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COLLABORATIVE PROJECT

Assessing and Monitoring the Impacts of Genetically modified plants on Agro-ecosystems

D10.1 Review of currently available economic data related to transgenic crops

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Objectives

The objectives of this paper are:

1. To review the current position as reported in mainly peer-reviewed articles which give details of economic impacts of GM crops that have already been commercially grown.
2. To consider economic implications surrounding current regulation of GMs
3. To briefly outline potential developments and events that may arise during the period of the AMIGA project
4. To briefly review literature related to food chain acceptance and economics
5. To summarise the implications of the above in relation to the future economic analysis within the AMIGA project.

Introduction

The AMIGA project, and this WP in particular, is concerned with the economics surrounding the growth and sale of GM crops in the European Union. However, it is important to recognise that much of the existing literature on this subject is based on experiences of growing these crops in other parts of the world. In this review we draw extensively on this literature in part to help guide the economic modelling which will be undertaken in subsequent sub-tasks. This review takes note of the report to the European Commission by Kaphengst et al (2011) which provided an assessment of the economic performance of GM crops worldwide. That report noted in particular a lack of methodological consistency amongst studies that provide raw data on crop performance, adding still further variability to that attributable to diversity in crop management.

Economic overview

The direct benefits relating to the growth of GM are reported to be substantial, even with only four widely adopted crops: Carlson (2009) estimated that global farm-scale revenues from GM maize, soy and cotton in 2008 were about $130 billion. This is reasonably consistent with the reports of James (2011) that the global area of transgenic crops in 2008 was 125 Mha, and of Qaim (2009) that the increase in farmers' gross margin attributable to GM adoption was of the order of $50-100/ha. However, it must be recognised that the inherent variability in crop production systems means that in some instances increases in margins are not always seen. Others would argue (e.g. Tiwari and Youngman, 2011) that a simple farm level financial analysis does not account for some of the potential negative impacts of the use of GM crops particularly in relation to current and potential future damage to the environment. Brookes and Barfoot (2009) suggested that a common cost ratio generally applies across all the transgenic crops: that is, payments to the seed supply chain (including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the transgenic technology provider) are typically about one-third of the net benefit, with the remaining two-thirds being shared among farmers.

Using a partial budgeting approach, Park *et al* (2011) estimated the revenue foregone by EU farmers, who, due to regulatory procedures, have been generally denied the chance and the choice to grow transgenic crops. This financial benefit would have accrued primarily from reduced input costs. If the areas of transgenic maize, cotton, soya bean, oil seed rape and sugar beet were to be grown where there is agronomic need or benefit. They estimated that EU farmer margins would increase by between €443 and €929 M/year. However, some caution is required in interpreting this data as it is based on experiences and margins achieved by farmers when growing crops outside of the EU and utilises broad approximations of potential uptake. These estimates are low in comparison to the global figure of $130 billion quoted from Carlson, in part because the GM crops that are available at present are only likely to be of limited agronomic (and therefore economic) benefit to farmers across the EU.

Across other areas of the world (i.e. outside the EU) a persuasive economic argument related to the benefits of GM crops is based on the fact that farmers are adopting GM crops because they believe it is to their advantage, either directly (e.g. more product, less inputs) or indirectly (e.g. rotational advantages, reduced soil erosion etc). For instance James (2012) estimates that 16.7 million farmers worldwide are using GMs, many of whom own small farms. Thus GMs are being grown on very large farms for instance in the Americas, as well as smaller farms (for instance in Asia). The assumption and argument is that irrespective of general positive financial data, farmers as generally astute business-people would not continue to grow such crops unless they derived a benefit from doing so.

Currently available transgenic events being commercially grown are all related to the modification of pesticide or herbicide use, potentially reducing the environmental loading and in particular the movement of toxic pesticides into water, giving further indirect economic benefit. Many farmers also report increased ease of crop management (Beckie, 2011). The level of adoption worldwide has grown without interruption since crops were first grown commercially in 1996.

Such increased interest and growth of GMs is related to the considerable financial costs associated with pest control across the globe. For instance, Oerke *et al* (1995) estimated that insects and plant pathogens reduced the annual global production of eight major crops in the 1990s by US$167bn, compared with the actual world production of US$325bn; weeds accounted for further losses of US$76bn. IFPRI (1998) reported expenditure on pesticides of US$6.5bn to avoid losses of more than US$25bn

Area Grown

GM varieties have been widely adopted with four major crops dominating uptake: transgenic maize, cotton, soya bean and canola. Cultivation in 2011 of 160 MHa by farmers would suggest many growers perceive there to be an economic or other benefit associated with the growth of these crops. It has been estimated that one million of those farms growing GM crops are in developed countries, and 15 million are generally smaller farms in developing countries (James, 2012). Further, it was noted that transgenic crops were planted in 29 countries during 2010, and an additional 31 countries, including Japan, granted approval for transgenic imports for food and feed use.

Green (2009) noted the introduction of glyphosate-resistant (GR) crops that have glyphosate resistance stacked with traits that confer resistance to herbicides with other modes of action to expand the utility of existing herbicides and to increase the number of mixture options that can delay the evolution of GR weeds. James (2011) recorded 29 Mha on which maize with 2 or 3 stacked IR or HT traits were cultivated in 2010, and 3.5 Mha of 2 stacked traits in cotton.

Where they occur, the major economic benefit is to farmers, and additional economic benefits are derived from the value added in the supply chain that links dedicated biotechnology firms with major seed firms, and from value added in downstream links between producers, distributors and consumers (OECD, 2009).

Table 1 illustrates the how the areas of the four most grown genetically modified species have expanded since 2001 in relation to total cropped area and the percentage of total world area of a given crop which is now cultivated using genetically modified seed.

