
Consultancy support for the analysis of the impact of GM crops on UK farm profitability

Final report

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By

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Executive summary

Objectives

This report reviews literature on the economic impact of genetically modified crops and places this within the context of UK arable farming. Its primary function has been to provide objective information and analysis that can help the Strategy Unit of the Cabinet Office in its work on the possible economic impacts of GM crops on UK farmers.

Background context to GM crop development and adoption

- Over the last few years there have been declining prices for most arable crops (notably cereals) and falling levels of profitability;
- The economic performance of farms can vary widely, both between and within regions. This means that the potential impact of a new piece of technology (eg, GM cost reducing technology) will be subject to significant variation in impact at a local level;
- The underlying policy environment, set by the Common Agricultural Policy (CAP) is changing. Levels of support are decreasing and the EU market is opening up to increasing levels of competition from world markets. To remain as competitive as possible, many UK producers are likely to explore all forms of new technology that can assist them (eg, through yield enhancement, cost reductions). The planting of GM crops could be an approach taken provided farmers perceive that there is a market for the produce. Others may look at other cost reducing technologies, focus on higher value, niche product production, like organics, where cost is less of a market driver, join agri-environmental schemes that target the delivery of environment and landscape goods for the wider public or leave the sector;
- Recent market changes of relevance to UK farming include the growth in demand for products that are perceived to better meet the demands of consumer concerns about the environment, health and production systems (eg, development of markets for organic produce). On the supply side, there has been significant development of more sophisticated supply systems that incorporate identity preservation and traceability. As a result an increasing number of farmers are now members of independently accredited, quality assurance schemes. There has also been greater adoption of 'more integrated crop management systems' (eg, less use of prophylactic spray regimes in favour of spraying according to pest and disease thresholds);
- New technologies take time to come to the market place. Thus the lifting of any moratorium on GM crop approval in the EU does not mean that GM crops will immediately be made available to farmers. Regulatory and seed approval procedures and requirements mean that the first GM crops that might be available to UK arable farmers are still 2-4 years away.

The market for GM versus non GM crops

A distinct non GM market began to develop in the EU from 1998 (for ingredients used in human food) and has since extended to the animal feed sector. The main points of relevance about this market development for UK farming profitability and take up of GM crops are:

- a) Current non GM versus GM price differentials (in favour of non GM) are low and on average within a range of 1% to 5%. The non GM market, in which there is a price differential (in favour of non GM) mainly exists post farm gate;
- b) At the farm level in countries where GM crops are widely grown, there has been and is currently very little development of a price differential. In Brazil, the focus of non GM supplies of soybeans, there has, to date been no evidence of a non GM price differential having developed. In the US and Canada, the farm level price for non GM supplies has been within the range of 1%-3% higher than GM supplies.

- c) Assuming some GM crops (containing agronomic traits) are eventually approved for use in EU agriculture, a key factor influencing whether UK farmers grow these crops will be whether there is a market for the GM crop(s). The evidence and analysis presented in this report (section 3 and appendix 3) suggests that this depends on the crop, use and market:
- crops going directly into human food have the highest level of requirement for non GM produce. Therefore crops with relatively high shares of produce going into the human food chain are likely to be markets in which GM crop take up may be least and slowest¹ (eg, sugar, potatoes, wheat). Sugar beet is probably the most ‘affected’ crop because British Sugar is the monopoly buyer of sugar beet and sole supplier of seed to farmers. Whilst British Sugar maintains a policy of not accepting GM sugar beet (its current policy) there will be no market for GM sugar beet. If this policy changes by the time of commercialisation (eg, for use in non food sectors such as bio-ethanol) and/or export opportunities in the bio-ethanol market arise, a GM market may develop;
 - In contrast, a significant part of the animal feed and industrial sectors (about three-quarters of the ingredients used in EU animal feeds) are largely indifferent as to whether crops used are derived from GM crops or not. For crops destined for these markets, there is less likely to be a problem in finding outlets for GM crops and hence the crops likely to see the highest level of interest in GM technology take up will probably be in grain and forage maize, oilseed rape, and starch potatoes;
 - The nature of competition may affect ‘willingness to accept GM crops’. In markets where (low) price is considered to be the primary driver of demand (this is relevant to both domestically consumed foods and to export markets), access to the lowest priced products and raw materials is the main criteria used for purchasing. In such markets (eg, frozen rather than fresh poultry), GM based feed ingredients tend to be attractive because they are often cheaper to produce than the non GM alternative.
- d) Take up of GM crops will also be influenced by the impact on farm incomes. Farmers will assess whether to grow GM crops according to the likely impact of the GM crops on factors such as yield and costs of production (and other factors that are more difficult to put a monetary value on such as convenience). Within this assessment the level of price differential between GM and non GM crops will play a role in influencing take up. The higher the level of price differential in favour of non GM crops, the less likely GM crop take up is likely to be and vice versa..
- e) It is important to emphasise that the GM crop traits examined in this study are intended to be cost reducing. This means that if the majority of global production switches to this technology there will a cost and price reducing effect on the baseline price of the commodity. To date this has probably only occurred in the soybean market. The net effect of this is that any price differential that may develop between GM and non GM products will partly reflect this cost of production differential and may also reflect any costs of segregation/IP of the non GM product. It is therefore incorrect to assume that price differentials only reflect segregation/IP costs. In the soybean sector, estimates of the impact of GM technology suggest that the real price of soybeans had fallen by 1%-2% by the end of 2001 because of the technology (see section 3).
- f) In the longer term (10 years plus), GM crops containing quality traits (eg, offering possible traits such as lower fat content, food products with improved taste) might be commercialised. This category of GM crop could offer farmers price premia to grow such crops and may be attractive to some farmers because of the premium price and/or because producing on contract to processors may contribute to reducing price risk.

