systems as glyphosate applications associated with RR crops reduce the need for mechanical weed control and are easy to integrate in a system that requires a greater soil coverage with plant residues. This is also true for the GM soy lines in the pipeline with tolerances to other broad-spectrum herbicides. In Argentina, in 2005, 13.2 (or 87%) of the total of 15.2 million hectares of soy was cultivated with RR soy using zero tillage, whereas in 1996, when virtually no RR soy was grown yet, only 36% of the soy area was under zero tillage (Brookes & Barfoot, 2006, adapted from Benbrook and Trigo). The link between zero tillage and RR soy is also supported by survey data from Argentina, 2001, in which 42% of the conventional soy growers were found to apply zero tillage practices, whereas 80% of the RR soy growers used zero tillage (Qaim & Traxler, 2005).

However, the large-scale adoption of zero tillage in Latin America started well before the introduction of GM crops, indicating that in many cases weeds can also be satisfactorily managed in a zero-tillage system with conventional soy. Moreover, the various benefits from zero tillage practices are also relevant for conventional crops.

GM soy facilitated the adoption of zero tillage in Brazil and Argentina, but past developments show that zero tillage practices in soy can in many cases also be implemented successfully without the availability of GM soy.

5.2.6 GM soy facilitates monocropping

For more information on the sustainability impact of monocropping, see section 4.12.

RR soy and the expected new soy lines with tolerance to broad-spectrum herbicides could facilitate soy monocropping in the following ways:

1. As weed control is relatively easy in RR soy, problems with an increased weed pressure in soy monocropping are, in the short term, less likely to occur in RR soy than in conventional soy. The benefit of easy weed control in a monocropping system is likely to change in the long term if glyphosate-resistant weeds impair these benefits.

2. If the net benefits from growing RR soy are higher than those from growing conventional soy, as suggested by Qaim & Traxler (2005), this could stimulate the continuous cultivation of RR soy. In general, the higher the net benefit of a particular crop, the higher the opportunity costs of growing an alternative crop.

In many other respects, the production methods associated with RR soy appear equally suitable for monocropping as those associated with conventional soybean. Prior to introduction of RR soy in Brazil, large scale operations monocropping soy also expanded rapidly.

Evidence of the role of GM soy in facilitating monocropping is inconclusive.

5.2.7 GM soy has an impact on biodiversity in and around agricultural fields

This claim does not refer to biodiversity losses due to the loss of natural lands due to soy cultivation (claim 10), but to biodiversity in and around agricultural fields. The weed management system associated with RR soy and expected new GM soy lines with traits leading to herbicide-tolerance could result in a loss of biodiversity in and around fields:

1. If GM soy enhances scale enlargement, this could lead to the disappearance of field margins and a reduction in landscape complexity. Field margins and other landscape elements can play an important role as refugia for functional biodiversity in rural landscapes (Marshall & Moonen, 2002; Roschewitz *et al.*, 2005). Moreover, large scale farming may stimulate particular farming practices, such as the application of herbicides with air-planes leading to high amounts of drift, that can lead to a reduction of the quality of field margins. The link between GM soy and the ongoing enlargement of the scale of soy farming is further discussed in section 4.15.

2. An efficient weed control enabled by GM crops can reduce the biodiversity associated with weeds. This is especially relevant if the species affected by weeds have an impact on agro-ecosystem functioning or include rare species. This type of biota may be referred to as functional biodiversity. For instance, in the UK, seed rain from weeds known to be important in the diets of granivorous farmland birds was significantly reduced in particular herbicide-tolerant GM crops, relative to conventional crops (Moorcroft *et al.*, 2002; Gibbons *et al.*, 2006). It is important to note that this was not directly the result of the presence of the GM trait, but of the more efficient weed control enabled by the GM trait. Beneficial organisms, e.g. earthworms, carabid beetles, microbial communities with an antagonist role, may be enhanced by the presence of a large and varied weed community. On the other hand, weed plants and their seeds may also host microbial communities pathogenic to crops and function as a reservoir of crop pathogens when a suitable host crop is absent (Franke *et al.*, 2009; Marshall *et al.*, 2003). In this case, biota enhanced by weeds have a negative impact on agroecosystem functioning. It is not possible to state whether the overall impact of a greater functional biodiversity effected by weed communities is in general positive or negative for agro-ecosystem functioning. RR soy in Argentina tend to have a lower weed density and species diversity than conventional soy (Puricelli & Tuesca, 2005). It is thus likely that the cultivation of herbicide tolerant GM soy will lead to a reduction in the functional biodiversity dependent on weeds in the field, which could work out positive or negative for soy production and agro-ecosystem functioning in general.