Table 1 – Areas of cultivation of transgenic crops worldwide (Mha)

	Soya			Maize			Cotton			Rape		
	GM	all	%GM	GM	all	%GM	GM	all	%GM	GM	all	%GM
2001	39.0	76.8	50.8	7.7	137.5	5.6	6.7	33.7	19.9	2.8	22.6	12.4
2002	40.0	79.0	50.7	9.9	137.3	7.2	6.2	30.4	20.4	3.0	22.9	13.1
2003	40.0	83.6	47.8	12.3	144.7	8.5	7.1	32.3	22.0	3.3	23.5	14.1
2004	47.0	91.6	51.3	15.0	147.5	10.2	8.6	35.8	24.0	4.0	25.3	15.8
2005	52.0	92.5	56.2	17.8	147.4	12.1	12.0	34.7	34.6	4.6	27.7	16.6
2006	59.0	95.3	61.9	20.1	148.3	13.5	13.8	33.5	41.2	4.8	27.4	17.5
2007	59.0	90.2	65.4	25.0	158.4	15.8	14.7	32.9	44.7	5.4	29.9	18.1
2008	67.0	96.5	69.4	33.0	160.8	20.5	15.5	30.7	50.5	5.9	30.7	19.2
2009	69.2	99.5	69.5	41.7	158.6	26.3	16.1	30.3	53.1	6.4	31.1	20.6

Sources: Total soya bean, maize, rape: FAOSTAT; Total cotton: USDA; GM: GMO-Compass

Safety concerns

Many people and agencies still have serious concerns about the food safety aspects associated with the growing of GM crops. However, studies to date appear to suggest that there is no evidence that food safety has been compromised as a consequence of the adoption of GM varieties of these major crops. Agencies such as the European Food Safety Authority (EFSA) and the United States Food and Drug Administration (FDA) have assessed the food safety implications of the presence in the food chain of transgenic crops and products derived from them. These agencies consistently find that GM food crops are as safe as their non-GM counterparts and that the overall allergenicity of the whole plant is not changed through the genetic modification (EFSA, 2009; FDA, 2005).

Safety assessments noted by the UN World Health Organisation (WHO) have covered a wide range of possible effects (WHO, 2009), including:

- direct health effects (toxicity)
- tendencies to provoke allergic reaction (allergenicity)
- specific components thought to have nutritional or toxic properties
- the stability of the inserted gene
- nutritional effects associated with genetic modification
- any unintended effects which could result from the gene insertion.

Paoletti et al (2008) observed that, although different regulatory frameworks are in place, almost all adopted risk assessment strategies are based on a common set of principles and guidelines (Codex Alimentarius, 2003). Essentially, the GMO is assessed relative to a conventional counterpart that has a genetic background similar to the GMO under assessment, and which has gained a history of safe use.

Environmental issues

Ferry and Gatehouse (2009) compiled a set of articles about the environmental impact of transgenic crops, including an extensive section on various weed and pest management strategies. Lu et al (2010) reported that Bt cotton has become a source of Mirid bugs and that their population increases are related to drops in insecticide use in this crop. Hence, alterations of pest management regimes in Bt cotton could be responsible for the appearance and subsequent spread of non-target pests.

However, other studies are either inconclusive or suggest a variety of potential advantages or dis-advantages resulting from transgenic crop adoption in terms of preserving biodiversity and maintaining sustainability. These issues relating to the environmental impacts of GM provide the main focus of the majority of the WPs within the AMIGA project and therefore will be reviewed elsewhere.

In a review of advances in breeding of stress-tolerant crops, Ashraf (2010) observed that a reasonable number of cultivars tolerant to drought stress had been developed by conventional breeding, and now that molecular mapping has become available, tolerance to drought stress has been found to be controlled by many minor genes that have additive effects in their expression. Ashraf concluded that transferring a number of prominent genes effectively involved in stress tolerance to transgenic plants seems to be a logical approach.

Co-existence and resistance

Precautions need to be taken when transgenic crops are released into the environment, for several reasons. Provision has to be made to minimise the risk that weeds develop resistance to herbicides used with herbicide-tolerant (HT) crop traits, and the similar risk that pests develop resistance to the insecticide, particularly *Bacillus thuringiensis* (*Bt*), that is the active component in insect-resistant (IR) crop traits. Care also needs to be exercised regarding coexistence, to avoid any potentially harmful effects of gene flow between transgenic crops and other crops grown nearby.

Deguine et al (2008) commented that Bt cotton will eventually suffer from the same resistance issues as the sprayed insecticides, and that rational deployment within integrated management practices is therefore essential; exclusive reliance on refugia strategy may be insufficient. For instance there have been a number of reports of emergence of herbicide resistant weeds (Tabashnik et al, 2003). However it is noteworthy that the development of resistance has long been a problem for farmers of conventional crops, to the extent that the Weed Science Society of America maintains a list of herbicide tolerant weeds that is made freely available (Weed Science, 2011). The approach used most widely to delay insect resistance to Bt crops is the refuge strategy, which requires refuges of host plants without Bt toxins near Bt crops to promote survival of susceptible pests (Tabashnik et al, 2008). Carriere et al (2012) carried out systematic large-scale tests of the refuge strategy; they observed that agronomic practices, abiotic and biotic ecological factors, metapopulation dynamics, and pest behavior, life history, and genetics interact to determine the trajectory of resistance evolution. In order to develop efficient refuge strategies, empirical approaches are needed to characterize effects of refuges on resistance evolution. Zhang et al (2011) observed that some farmers in China relied on "natural" refuges of non-Bt host plants other than cotton. They found that bollworm susceptibility to Cry1Ac was significantly lower where Bt cotton has been planted intensively, than in populations where exposure to Bt cotton has been limited. Kruger et al (2012) conducted surveys to monitor South African maize farmers' attitudes to regulatory aspects guiding the planting of Bt maize and refugia between 1998 and 2010. Compliance with refugia requirements was low especially during the initial 5–7 years after release, to the extent that resistance became a problem. A large proportion of farmers reported significant borer infestation levels on Bt maize and many had to apply insecticides to limit pest damage.

The onset of resistance is not limited to Lepidopteran pests and cases of field evolved resistance of rootworms to genetically modified corns were recently reported (Gassmann et al., 2011). The latter case is receiving particular attention, since the maize events commercialized so far are not considered to express high doses and therefore their refuge strategy needs to be specifically adapted (EFSA, 2011; Tabashnik and Gould, 2012).

Sustainability and food security

The steady increase in the area of GM crops grown has led researchers to investigate the potential contribution of biotechnology towards sustainable agriculture, particularly in developing countries (Park *et al*, 2010; Adenle, 2011). Sustainable intensification of agricultural production was one of the key recommendations of the Commission on Sustainable Agriculture and Climate Change (Beddington et al, 2012) who identified a number of areas of science that contribute to sustainable intensification including improved soil management, agro-ecological approaches that inherently support agriculture and that better manage risks, and promotion of technologies that increase water use efficiency.