¹ It is possible that initially there could be no market for GM crops in human food products, if for example, current non GM policies in sectors like sugar were to continue for several years

Technology costs

GM technology is largely charged for via seed price premia (as applies to new conventional seed). The level of premia charged will vary according to a number of commercial factors and market conditions. The price paid by farmers may also vary according to the margin added to seed by their supplier (eg, local merchant) and farmer ability to negotiate discounts on list/recommended prices. This is important to recognise when examining literature on the impact of GM technology because the higher the assumed cost of the technology, the lower the benefit and vice versa.

Co-existence

Co-existence relates to the economic consequences of adventitious presence of material from one crop in another and the principle that farmers should be able to cultivate freely the agricultural crops they choose, be it GM crops, conventional or organic crops (EU Commission 2003).

The issue of adventitious presence of (unwanted) material from one crop in another is not a new issue and almost all agricultural commodities are traded in recognition of some degree of adventitious presence of unwanted material occurring. Tolerances are invariably set for the presence of unwanted material because of the impossibility, in any practical agricultural crop product and food processing/handling chain, of ensuring absolute purity of products.

Some types of agricultural production are also based on practices and principles to maintain purity levels and minimise adventitious presence of impurities (eg, requiring maintenance of separation distances, segregation of crops at/after harvest, cleaning of equipment). These include seed production systems and speciality crops like high erucic oilseed rape.

Adventitious presence of GM crops in non GM crops has become an issue because of the development of distinct markets for non GM derived products (see above). Some non GM producers, particularly in the organic sector, raise the issue of possible negative economic consequences on their sector from co-existence with GM crops (ie, where an organic producer finds adventitious presence of GM crops in his/her crop above a given threshold and, as a result, may lose an organic price premia or incurs additional costs on-farm to minimise the risks of adventitious presence).

The key findings relating to co-existence, tolerance-related costs for GM crops are:

- There is an underlying principle that the tighter the tolerance, the higher the cost involved in meeting that tolerance. Within the GM market context, this principle is clearly evident in respect of the current non GM market premia for soybeans and soymeal (see section 3.1), where the average premium for non GM soybeans and meal to a tolerance of 1% (presence of GM material), over the last year has been in the range of 2% to 5%, whilst the average non GM premium to a tolerance of 0.1% has been 7% to 10%.
- There is limited evidence available on the possible incidence of adventitious contamination of non GM crops with GM material, of changes in farm practices that might be required to minimise adventitious presence and the feasibility of meeting possible threshold levels for adventitious presence (including associated costs). Where studies have examined these issues, the data presented should be treated with caution. In particular, costs cited for meeting tolerances of GMOs in non GM material are probably overstated because many of the activities suggested (for minimising adventitious presence) are already part of good agricultural practice and/or part of requirements for farmers who are members of quality assurance schemes². Therefore the additional cost involved for

² For example, the Assured Combinable Crops Scheme, which covers about 58% of the total combinable arable crop area in the UK has membership charges which vary according to the size of farm and are equal to about £0.44/ha for a 400 hectare arable farm, £0.7/ha for a 200 hectare arable farm and £1.4/ha for a 75 hectare arable farm

many farmers could be fairly low (or none at all) and in line with the fees paid for membership of quality assurance schemes.