On the other hand, zero tillage often increases soil biodiversity and an increased soil coverage in zero tillage systems may benefit aboveground biodiversity as well (Holland, 2004; Kladivko, 2001; Benckiser, 1997). If GM soy enhances the implementation of zero tillage techniques (see section 4.5), GM soy could stimulate the biodiversity in and around fields through a change in tillage practices.

GM soy probably had an impact on biodiversity in and around fields different from that of conventional soy.

5.2.8 GM soy is a threat to nearby farms that want to cultivate GM-free soy

Soy plants are by large self pollinators with outcrossing levels on average in the order of 1%. This implies that coexistence measures in the field can be relatively easy. Experiments in Brazil indeed revealed a maximum of 1.3% outcrossing at 0.5 m, lowering to 0% after 2.3 m (Andrade Pereira *et al.,* 2007) Other Brazilian experiments found 0.6% at 1 m to 0.2% at 5 m in the Southern Brazilian state of Paraná (Schuster *et al.,* 2007) or 0.5% at 1 m to 0% at 10 m in Cerrado biome region (Abud *et al.,* 2007). Outcrossing of conventional soy fields with adjacent GM soy fields, is therefore likely to be minimal, certainly so if the fields are situated more than 10 meters apart.

The drift of herbicides between fields should always be avoided as much as possible. This is even more urgent when crops in a neighbouring field are highly susceptible to the applied herbicide, which is the case when glyphosate is applied nearby a field cultivated with conventional soy. The amount of drift can be minimised to levels where no crop damage occurs if appropriate measures are taken (e.g. correct spraying equipment, training of the operator, the use of spray-free buffer zones) (van de Zande *et al.*, 2008).

Admixture of GM and conventional soy is more likely to occur during field operations and in various post-harvest steps. The co-existence of GM and conventional soy requires a separation of production chains, i.e. checking whether sowing or harvesting machinery shared between farms can be thoroughly cleaned or otherwise separate machinery for GM and conventional operations can be used.

The cultivation of GM soy does not pose a threat to nearby farms that want to cultivate GM-free soy provided that appropriate measures are taken to minimise outcrossing and herbicide drift in the field, and provided that admixture during field operations and in post-harvest steps is avoided as much as possible.

5.2.9 GM traits in soy can spread and persist outside agricultural fields

The likelihood of GM soy traits spreading and persisting outside agricultural fields is very small in Latin America. Soy originates from East Asia where wild relatives are still present. No wild species that can somehow cross-fertilise naturally with soy exists in Latin America (Anonymous, 2000). The occurrence of cross-fertilisation between GM soy and wild plants can thus be excluded in Latin America. Soy seeds are not dormant and soy seeds are unlikely to form a persistent seed bank in the soil. Due to its nutritious content, soy seeds are also highly predated. In many parts of Latin America, soy can only grow and produce seeds in particular seasons of the year. In the more tropical parts of Latin America, soy can grow all year round, but predation and weed pressure appears to be too high for soy seeds to produce viable seedlings. The risk of a persistent soy population growing outside agricultural fields is minimal and soy populations outside agricultural fields have not been reported in Latin America.

It is highly unlikely that GM traits in soy spread and persist outside agricultural fields in Latin America.

5.2.10 GM soy facilitates the expansion of soy production into natural areas

The expansion of soy production in Latin America has come with a reduction in the cultivation of other crops and an intensification of existing arable farming systems. Moreover, natural areas and pastures have been converted into arable land for soy production. The conversion of pastures into arable fields has stimulated livestock keepers to start farming in previously natural areas. The large soy expansion has resulted in biodiversity losses in Latin America and substantial additional emissions of green house gasses due to the loss of forests and grass lands. Below we identify mechanisms how GM soy could contribute more to the loss of natural areas than conventional soy production:

The RR trait in soy makes weed control easier and more flexible, and other GM soy lines with tolerance to broad-spectrum herbicides will have a similar effect. Weed pressure in arable fields is particularly high, for instance, in the humid tropics, where weeds tend to grow faster and complete more lifecycles per year than in temperate climates. Weed control is often one of the factors limiting the expansion of soy into particular areas such as the humid tropics. The relatively easy weed management associated with RR soy could thus facilitate the expansion of soy in those areas. There is evidence this has been the case in northern Argentina. See section 4.14. Weed control characteristics in RR soy could also be particularly suitable for the conversion of (degraded) pastures into arable lands. This conversion is also hindered by a high weed pressure. The expansion of the soy cropping area through the recuperation of degraded pastures can be seen as a relatively environmentally friendly way of expanding the arable lands.

Thus, RR soy can facilitate the expansion of soy into particular natural areas in the early years after conversion of natural areas into farmland if weed infestation that hampers expansion can be more easily controlled.

5.2.11 GM soy affects the genetic diversity of soy in Latin America

The RR trait came to be used in a broad set of varieties from different companies (Sneller 2003). There is no evidence that the genetic pool of soy was reduced during the breeding process of RR soy. RR traits are bred into existing cultivar base. Therefore, there appeared to be no decrease in genetic diversity as compared to conventional varieties.

There is no evidence that GM soy affected the genetic diversity of soy in Latin America.

5.2.12 GM soy changes the scale of farming in Latin America

The scale of soy farming has increased in Brazil and Argentina in recent years. See section 4.15. The characteristics of RR soy fitted in this development towards an enlargement of the scale of farming. The flexible timing of application of glyphosate as a post-emergence herbicide in RR soy, as well as soil zero tillage practices associated with GM soy, require less labour for weeding than conventional tillage in conventional soy. Labour extensive cultivation methods can facilitate an enlargement of the scale of farming, as labour extensive systems are usually mechanised knowledge-intensively, and tend to succeed in lowering the production costs per hectare as farm size increases.

In Brazil, the development of large-scale soy production started well before the introduction of RR soy, which indicates that RR soy was not a main driver of enlargement in scale. In Argentina on the other hand, the enlargement of the scale of soy production did coincide with the adoption of RR soy. Simultaneous with the RR soy introduction (1996/1997) other changes occurred, such as the introduction of free-market policies, the concentration of farm management, and the introduction of external economic actors in the agricultural sector. While RR soy fitted in the move toward large scale farming, these changes in scale probably would have occurred as well without the availability of RR soy.

Thus, GM soy probably facilitated an enlargement of the scale of farming, but the availability of RR soy was not an essential or decisive factor in this process.

6. Discussion and recommendations

In this chapter, weed management under GM soy is discussed as a change in weed management is the most direct impact resulting from the adoption of RR soy. Furthermore, the issues of tillage techniques, the scale of operations and the practice of monocropping in GM and conventional soy are further discussed. Finally, recommendations are given on what issues the focus of the debate on GM and conventional soy could be placed and how to practically deal with potential weed management problems in GM soy.

6.1 Weed management

Weed management is a prerequisite for almost all arable farming systems to be productive. The introduction of any new weed control technique (chemical, mechanical or biological) usually causes a shift in weed species composition towards species that can somehow resist or escape the weed control method. Weeds also tend to develop resistance to weed control methods, especially when a weed control strategy relies on one or a very limited number of methods that are not varied over time. A diverse weed management strategy is in general most suited to control weeds in the long term, while reducing the risk of weeds developing resistance to particular control methods.

Glyphosate is the main herbicide used in conjunction with RR soy. Glyphosate, generally considered as a herbicide with a low environmental impact and human toxicity, has been approved for use as a broad-spectrum herbicide in many crop cultivations and for other uses in many parts of the world, including Europe. The ultimate impact on the environment is determined by the application rates in field operations, which depend on environmental conditions, the method of application and the occurrence of resistance in weed species. This impact will therefore be location-specific and should be looked into as such.