Clearly, the management strategies required to reduce resistance build up have to be integrated into the farming system and need to be accounted for in overall calculations of farm profitability. In a publication from the industry and government sponsored International Service for Acquisition of Agri-biotech Applications (ISAAA), James (2011) claimed that yield improvement following adoption of GM crops has been such that since 1996 about 75 MHa worldwide that would have been needed for the same output from conventional crops has been preserved, based on the measured yield gain from transgenic crops converted to an area estimate using data for yield of equivalent conventional crops, but many factors influence land use. Ewers et al (2009) assessed the changes in per capita cropland area in 124 countries over the period 1979-1999 and concluded that land-sparing is a weak process that occurs under a limited set of circumstances. Lambin and Meyfroidt (2011) analysed opportunities for preserving natural ecosystems in tropical developing countries while enhancing food production; they commented on the complexity of pathways of land use change, and reported that only minor success has been achieved so far in managing transition to more efficient land use.

Regarding the environmental effects of pest control strategies, Brookes and Barfoot (2011) claimed that, since 1996, the use of pesticides on the biotech crop area was reduced by 393 million kg of active ingredient (8.7% reduction), and the environmental impact associated with herbicide and insecticide use correspondingly reduced. The environmental benefits of reduced insecticide usage are sometimes assessed using the environmental impact quotient (EIQ). In a review of the performance of Bt cotton in Australia, Knox et al (2006) found that, due to changes in insecticidal choice and reduction in usage, there was a reduction of 64% in EIQ from growing Bt cotton compared with conventional non-GM cotton.

Development and investment

The main investors so far in the development of new biotechnology are large corporations, whose transnational operations can arouse public hostility when they appear to operate beyond the control of national governments (Koenig-Archibugi, 2004). However, the complex regulations surrounding the release of novel traits into the environment may impose a barrier to entry for smaller biotechnology companies, who may not be able to afford to complete complicated and expensive regulatory processes.

This high cost of biotechnology development has stimulated cooperation between the specialised bodies that make up the Consultative Group on International Agricultural Research (CGIAR), a global partnership that unites organizations engaged in research for sustainable development with the funders of this work. The funders include developing and industrialized country governments, international and regional organizations, and foundations such as the Rockefeller Foundation (Rockefeller Foundation , 2012) and the Bill and Melinda Gates Foundation (Gates Foundation, 2012). The work they support is carried out by the fifteen members of the Group; eleven of the members maintain international genebanks. These preserve and make readily available a wide array of plant genetic resources (CGIAR, 2012).

Overall economic analysis clearly needs to take into account the potential for changes in yield combined with changes in the amount and toxicity of pesticide use. Both of these aspects will vary with cropping system and agroecological conditions. Consideration needs to be given to the cost of wider landscape protection for instance via the need for buffer strips and refugia. A generally poor public perception of GM may mean that market prices for GM commodities could be depressed, although it as outlined in table 1, there are already considerable growth and therefore provision of GM crops into world markets.

Current position

An on-line database of GM crops approved for cultivation, listing 24 categories of crop, is provided by ISAAA (ISAAA, 2011), searchable by crop, trait, developer, country and type of approval. GMO-Compass (2010), which was set up with assistance from EC FP6, provides an extensive range of data of GM crops in the European context.

Entries in the ISAAA database were sourced principally from the Biotechnology Clearing House of approving countries and from country regulatory websites. The database shows that 20 crops with at least one GM trait have been approved for planting in at least one country; 9 are herbicide-tolerant (HT), 7 are insect-resistant (IR) and cotton, maize and soya bean are available with both those traits. Only maize has been approved with traits giving tolerance of two classes of herbicide (Table 2).

Table 2 – Transgenic crops approved for planting in at least one country

all GM crops	HT crops	IR crops	HT+IR crops	HT+HT crops
Alfalfa	Alfalfa	Cotton	Cotton	Maize
Canola	Canola	Maize	Maize	
Carnation	Carnation	Poplar	Soya bean	
Chicory	Cotton	Potato		
Cotton	Linseed	Rice		
Linseed	Maize	Soya bean		
Maize	Rice	Sugar beet		
Papaya	Soya bean			
Petunia	Sugar beet			
Plum				
Poplar				
Potato				
Rice				
Rose				
Soya bean				
Squash				
Sugar beet				
Sweet pepper				
Tobacco				
Tomato				

Source: ISAAA database

ISAAA publishes an Annual Review of the global status of commercialized biotech crops, and is a prime source of information and statistics relating to the adoption of transgenic crops. An overview of the 2011 publication can be found in the Executive Summary of ISAAA Brief 43 (James, 2012).

The GMO-Compass database includes cultivation areas for all forms of transgenic maize relative to total cultivation; selected data for seven countries with 19% or more by area is shown in Table 3, together with the global areas showing that 27% of global maize is GM.

Table 3 – Adoption of transgenic maize in selected countries

	Total Mha	GM Mha	% GM
USA	35.2	29.9	85
Brazil	14.0	5.0	36
South Africa	3.0	1.9	63
Philippines	2.7	0.5	19
Argentina	2.5	2.1	84
Canada	1.4	1.2	86
Spain	0.30	0.06	20
Global	**158**	**42**	**27**

Source: GMO-Compass database, data for 2009 (except Canada, 2007)

Carpenter (2010) summarised the results from 49 peer-reviewed publications reporting on farmer surveys that compare yields and other indicators of economic performance for adopters and non-adopters of currently commercialized GM crops. Their results based on outputs from 12 countries indicated that the main impacts, especially in terms of increased yields, have been greatest for the mostly small-scale farmers in developing countries. In addition to the economic benefit that can be presumed to be the motivation for widespread adoption by small farmers, there have been other consequences. Some of these have been positive, for example from reductions in pesticide quantity and toxicity, from preservation of soil quality by enabling wider adoption of no-till strategies, and from the net effect on biodiversity. Such benefits have been partially offset by additional cost of seeds, and by cost of compliance with coexistence regulations. It is also important to note that despite the large hectares grown across the world, and the evidence of economic benefit in many cases, that there is still considerable public concern related to the use of transgenic technologies. Some of the key issues are discussed in further detail below.