- If GM crop growers were required to comply with specific conditions (eg, SCIMAC guidelines), there could be additional cost involved associated with compliance audit requirements. The current audit charges for the Farm Scale Evaluations (£800/site) represent one benchmark cost, although if this independent auditing activity were to be opened to wider competition, the level of audit fees paid might reasonably be expected to fall to levels in line with membership of quality assurance schemes (£0.44/ha to £1.4/ha).
- The incentive for any non GM producing farmer to implement measures to minimise adventitious presence of GM material in non GM crops will be directly influenced by the relative costs involved compared to the consequences (eg, possible loss of non GM price premia, inability to sell the non GM crop in a given market). Where the consequence of not minimising adventitious presence is significant (eg, a significant non GM price premia, a significant organic premia or where a retailer insists on a tolerance of 0.1% as a condition of supply), then it is likely that farmers will be prepared to change farming practices and incur the associated costs. However, where the non GM price premia is low (eg, 1%-3%) or criteria for downgrading produce (eg, organic to non organic) are based on adherence to principles rather than regular testing, it is probable that many farmers will not feel it necessary to incur costs of monitoring or changing.
- The same principles apply to any farmers faced with possible liability 'claims' from other producers (these could be GM producers facing possible liability claims from non GM producers who have lost non GM price premia or non GM producers facing liability claims from GM producers of crops containing quality traits that have lost quality trait-related premia). The underlying willingness to take actions (eg, changing farming practices, siting of crops, taking out insurance) to minimise adventitious presence of their crop in someone else's will be directly related to their perception of the risk of adventitious presence occurring and the level of liability that might be incurred.

Possible development of herbicide resistant weeds, weed shifts and pest resistance

Whilst it is beyond the remit of this study to examine the incidence of these potential problems (which are not GM crop-specific and relate to agriculture in general), there are possible implications for farm profitability. Our review of the evidence to date shows the following:

- The development of weed resistance to the main herbicides used in herbicide tolerant crops (glyphosate and glufosinate), and problems with volunteers has probably not had any significant impact on the economics of using herbicide tolerant crops to date.
- In the longer term, some degree of reduced effectiveness of glyphosate and glufosinate against weeds may develop, along with some possible instances of weeds with resistance to more than one herbicide.
- To the extent to which weed or pest resistance may occur, this will add cost to farmers who are required to use additional levels of glyphosate/glufosinate or include low dose applications of other herbicides in their weed control programmes³. For example in Australia, where instances of glyphosate resistant weeds have been found, farmers increasingly use other herbicides like trifluralin as a pre-sowing treatment instead of glyphosate. This may therefore reduce, marginally, the average level of cost saving and profit gains cited in the most recent studies of GM herbicide tolerant crops.
- Similar problems of weed or pest resistance build up to herbicides/insecticides used on conventional arable crops can also be expected to develop, leading to similar problems and solutions for conventional crop producers (ie, the issue of weed resistance to herbicides is not a GM specific issue). Any assessment of the possible benefits and costs of GM crops should recognise these points because to only examine the possible impact of weed/pest

³ Farmers could also revert to conventional cropping and crop protection practices

resistance build up in relation to GM crops would not be comparing ‘like for like’ with the alternative production systems.

- The net impact on profitability of weed/pest resistance, weed shifts and volunteer problems is likely to be fairly small. Current commercial practice in conventional agriculture is to use tank mixes of herbicides (and possibly other products) to deal with difficult weeds/pests. Where farmers are faced with the build up of weed resistance to one herbicide, the solution is to add a different herbicide into an existing tank mix that is effective against a particular weed. Additional spray runs are rarely needed and therefore the overall impact on variable costs of production is very low (+1 to +2% for the additional herbicide). This issue is examined further in section 4;
- Farmers decide to adopt new technology based largely on their perception (and eventual experience) of the level of benefit for them. With time and repeated use of a specific piece of technology (eg, a particular herbicide, or seed), the effectiveness of the seed, herbicide etc declines, reducing the level of benefit derived. Eventually the technology is replaced, itself by newer technology (eg, a new seed containing a different GM herbicide tolerant trait, or a new herbicide that may have broad spectrum applications like glyphosate, or targets the weeds that glyphosate is less effective against) and the cycle of adoption/rejection of technology continues.