With glyphosate having a low environmental impact quotient, both farmers and the environment could benefit from RR soy. These economic and environmental benefits may however diminish over time with the build-up of glyphosate resistance in weeds or when farmers apply higher doses of glyphosate than expected for other reasons. Data comparing herbicide use in GM and conventional soy in Latin America is scarce in the scientific literature. Studies did however show that some weeds have developed resistance against glyphosate after the introduction of GM soy. Our data from a major production region in Argentina (North Buenos Aires - South Santa Fe) indicate that the use of GM soy resulted in increased application rates of glyphosate to the extent that the environmental impact from herbicides exceed that in conventional soy. While the largest increase in the use of herbicides is associated with the tillage practice, i.e. a change from conventional tillage to zero tillage, the field environmental impact was further increased under GM soy.

We do not know how generally applicable this finding is. The comparison with conventional soy may be flawed, because the application rates in conventional soy apply to the year 2001, while the data for GM soy are an average for 2001-2007. Over time the use of herbicides in conventional soy could have increased also, but this cannot be assessed simply because conventional soy is hardly being cultivated in this region any longer. Another study by Brookes & Barfoot (2006) found no effect, or a slightly reduced effect, of GM soy on herbicide impact across all production areas in Argentina, which also includes less intensive production areas. This location specific case is therefore not conclusive for glyphosate resistant GM-soy in general, but does warrant further research to explore whether at this point in time the perceived environmental benefits of GM soy in other locations are also diminishing. With the same token, it should be realized that the introduction of other GM soy events may overcome this problem because of the use of herbicides with different modes of action.

Various reasons could explain why the environmental impact from herbicide appears to increase in RR soy in specific areas of Argentina. Farmers' main goal of their weed management strategy in soy is likely to be effective weed control, and not necessarily reducing the environmental impact from herbicides. Farmers may thus rather apply glyphosate in excess than risking the possibility of yield losses due to insufficient weed control. As excessive glyphosate applications do not damage an RR crop, the prime limitation to glyphosate use may be economical. Moreover, farmers may have limited awareness how to apply a weed control strategy most effectively. An alternative explanation is that the build up of resistance by weeds to glyphosate over time has stimulated farmers to increase glyphosate application doses in RR soy in order to achieve acceptable weed control. The positive interaction between RR soy and the implementation of zero tillage practices may have further stimulated the use of herbicide in RR soy, as well as the associated environmental impact from these herbicides. Zero tillage practices, which have a range of agricultural and environmental benefits, rely strongly on chemical weed control methods and are associated with a higher herbicide impact than conventional tillage systems. It should be noted that most of these factors that lead to increased herbicide application rates also apply to conventional crops. Broad-spectrum herbicides such as glyphosate used as pre-emergence herbicides also make up an important component of the weed management in conventional crops. Zero tillage practices were introduced in large parts of Latin America independent from GM crops. Weeds also develop herbicide resistance in conventional crops.

6.2 Tillage practices

A major concern in arable farming in Latin America is the degradation of soils. In response to this, zero tillage practices were introduced in Latin America in the 1970s and 1980s to reduce soil erosion, to sustain soil quality and improve soil water balances. Moreover, the implementation of zero tillage practices can save machinery, labour, and inputs, with the exception of herbicide use that tends to increase in zero tillage. Though the effectiveness of this practice depends on location specific conditions and cannot be readily adopted, zero tillage practices have been rapidly adopted in many parts of Latin America, especially in cereal-based rotations.

A major difficulty associated with this practice is the control of weeds. When soils are no longer tilled, weeds are not mechanically controlled anymore and alternative control methods are required. The availability of (broad-spectrum) herbicides is therefore linked to these practices and has been at the base of the widespread adaptation of zero tillage practices. Before the introduction of GM crops, broad-spectrum herbicides were used as pre-emergence herbicides at a large scale in zero tillage systems. In RR soy, glyphosate can also be applied post-emergence without risking crop damage, which has further eased weed control in zero tillage systems. While zero tillage techniques were adopted in Latin America well before the introduction of RR soy, the characteristics of RR soy were likely to facilitate the rapid expansion of zero tillage.

The energy savings, increased carbon sequestration in the soil and reduced erosion rates due to the expansion of zero tillage has been claimed as one of the main environmental benefits achieved by the adoption of RR soy. However, it cannot be stated with any degree of certainty how the area under zero tillage would have developed in Latin America without the availability of RR soy.