Economic impacts of insect-resistant crops

Bacillus thuringiensis (or Bt) is a soil-dwelling bacterium, in common use as a biological pesticide since the 1920s (Lemaux, 2008). The first isolation of Bt in 1901, the gradual expansion of Bt-based formulations between 1950 and 1990 and the development of transgenic Bt crops since first commercialisation in 1995-96 were reviewed by Sanchis (2011). IR GM crops have been endowed with insect resistance by incorporation of means to express *cry* proteins from *B. thuringiensis*; due to their high specificity these toxins are generally thought to be harmless to non-target insects and the end-user.

The release of the first events with insect resistance (Bt) (Schuler et al., 1998; Bates et al., 2005) were not expected to increase yield directly, but experience has shown that, by reducing losses from pests, these varieties have in many cases delivered increased yields when compared with conventional crops. Fernandez-Cornejo and McBride (2002) reviewed the rates of adoption in USA of Bt cotton and Bt maize, and reported a positive impact on net returns among cotton farms a negative impact on net returns among specialized maize farms. Their analysis suggested that Bt maize may have been used on some acreage where the value of protections against the European corn borer was lower than the Bt seed premium. Li (2005) analysed the on farm impact of adoption of Bt maize, using USDA data from a 2001 survey. Raw data indicated a yield improvement of 9%, but after controlling for self-selection bias (i.e. greater likelihood of adoption on well-managed farms) and other factors, Fernandez-Cornejo and Li concluded that the introduction of Bt maize generated an overall yield improvement of just 0.39%. Commenting on yield increases obtained by Bt maize farmers in Spain, Gomez-Barbero et al. (2008) observed regional differences in yield between Bt and conventional maize ranging from)1.3% to +12.1%, with the yield advantage of Bt directly related to local pest pressure. Demont et al (2007) reported that 5.7% of maize grown in Spain1998–2003 was IR transgenic maize, delivering a net benefit of €70/ha, consistent with the economic impact by country estimated by Brookes (2008) of improvement in gross margin of €86-108/ha, but only in areas of high insect infestation.

The economic advantage of adopting Bt cotton is also directly related to pest pressure. Gianessi (2008) reported that Bt cotton produced higher lint yields. Karihaloo & Kumar (2009) noted that between 2003–04 and 2006–07 the increase in cotton yields in India suggest a significant yield advantage of GM over conventional.

There is further economic advantage from input savings, specifically reduced pesticide use, or the use of cheaper pesticides with wider efficacy. Qaim (2005) reported average pesticide savings between 33% and 77% for HT and insect-resistant (IR) events, and in more detail, Qaim and Traxler (2005) noted savings of 24% in weed management costs in favour of HT soya bean when compared with conventional soya bean; benefits to Argentine farmers who had adopted HT soya beans was estimated to be $30 per ha. Other input savings included lower fuel input cost and reduced the time needed for harvesting.

IR Bt Maize has been adopted very widely as a method of managing pest pressure, and the single trait modifications have been followed by stacking of traits, so that Bt/Bt, Bt/HT and Bt/Bt/HT now offer farmers a range of alternate strategies to counter pest and weed pressures. In North America the European Corn Borer (ECB, *Ostrinia nubilalis*) has been a major pest affecting maize (corn) crops for over 60 years (Kaster and Gray, 2005). Initial control with DDT became unacceptable, and organophosphates and pyrethroids were subsequently used but their application is limited by plant height, especially in areas where ECB completes a second generation later in the growing season. Plant breeders tried to develop strains resistant to ECB, with mixed success. Koziel et al. (1993) were eventually able to report successful trials with transgenic maize plants expressing insecticidal protein derived from Bt. Western Corn Rootworm (*Diabrotica virgifera virgifera*) (WCR) another major pest affecting maize, can also be controlled by expression of proteins from Bt.

The performance of IR maize in particular was reviewed by Pilcher, Rice and Obrycki (2005), Price, Hyde and Calvin (2006), and Diffenbaugh *et al* (2008). Collinge *et al* (2008) considered that transgenic maize with *Bt* toxin genes has been widely adopted because of its ability to increase yield when there was a high insect risk. In addition these crops were less susceptible to secondary fungal attack by *Fusarium*, with the result that the grain contains consistently reduced levels of mycotoxin, potentially resulting in safer food for people and safer feed for livestock. Detailed descriptions of the effectiveness of *Bt* maize in a wide geographic spread of cereal cultivation against different insect pests were provided by Gray *et al* (2009), Kruger, Van Rensberg and Van den Berg (2009), Consmuller, Beckmann and Schleyer (2009), and Hutchinson *et al* (2010). However, Gouse et al (2009), having analyzed the results of a sample survey of 249 smallholders growing Bt maize in South Africa, cautioned that the results were not unambiguously favourable. There was a slight yield advantage per hectare, but average seed efficiency, in terms of yield per kg of seed, was below that for conventional seed.

The performance of IR cotton has been reviewed by many authors, including Bennett *et al* (2004a), Bennett et al (2004b), Cattaneo *et al* (2006), Frisvold, Reeves and Tronstad (2006), Vitale *et al* (2007), Subramanian and Qaim (2009) and Naranjo and Ellsworth (2010). These generally suggest that adoption is economically beneficial mainly in terms of yield, but also in input savings. One drawback is that land holdings in parts of India are so small that farmers fail or are unable to provide refuges in the proportion recommended (APCoAB, 2006). Stone (2011) also suggested that crop yields from India's IR cotton may have been overemphasized, as modest rises in crop yields may come at the expense of sustainable farm management. Stone compares village yields in 2003 and 2007, which conveniently had very similar levels of rainfall. Cotton yields rose 18% while pesticide sprayings were down by 55%, but conditions in the cotton fields change quickly. Populations of insects not affected by Bt began to explode. This outcome has also been reported in China, in the form of Mirid bug infestation (Lu et al, 2010). Duke (2011), using data from cotton farms in northern China to illustrate the indirect influence on pest management in neighbouring farms not using GM, noted that *Bt* cotton not only reduced bollworm damage to the crop, but also reduced pest damage in adjacent crops.

Overall there are many indications that the use of IR can increase yields and reduce the use of pesticide, with potential knock-on environmental benefits, but the above review suggests that caution is required in interpreting the various data. Clearly any economic model needs to be able to deal with and explore the variability of crop yield and pesticide use. The developing literature associated with the impacts of secondary pests requires further investigation, and indeed sub task 10.3 deals with aspect directly.

Economic impacts of herbicide tolerance

The mode of action of HR is usually to inhibit an enzyme involved in the synthesis of amino acids, and therefore glyphosate is only effective on actively growing plants. HT crops were developed to be resistant to glyphosate.