Possible impact of GM technology on wheat grown in the UK

Key profitability features of the crop

Profitability (as measured by gross margins) in 2002 was within a range of £486/ha and £607/ha. Wheat has generally been the most profitable combinable crop and performs best when grown after a break crop (eg, oilseed rape). It accounted for 48% of the UK arable cropping area in 2002.

Total variable costs in 2002 were within a range of £197/ha and £271/ha, of which herbicides accounted for between 10% and 18% of costs and fungicides accounted for between 20% and 26% of costs. Average yields in 2002 were about 8 tonnes/ha.

GM traits of relevance to the UK

The main GM wheat traits with commercial possibilities over the next ten years are fusarium resistance and glyphosate tolerance. Their potential applicability, adoption and impact on UK farming profitability are summarised in Tables a and b. For further details the reader should read section 5.1 and appendix 5.

Table a: Summary of possible farm level economic impact of GM herbicide (glyphosate) tolerant wheat

Possible date for commercialisation in the UK	2008-2011
Impact on costs of production	Premium control of weeds difficult and expensive to control (eg, wild oats) Reduced variable costs from lower herbicide use costs – could be savings of £23-£36/ha but will depend on cost of technology (no benchmark available). Greatest benefit for above average herbicide users. Limited empirical data to verify this and no UK based research Added crop flexibility – removal of difficult weeds and lower control costs over a rotation
Impact on yield	None expected – largely yield neutral
Impact on rotation	Could offer greater scope for continuous wheat growing (wheat being the most profitable combinable crop) via improved weed control – would however, still require overcoming problems like take all disease in follow on wheat

Facilitation of low/non tillage practices	May re-inforce this husbandry trend which offers scope for lower energy use, less ploughing and higher profitability
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Note: For consideration of generic issues such as herbicide tolerant weed resistance, volunteers, whether there is a market for GM wheat, non GM price differentials and co-existence issues see sub-section above

Table b: Summary of possible farm level economic impact of GM fusarium resistance wheat in the UK

Possible date for commercialisation in the UK	2012-2014
Impact on costs of production	Difficult to estimate as fungicides used to control a range of diseases and incidence varies by location and year. A 25% reduction in fungicide use could save £10/ha-£15/ha on current usage
Impact on yield	Some yield loss still occurs even though fungicides are used. A 5% improvement is thought possible. This equates to a 0.4 to 0.45 tonnes/ha increase and a £23.2/ha to £26.1/ha increase in gross revenue
Improved quality of grain	Mycotoxin levels in cereals are a concern and presence outside prescribed limits can lead to downgrading of supplies. Very difficult to evaluate as current incidence and extent of downgrading or rejection of supplies is not known

Possible impact of GM technology on oilseed rape grown in the UK

Key profitability features of the crop

Profitability (as measured by gross margins) in 2002 was within a range of £506/ha and £527/ha. Oilseed rape tends to be the profitable break crop grown in the UK (excluding sugar beet) and is usually followed by wheat. It accounted for about 10% of the total UK arable crop area in 2002.

Total variable costs in 2002 were within a range of £193/ha and £212/ha, of which herbicides accounted for between 18% and 23% of costs. Average yield in 2002 was about 3.4 tonnes/ha.

GM traits of relevance to the UK

The main GM oilseed rape traits likely to be commercialised in the next few years are GM derived hybrid varieties, also containing herbicide tolerance (to glufosinate). The potential applicability, adoption and impact on UK farming profitability of this product is summarised in Table c. For further details the reader should read section 5.2 and appendix 5.