6.3 Monocropping and size of operations

Already in the early days of the 20^{th} century, wheat was grown continuously in large fields on the Argentinean Pampas. Later, wheat was replaced by large-scale maize production, which in its turn was largely replaced by soy. The increase in the scale of soy farming was associated with major liberalisation reforms of the economy of Argentina. The introduction of RR soy in the country coincided with these reforms. The increase in the scale of soy farming in Latin America was driven by the need to benefit from economies of scale required to export grain bulk products at competitive prizes. The availability of vast areas of new lands at the agricultural frontiers facilitated the expansion of large scale operations. The availability of suitable farm machinery also made these operations feasible, even with few but skilled labour. In Argentina, outsourcing of farm management practices to specialized companies lead to a further professionalization and increase in farm size. Hence, enlargement of the scale of soy farming was driven by the economic factors associated with an export-oriented crop.

The introduction of glyphosate-resistant GM soy fitted well in these developments. The flexible timing of application of glyphosate as a post-emergence herbicide in RR soy could facilitate an enlargement of the production fields. Also the availability of zero tillage techniques, which on its turn was facilitated by RR soy, aided an enlargement of the scale of farming. However, in our opinion there is no evidence that the availability of RR soy was an essential or decisive factor in this process. Grain cultivation has always been large scale in Argentina, and scale enlargement of soy cultivation was initiated prior to the introduction of GM soy, driven by the economic factors mentioned above.

Farm scale enlargement took also place in Brazil due to the consolidation of farms and the establishment of new large scale farms in the agricultural frontier areas, with GM soy being introduced much later. Currently, some very large scale farms in northwestern Brazil still grow conventional soy. Also in Brazil, RR soy probably facilitated the enlargement of soy production farms, but was certainly not the only or decisive factor behind the scale enlargement.

Monocropping, i.e. the cultivation of the same crop year after year, is heavily driven by the attainable profit margins of crops. Whether or not other crops are introduced in a cropping system through rotations depends on opportunity costs (i.e. the loss in income if other crops have lower profit margins), climatic and agro-technical possibilities to grow alternative crops, export abilities of the produce from the generally remote production areas of Latin American countries (favouring non-perishable grain crops only), ability to mechanize the operations and the like. These factors stimulated Argentinean farmers to monocrop wheat or maize in the past and stimulate nowadays Brazilian and Argentinean farmer to monocrop soy. If the net benefits made from RR soy are higher than those from conventional soy, the stimulant to monocrop soy would be higher in RR soy than in conventional soy. The relatively easy weed management in GM soy may initially avoid weed control problems that worsen when crops are not rotated. As with the scale of farming, it is unlikely that the availability of RR soy has been an essential or decisive factor in allowing farmers to monocrop soy.

6.4 Recommendations

For the specific case of the production system in a major production region in Argentina, herbicide application rate and the environmental impact from these herbicides was found to be higher in GM soy than in conventional soy. These findings warrant further research and debate about the role of GM soy on the environmental effects of herbicide applications in the long term. A range of options can be introduced to limit accumulating environmental impact from herbicide applications such as:

- Decision support and extension services, that operate independently of any involved actor in the chain, could inform farmers about best management practices.
- Governments can install rules and regulations that the use and application of herbicides, and other agro-chemicals for that matter, should comply with.
- A mix of crop varieties with tolerance to herbicides other than glyphosate could be integrated in the production system to diversify the use of herbicides as a strategy to slow down build-up of weed resistance.
- Rotating soy with other crops also offers opportunities to diversify the weed management strategy and slow down the build-up of herbicide resistance.

The scale or type of cultivation practices (i.e. monocropping, large scale cultivation, tillage practices) and the expansion of soy production into areas which are environmentally sensitive or rich in biodiversity, are very relevant for the discussion on sustainable soy production in general. The limited or untraceable role of GM soy on these aspects of soy cultivation suggests that stakeholders in the debates about GM and conventional soy might refrain from them. Also the environmental effects of the GM construct itself appear irrelevant for the debate on the ecological impact of GM soy. The co-existence of GM and conventional soy production can be achieved in the field if appropriate measures are taken to avoid admixture, cross pollination and herbicide drift. We therefore recommend to focus the GM soy discussion on the use of herbicides and the environmental impact from these herbicides in the long term, specifically related to the build-up of herbicide resistance in weeds associated with RR soy and other GM soy varieties to be released in the near future with comparable features.

7. Literature

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