US$15bn was spent worldwide on herbicides in 1998 (IFPRI, 1998), and this had risen to about US$45bn by 2010, illustrating the potential importance of technologies which can lead to pesticide savings HT crops provide one such technology, with the area of herbicide-tolerant (HT) crops grown in 2010 being about 90MHa (James, 2011). Glyphosate, a broad-spectrum systemic herbicide, has played a key role in the adoption of transgenic HT crops.

Fernandez-Cornejo and McBride (2002), cited above regarding IR crop adoption, also reviewed the rates of adoption in USA of HT maize and HT soya bean. They commented that the limited acreage on which HT maize had been used was confined to acreage with the greatest comparative advantage for this technology. The adoption of HT soya beans did not have a significant impact on net farm returns in either 1997 or 1998. This suggested that other factors may have driven adoption for some farms, such as the simplification of farm management and the opportunity to use one product instead of several herbicides to control a wide range of weed pressures.

The agronomic performance of HT crops was reviewed by Firbank *et al* (2006) and Christoffoleti *et al* (2008). The overall conclusions were that adoption of HT crops has helped to reduce the density of many weed species, although in many cases overall biodiversity has been maintained. Dill, CaJacob and Padgette (2008) noted that glyphosate-resistant crops (GRCs) represent one of the more rapidly adopted weed management technologies, and that the development of stacking with biotechnology traits that confer resistance to other treatments has given farmers the benefits and convenience of multiple pest control technologies within a single seed.

Gianessi (2008) noted that widespread planting of glyphosate-resistant crops led to significant savings of farm inputs, both directly in terms of herbicide, but also indirectly in terms of fuel and time associated with the spraying of these crops. Net savings of $23/ha were reported using data from a farm survey of maize growers, in comparison with effective weed control programs in conventional maize. Gianessi also reported that aggregate yields increased generally, and in the case of canola by about 10%. However, Ceddia *et al* (2008) noted that the main benefits usually arose from increased flexibility of management and potential rotational benefits. Such benefits have been noted by growers of HT soya bean, maize, cotton and canola, with additional value from crops that involve less management time. For example, Smyth *et al* (2011) reported that adoption of transgenic HT canola in western Canada enabled farmers to sow seed directly with no prior tilling, which gives significant benefit in soil conservation. Furthermore, annual carbon sequestration attributable to adoption of transgenic HT canola in western Canada had reached one million tonnes. They also estimated that the disadvantage if HT canola had not been developed and Canadian canola farmers had continued to use previous production technologies would have been that 60% more active ingredient would have been required. Gusta et al (2011) used farm survey data for the years 2005-7 to calculate that the net benefit of adoption of HT Canola in the range Can$25-28 per ha.

The risk that weeds may become resistant to herbicide is well known. A collaborative monitoring study (Heap, 2010) identified 194 herbicide-resistant species in 19 herbicide groups. Of the 194, 19 species show resistance to glycines, including glyphosate. Strategies have accordingly been developed to manage the cultivation of glyphosate tolerant transgenic crops so as to delay the emergence of resistant weeds. Hurley et al. (2009a, b, c) described the weed management programmes, best management practices and the economic effects for growers of transgenic maize, cotton and soya beans. Based on farm surveys in USA, they reported that the emergence of resistant weeds reduced the economic benefit of growing these herbicide-tolerant crops by up to about one-third. The adoption of HT soya beans and no-tillage agriculture in Argentina has increased the use of glyphosate as the main tool to control weeds. This has helped to reduce the density of many weed species but has increased the density of some others that were previously not always part of the community (Qaim and Traxler, 2005). Overall, two weed management practices were considered effective: the use of a residual herbicide with glyphosate and the rotation of crops.

Ceddia *et al* (2011) analysed the problem of pollen-mediated gene flow as a particular type of production externality, using an economic model to test the effect of variables such as width of buffer zones on the magnitude of gene flow; results show that buffer areas on conventional fields are more effective than those on GM fields, with implications for coexistence policies in the EU. Demont *et al* (2009) suggested that any EU approach needed to be "proportionate to the aim of achieving coexistence", and proposed a spatial framework based on an existing landscape. They argued for flexible pollen barrier agreements between farmers rather than imposing rigid isolation distances. Clearly the financial implications associated with co-existence require further investigation and may provide a major determinant of the overall profitability of growing GM crops from the perspective of the individual producer.

USDA (2011) expects all interested parties to cooperate over coexistence, with strong reliance on science to help inform coexistence. Overall the view appears to be that with the appropriate conditions, and the management thereof there appears to be no major issue in terms of gene containment, although clearly the nature of the management will have profitability consequences for a given producer. This view is supported by scientists at the John Innes Centre (Sense about Science, 2011).

There are clear implications of the above for economic modelling, which needs to be able to account for the potential benefits of utilising HR crops, but also account for issues related to potential resistance, co-existence, pollen mediated gene flow and thus the costs associated with maintaining effective isolation distances.

Future developments likely during the period of AMIGA

The above sections set out the current economic performance of a limited set of GM crops. Indications are that increasingly diverse events will come to market at an increasing rate, with a variety of new events coming to market during the life span of AMIGA, i.e. through to 2015/16. These will be picked up mainly in sub task 10.6, but are worth bearing in mind at the model construction stage to ensure the tool is fit for this purpose as well.

Crop development has been accelerated by various aspects of biotechnology; the process remains lengthy, and it is to some extent possible to forecast when new crops may be available for release from announcements of preliminary field trials. APHIS provides details of applications for field trials and associated transportation of GMO seeds and plants, together with details of applications for deregulation of GMOs considered safe for general release (APHIS, 2011). Stein and Rodriguez-Cerezo (2009) reviewed the data published up to 2008 and observed that most new GM crops were marketed when the number of field trials had reached a peak in the preceding years.

The APHIS data file gives an indication of the time taken between initial application for release of a GMO and approval. The time required to obtain each of the 23 approvals granted since 2004 is shown in Table 4, and the 19 release applications awaiting decision in August 2011 are shown in Table 5. Nine of the pending applications are for HT traits, and four for IR traits, while traits are stacked in six instances. The lists of phenotypes show some of the novel properties that are likely to be introduced commercially before 2015.