Table c: Summary of possible farm level economic impact of GM hybrid vigour and herbicide tolerant (to glufosinate) oilseed rape

Possible date for commercialisation in the UK	2005-2008
Impact on costs of production	May offer reduced variable costs from lower herbicide use costs but this depends on baseline current costs and number of glufosinate applications made. Current costs of £36-£45/ha compare with possibilities of £21-£65/ha for glufosinate use depending on volume of herbicide used, assumed price of herbicide and number of applications. Using the assumptions presented in this report, cost savings will only emerge if farmers use one application or, if they use two applications, are above average spenders on herbicides. These calculations also do not take into consideration the cost of technology (see section 5.2 for illustration of a possible cost). Overall, cost savings are only likely for a minority of users and take up will be driven by other factors – see below
Impact on yield	Main source of farm level benefit. Yield gain expected anywhere between

	10% and 15%. This comes mostly from the improved hybrid vigour but may also come from improved weed control and reduced 'knock-back' experienced from existing herbicide treatment of crops. A yield gain of 10% would result in an increase in the gross margin of 9.5% relative to 2002 (+14% at a 15% yield gain)
Impact on rotation	Possible benefits for subsequent crops like wheat, especially as may offer improved control of difficult and expensive to control weeds like black grass (which are resistant to a number of herbicides). Could lead to savings across the rotation on herbicide costs and reduced carry over of residual herbicides in the soil (which may damage crop growth)
Facilitation of low/non tillage practices	May re-inforce this husbandry trend which offers scope for lower energy use, less ploughing and higher profitability
Note: For consideration of generic issues such as herbicide tolerant weed resistance, volunteers, whether there is a market for GM oilseed rape, non GM price differentials and co-existence issues see sub-section above	

Possible impact of GM technology on sugar beet grown in the UK

Key profitability features of the crop

Profitability (as measured by gross margins) in 2002 was within a range of £707/ha and £988/ha. Sugar beet has generally been the most consistently profitable arable crop in the UK, although the area planted is controlled by the EU sugar regime production quotas. It accounted for about 4% of the total UK arable crop area in 2002.

Total variable costs (including haulage, harvesting and contracting) in 2002 were within a range of £792/ha and £853/ha, of which herbicides accounted for between 8% and 9% of costs. Average yields fall within a range of 50 tonnes/ha and 63 tonnes/ha.

GM traits of relevance to the UK

The main GM sugar beet trait likely to be commercialised in the next few years is GM herbicide tolerance (to glyphosate). The potential applicability, adoption and impact on UK farming profitability of this product is summarised in Table d. For further details the reader should read section 5.3 and appendix 5.

Table d: Summary of possible farm level economic impact of GM herbicide tolerant (to glyphosate) sugar beet

Possible date for commercialisation in the UK	2006-2008
Impact on costs of production	May reduce average level of expenditure on herbicides – amount subject to debate/dispute. May (2003) estimates that the likely herbicide costs for a farmer using herbicide tolerant sugar beet would be between £26/ha to £40/ha. This compares with the current average herbicide costs (including application) for conventional sugar beet of £129/ha-£149/ha using May's data, £84-£104/ha using FARM data, £102/ha using ADAS data and £167/ha using Velcourt data. Assuming a technology fee/seed premium of £20-£30/ha (May 2003), this would result in an approximate net saving on herbicide costs of £80/ha based on May's data, £36/ha using FARM data, £44/ha using ADAS data and £109/ha using Velcourt data;
Impact on yield	Based on trials data and existing analysis such as May 2003, Dewar et al 2000 & 2003 and Gianessi et al 2002, an increase in yield is likely. This could be within a range of 5% to 10%. At 5% (relative to an average yield of 50 tonnes/ha) this is equal to an additional £75/ha in gross margin and at 10% it is equal to an additional £150/ha
Other possible cost savings	Possible cost savings from reduced use of crop consultants, greater management flexibility, adoption of minimum tillage practices, improved

	rotational weed control and reduced stubble control. These possible savings will vary by farm and could be within the range of zero to £32/ha (these boundaries are based on the respective views of FARM and May)
Facilitation of low/non tillage practices	May re-inforce this husbandry trend which offers scope for lower energy use, less ploughing and higher profitability
Increased management flexibility	Efficient weed management is critical to sugar beet because of its vulnerability at early stages of growth to weed competition (can affect yield) and crops are typically sprayed 4 to 5 times to a strict timetable in line with weed stage development. A move to a glyphosate based system (2 sprays) would offer increased flexibility on timing

Notes:

1. For consideration of generic issues such as herbicide tolerant weed resistance, volunteers, whether there is a market for GM sugar beet, non GM price differentials and co-existence issues see sub-section above
2. The assumed technology fee (May 2003) does not reflect actual fees – these are not known and the values used are purely illustrative

Possible impact of GM technology on potatoes grown in the UK

Key profitability features of the crop

Profitability (as measured by gross margins) in 2002 was within a range of £2,000 and £2,683/ha⁴. It accounted for about 4% of the total UK arable crop area in 2002.