Table 4 – APHIS release approvals 2004-2011

Article	Phenotypes	Sought	Approved
Cotton	IR-Lepidopteran resistant	05/02/2003	15/07/2004
Cotton	IR-Lepidopteran resistant	05/02/2003	15/07/2004
Corn	HT-Phosphinothricin tolerant / IR-Lepidopteran resistant	30/06/2003	21/10/2004
Cotton	HT-Glyphosate tolerant	26/03/2004	20/12/2004

Beet	HT-Glyphosate tolerant	19/11/2003	04/03/2005
Cotton	IR-Lepidopteran resistant	04/06/2003	06/07/2005
Corn	HT-Phosphinothricin tolerant / IR-Lepidopteran resistant	19/12/2003	23/09/2005
Corn	IR-Coleopteran resistant	04/05/2004	14/12/2005
Corn	PQ-Lysine level increased	16/08/2004	23/01/2006
Rice	HT-Phosphinothricin tolerant	22/08/2006	24/11/2006
Corn	IR-Western corn rootworn resistant	27/12/2004	16/03/2007
Plum	VR-PPV resistant	20/09/2004	27/06/2007
Soya bean	HT-Glyphosate tolerant	27/06/2006	23/07/2007
Corn	IR-European corn borer resistant	25/10/2006	24/07/2008
Soya bean	HT-Glyphosate tolerant / HT-Acetolactate synthase tolerant	28/09/2006	24/07/2008
Cotton	HT-Glyphosate tolerant	28/11/2006	26/05/2009
Papaya	VR-PRSV resistant	02/12/2004	01/09/2009
Corn	HT - Glyphosate tolerant / HT-Imidazolinone tolerant	01/06/2007	09/12/2009
Corn	IR-Lepidopteran resistance	10/09/2007	20/04/2010
Soya bean	PQ-High Oleic Acid	20/12/2006	08/06/2010
Alfalfa	HT-Glyphosate tolerant	19/04/2004	27/01/2011
Corn	PQ-Thermostable alpha-amylase produced	07/10/2005	15/02/2011
Corn	AP-Fertility restored / Male Sterile / Visual Marker	03/12/2008	28/06/2011

Key:

AP	Agronomic Properties
FR	Fungal Resistance
HT	Herbicide Tolerance
IR	Insect Resistance
OO	Other
PQ	Product Quality
VR	Virus Resistance

Table 5 – APHIS release applications awaiting decision in August 2011

Article	Phenotypes	Sought
Rapeseed	HT-Glyphosate Tolerant	04/03/2011
Eucalyptus	AP-Freeze-tolerant/AP-Fertility Altered	19/01/2011
Corn	IR-Corn Rootworm Resistant	02/12/2010
Corn	HT-Tissue-selective Glyphosate Tolerant	08/10/2010
Soya bean	HT-Dicamba Tolerant	07/07/2010
Apple	PQ-Non-browning	10/06/2010
Peanut	FR-Sclerotinia blight resistant	11/03/2010
Soya bean	HT-2,4-D tolerant / HT-Glufosinate tolerant	15/12/2009
Soya bean	HT-Glyphosate / HT-Isoxaflutole Tolerant	24/11/2009
Corn	HT-2,4-D tolerant / HT-ACCase-inhib tolerant	21/08/2009
Soya bean	AP- Impr Fatty Acid Profile / HT-Glyphosate	20/07/2009

Soya bean	PQ-Altered Fatty Acid Profile	02/07/2009
Soya bean	IR-Lepidopteran Resistant	23/03/2009
Corn	HT-glyphosate tolerant	04/03/2009
Corn	AP-Drought tolerance	25/02/2009
Soya bean	HT-Herbicide tolerant	15/01/2009
Cotton	HT / IR	05/12/2008
Rose	OO-Altered flower color	10/11/2008
Cotton	IR-Lepidopteran resistant	18/04/2007

Early releases were based on single trait modification, for instance in relation to a specific pest or disease. In 1997, Monsanto released the first commercial stacked traits, HT plus IR in a variety of maize. Whilst the engineering of multiple traits (gene stacking) is a complex procedure, it appears to be proving commercially worthwhile, for example in enabling tolerance of more than one herbicide, which has the advantage, in combination with methodical weed management, of significantly reducing the risk of emergence of herbicide tolerant weeds. Ow (2011) reviewed methods for simplifying the tasks involved in gene stacking using specialist knowledge of methods for DNA transformation.

Stein (2010) noted that in 2008 the Institute for Prospective Technological Studies (IPTS) of the European Commission's Joint Research Centre (JRC) organised a workshop on ‘The global commercial pipeline of new GM crops’, and predicted on the basis of that workshop and subsequent research that by 2015 there could be over 120 different transgenic events in commercialized GM crops worldwide, compared with around 30 GM events in commercially cultivated GM crops in 2008. Stein expected that about half of the new transgenic events that could be brought to market by 2015 will have been developed in Asia and Latin America, with the other half coming from companies in the United States and the EU. Such predictions if they materialise by 2015 are likely to mean that the global food markets will contain a greater proportion of products derived from GM, that farmers who grow GMs may be at a competitive advantage in relation to those that do not, and from the EU perspective there may be increased pressure to allow the wider growth of GM crops.

Events that are awaiting approval for release include those relating to drought-tolerance, salt-tolerance and improved nitrogen use efficiency; clearly if successful in a commercial setting these will be important new traits, and their adoption will depend on their being able to maintain yields even when the stresses are at low levels. Some of the other new traits are relevant to pest control, and some offer nutritional advantages for both people and livestock. A key question is the degree to which existing and new releases have agronomic and/or financial benefits for farmers in the EU. If such benefits are limited then the uptake, even if approved for growth within the EU, is likely to be limited. However, the growing number of GM releases with stacked traits, and the prospect of “designer” seed is likely to mean that agronomic and /or the financial benefit associated with the growth of GM crops in EU agricultural systems will increase.

Stacked traits

Scientists at one of the major biotechnology companies (Que *et al*, 2010) noted that a number of agronomic and quality traits are being developed, for yield enhancement, drought tolerance, nitrogen utilization efficiency, disease resistance, fertility control, grain quality and grain processing, and the number of trait genes that could be transformed into corn could easily add up to 15 or more. This is almost unmanageable if each transgenic locus only carries one or two traits. Thus, it is desirable to deliver several traits simultaneously. So-called 'molecular stacks' of traits, effectively behaving as a single gene, may accelerate development by this means as well. Green (2009) reported an example of such a molecular stack to confer resistance to glyphosate and all five classes of acetolactate synthase (ALS)-inhibiting herbicides.

Cox et al (2009) reported that field-scale studies were conducted on four farms in New York to evaluate the agronomics and economics of double-stacked hybrids, finding a range of outcomes between $89/ha net gain to $71 net loss. Although a range of stacked traits are already at market, and this range is predicted to expand over the duration of the AMIGA project, there are also developments associated with tolerance to a variety of environmental stresses in development, although unlikely to be at market within the timeframe of the AMIGA project.

Given that stacked traits are already available in the market and it is likely that other stacked traits which potentially give greater benefits to farmers will continue to emerge it is essential that the economic modelling approach adopted is able to integrate such events.

Stress tolerance

Early attempts to use GM to develop drought-tolerance were based on incorporating a single trait, as for example in maize event MON87460, the trials of which were reported by Harrigan *et al* (2009). Performance of such events in some conditions was encouraging, but at other times yields were reduced. Gao *et al* (2011) reported progress with application of molecular cell biology to achieve strong improvement in drought tolerance in rice. Sinclair (2011) supported the view that sophisticated tools will be needed to monitor phenotype expression at the crop level in work to prepare crops modified to give good agronomic performance in a range of environments.

It is now recognised (Waseem *et al*, 2011) that numerous genes encoding structural and regulatory proteins determine the ability of a plant to tolerate stresses, which makes it very difficult to improve stress tolerance by conventional breeding alone. Waseem *et al* noted that identification of molecular markers associated with relevant traits has provided a new pathway for accelerating development of tolerance.

Overall, it is still perhaps too early to predict accurately the economic implications of new events coming to market, although it is likely that within the timescale of the project clearer indications of the field scale benefits of such crops will become more apparent and thus it is hoped to be able to make some estimates economic impacts toward the end of the AMIGA project. A key factor within the EU is whether new events will actually have agronomic and/or financial benefit to farmers within the EU.

Economic implications of transgenic crop regulation

GM crops are subject to a range of food safety and biosecurity controls, which vary widely between countries. The drafting, operation and administration of these controls have been discussed in a number of publications, including articles by Fuchs and Gonsalves (2007), McHughen and Smyth (2008), EC Food Chain Evaluation Consortium (EC, 2010), Davison

(2010), Meyer (2011) and Kuntz and Ricroch (2012). Most of the studies are concerned with the situation in Europe, where legislation on GM crops has had major economic consequences. Ammann (2010) set out the costs and lost benefits of over-regulation, concluding that the regulatory regime hampers public research in molecular breeding considerably due to enormously high regulation costs.

Heinemann, Kurenbach and Quist (2011) strongly supported the use of molecular profiling in GMO risk assessment, noting that as more and more kinds of GMOs and traits are developed, molecular profiling is becoming an important way to increase confidence in risk assessments. Molecular linkage maps have made it possible to identify the effects of the individual genes on genetic variation in a population.

The USA is the largest commercial grower of GM crops; for a GMO to be approved for release it is assessed by the US Department of Agriculture (USDA), the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA). The Animal and Plant Health Inspection Service (APHIS), an agency within the USDA, which is responsible for protecting agriculture and the environment from potential pests, determines whether a GMO is as safe for the environment as its traditional counterpart and hence can be freely used in agriculture. Field trials may be approved by APHIS under the notification procedure, which involves stating how the proposed GMO meets criteria that include not being of a noxious weed species, and not transformed with human or animal pathogenic sequences. The notification can be used for field trial approval as well as importation and transport within the USA.

The adventitious presence of GM crops in non-GM crops can and has been viewed as an economic problem, and in April 2009, the European Commission issued a substantive report on coexistence (EC, 2009), including the state of implementation of national coexistence measures. It was found that the majority of Member States had designed the coexistence measures in such a manner that they prevent the labelling threshold for GMOs in food and feed at a level of 0.9% from being exceeded. Segregation measures vary among Member States, with isolation distances for maize production between 25m and 600m. Such measures clearly have financial\implications to both primary producers and businesses dealing with GM crops within the food chain.

It has been observed (EuropaBio, 2011) that the EU differentiates between import and cultivation regulation, whereas in Brazil, USA and Canada authorisations are given for the full scope of planting, import and consumption. The Canadian system is also noteworthy in being product-based – the presence of a novel trait, irrespective of the method used to introduce it, can trigger notification and authorisation requirements.

Herbicide-tolerant crops have also been produced from existing crop germplasm without recourse to genetic engineering. Examples of non-GMO herbicide-tolerant crops include sulfonylurea-tolerant soya beans and Clearfield maize and wheat; because they fall outside GMO regulation, these crops present different challenges for the introduction of crops with novel traits.

Food chain acceptance and economics

It is thought that the safety of processed foods containing GM ingredients is relatively straightforward to ensure. Clark et al (2005) observed that the normal mode of toxic action for the proteins is very unlikely to occur in the vertebrate digestive system, and the protein has been used in direct testing with mammals with no adverse effects reported. Hammond and Jez (2011) pointed out that proteins such as the Cry protein associated with *Bt* traits are readily degraded. During processing, proteins in corn and soy are subjected to harsh environmental conditions that lead to denaturation and loss of protein function. Thus, dietary exposure to functionally active proteins in processed food products are often negligible and below levels of any safety concerns.

Binimelis et al (2009) noted that dialogue between stakeholders in the food chain had encountered difficulty in framing the concerns to be taken into account. A lack of understanding among administrators, organic farmers, farmers growing GM crops, environmental groups and business representatives of each others' positions had contributed to conflict.

In the European Union, GM foods are only authorised by the European Food Safety Authority (EFSA) if they have passed a rigorous safety assessment. The procedures for evaluation and authorisation of GM foods are laid down in Regulation (EC) No 1829/2003 on GM food and feed, which came into force in April 2004; copious information on the assessment of various GM traits is accessible via EFSA (2012).

In UK, the Nuffield Council on Bioethics (Nuffield Bioethics, 1999) examined ethical and social issues associated with GM crops, and found the following specific concerns about GM food:

- some consumers, including vegans, vegetarians and some religious groups are concerned about the possible introduction of genes of animal origin into other animals or crops
- there is concern that farmers, manufacturers and retailers will not pass on savings gained through genetic modification to the consumer
- the suspicion exists that research is more likely to be focused on genetic modifications that help the farmer, manufacturer or retailer, such as herbicide tolerance or longer shelf-life, than on those that might benefit the consumer, such as improvements in nutrition or a reduction in allergens
- some people believe that humans might absorb and be affected by DNA transferred to them through the cell walls during digestion
- the risk that allergenicity could be transferred from one food plant to another with the transfer of genes has concerned some scientists and others
- there is also a more general unease that there may be long-term risks to human health from this technology. Because the nature of such risks is unknown, questions were raised about whether they would necessarily be picked up by the safety tests that GM foods undergo.

Some of the unease expressed has dissipated, and developments in biotechnology have been informed by public questioning. From the point of view of a dietician, Lilyquist (2010) considered her view on safety of GM food to be necessarily equivocal, because of the impossibility of guaranteeing absence of risk to health, while acknowledging that 'one cannot dispute the potential for increased nutritional content of foods, nor can one dispute the potential for more efficient food production’. McHughen (2011), in a brief review of the role of GM regulations in the bio safety of the food chain, commented that Europe has failed to assign resources commensurate with real food safety risks; instead, as illustrated with the “farm to fork” program, disproportionately placed regulatory safety resources to guard against low level, or even phantom, perceived threats. The EU-funded CO-EXTRA project (Bertheau and Davison, 2006) addressed the co-existence of GM and non-GM supply chains. They concluded, among other findings, that coexistence in the supply chain is considered possible with an appropriate organisation of the chain, generating specific costs related to keeping the products separate from farm to factory, to performing analytical tests and to maintaining product traceability.

A Food Chain Evaluation Consortium was set up (EC, 2010) to examine the effectiveness of the the Community Plant Health Regime (CPHR) in controlling the spread of pests affecting plant health in the European Union, with particular reference to the system of import controls and its role in the overall EU phytosanitary regime. They were asked to define the appropriate tools for effective and efficient risk assessment and risk management. In their report, they made comparisons within a set of policy options, using modelling to quantify the environmental impacts over a period of 25 years. They noted that where Harmful Organisms (HOs) had emerged, lack of incentives and disincentives and the limited support and lengthy decision-making process resulted in measures being taken too slowly and too late. Together with numerous operational recommendations, a specific financial instrument was considered to be necessary, possibly in the form of a Plant Health Fund.

Implications for further overall economic analysis

In this review we have considered the range of literature available broadly related to or impacting on the economics of growing genetically modified crops. Most of this literature is based on the wide-scale growth of modified crops outside of Europe. Several of the sub-tasks in WP10 are related to the modelling of the economic and financial aspects of growing GM crops in Europe. Based on the research reviewed this suggests that the economic model to be constructed as part of the AMIGA project needs to be able to:

1. Emulate in an approximate way the crop growth cycle in such a way that different crop establishment practices can be accounted for as well as different post-establishment management practices
2. Allow for both conventional and GM crops to be grown within a rotational context as this is likely to happen in farming systems across EU.
3. Account for production issues and the economic consequences arising from and associated with resistance, co-existence and refuge strategies
4. To provide output that is delineated by the 5 agro-ecological regions adopted by the AMIGA project
5. Be flexible enough to accommodate outcomes from other sub-tasks associated with WP10, i.e IPM modelling, secondary pest modelling and more detailed on farm financial models
6. If possible to make use of the data collected during the experimental phases of the project for calibration or validation purposes.

Concluding comments

In this paper we have reviewed the economic impacts of GM crops that have already been commercially grown. The possibilities of new events both in the short-term and looking further into the future have been considered. Tait and Barker (2011) noted that Foresight and Horizon-Scanning are important tools for the development of government policies and planning, and help to determine both the level of investment in scientific research and the policies that facilitate the application of such knowledge. It could be argued that a decade of negative attitudes throughout Europe to transgenic crop development has led to a lack of new GM crop varieties for European agriculture. In place of government leadership, public apprehensions encouraged the involvement of non-government actors, an increasingly complex set of state–society relationships, and a blurring of the boundaries between the public and private sectors. The role of the state moved from being the main provider of policy to facilitating interaction between interested parties. Tait and Barker called for clearer strategic thinking on how to implement a governance approach to food security.

Based on this review we would make the following observations:

1. Current cultivation and major issues:

With an estimated cultivation in 2011 of approximately 165Mha (James, 2011), [compared to an approximate total arable area in the EU of about 100Mha] the overall picture suggests that financial benefits must generally accrue to farmers who continue to grow GM varieties. Many of the environmental concerns are either not emerging in the field, or are not creating issues beyond those experienced as part of conventional farm management practice.

2. Farmers benefits worldwide

James' estimates that 15.4 million farmers worldwide grew genetically modified crops in 2010. About one million of these were on larger farms in developed nations, but by far the majority, 14.4 million, were on smaller farms in developing countries. Farmers in general, like many business people only persist with practices that make them more money, save them time or perhaps have some other tangible benefit related to safety or environment.

3. Limited benefit to EU farmers

It is likely given the event currently available that even if EU farmers had open access to GM seed that only a minority would derive a financial benefit from their growth. However, as more events come onto the market, particularly if they provided new agronomic opportunities for EU farmers, then evidence suggests that those outside the EU could derive an increasing competitive advantage in relation to either increased yield or input savings.

4. New events in the short term

To date the events that have been approved and released have been limited mainly to herbicide tolerance and insect resistance. These appear to have been successful in relation to four major crops. Indeed the overall economic benefit from 1996 to 2009 has been estimated by James at US$65bn.

5. Events in the medium term

It is difficult to predict exactly when new events will become available for commercial use but research on traits relating to drought and salt tolerance and nutritionally-enhanced crops is well advanced. Release of such events may still be some way off but potential benefits in marginal and stressed agronomic regions could be considerable. The Golden Rice example suggests that release of potentially very beneficial crop traits may continue to be hampered by political wrangling rather than being based on science-based evaluation.

Overall, it appears that GM technologies have and will continue to have economic and production benefits in many environments across the globe. With news that the world population has reached 7 billion, and noting an estimated 8 billion by 2023, the United Nations Department of Economic and Social Affairs commented (UN DESA, 2011) on the conflicting requirements for food and energy production on the one hand and natural resource conservation on the other, recommending further investigation by decision-makers into ways to resolve this conflict via all technologies and production systems. It is likely that biotechnology and genetically modified crops will continue to have a key role to play across the globe, if not in the EU.

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