Total variable costs in 2002 were within a range of £1,720/ha and £1,870/ha for main crop potatoes, of which herbicides accounted for between 3% and 4% of costs, fungicides accounted for about 8% of variable costs and nematicides accounted for about 14%-16% of variable costs. Average yields were about 44 tonnes/ha in 2002.

GM traits of relevance to the UK

The main UK applicable GM potato research is related to nematode resistance⁵. However, this research is still at a fairly fundamental level and is at least ten years away from possible commercialisation. No analysis of possible impacts on the UK potato grower has been provided because there is no data ‘to work on’ from trials, as no field scale trials examining impacts on yields, costs of production etc have yet been established.

Possible impact of GM technology on forage maize grown in the UK

Key profitability features of the crop

As forage maize is mostly consumed on-farm, the key variables influencing whether it is grown are not profitability but nutritional value relative to other forage crops and the cost of production. In recent years the area planted to the crop has increased to about 100,000 hectares (relative to for example about 420,000 ha for oilseed rape), highlighting its cost competitiveness with alternatives such as whole wheat and permanent pasture.

GM traits of relevance to the UK

The main UK applicable GM forage maize research has been related to herbicide tolerant (to glufosinate) forage maize. The potential applicability, adoption and impact on UK farming profitability of this product is summarised in Table e. For further details the reader should read section 5.5 and appendix 5.

⁴ Can vary widely on an annual basis due to yield and price variations and therefore can be one of the most profitable crops in the UK one year but not so the next.

⁵ Herbicide tolerance, insect resistant (to Colorado Potato Beetle: CPB) and virus resistant potatoes have all previously been commercialised in North America (or in the case of herbicide tolerance were close to commercialisation). However, there is little prospect of these products coming to the market in the UK over the next few years because a) the original technology provider, Monsanto has withdrawn from the potato sector, b) CPB is not a problem in the UK, so there would be no market and c) weeds are not a major problem to UK potato growers (relative to nematodes, viruses and fungal diseases).

Table e: Summary of possible farm level economic impact of GM herbicide tolerant (to glufosinate) forage maize

Possible date for commercialisation in the UK	2005-2008
Impact on costs of production	<p>The range of current herbicide costs is between £15/ha to £42.2/ha. The likely cost under the glufosinate tolerant crop is (one application) £25/ha to £30.44/ha rising to between £54-£60.88/ha for two applications. However, the current 'alternative' costs are likely to rise because the main herbicide currently used (atrazine) may be banned. If so, costs could rise to about £55.01/ha. On the basis of these costs, glufosinate tolerant forage maize would provide the largest cost savings for farmers who currently use two sprays and could revert to one application of glufosinate (also it would be attractive if atrazine were to be banned). Where farmers would need to use two applications of glufosinate the cost savings would be significantly reduced and may be marginal.</p>
Impact on yield	<p>Current herbicides used may adversely affect yield via 'knock back' (eg, slow down rate of seed germination). Detailed data is not available on this impact but the use of a post-emergent contact broad-spectrum herbicide, such as glufosinate, that does not "knock-back" the plant could increase yields by between 10% and 20%. A 10% increase in yield equates to an additional 1.19 tonnes of maize dry matter which costs £46.70 (based on £39.38/t X 1.19) to produce.</p> <p>Given the limited nature of the possible cost saving benefit identified above, take up of this technology in forage maize will probably depend on its ability to deliver the yield benefits suggested above. If not, and after taking into consideration the technology fee, the benefits will be limited to only some farmers. It may necessitate a fairly low technology fee and/or be accompanied by a reduction in the herbicide price (of glufosinate) to facilitate take up. This analysis is however speculative and is not based on empirical evidence of herbicide tolerant forage maize grown in the UK (as no publicly available empirical evidence was identified).</p>

Notes.

1. For consideration of generic issues such as herbicide tolerant weed resistance, volunteers and co-existence issues see sub-section above
2. In relation to whether there is a market for GM forage maize, as all of the crop is fed to livestock, there is likely to be a reasonable market for GM forage maize

Herbicide tolerant crops in the rotation

It is likely that farmers faced with any possible future option of, for example herbicide tolerant wheat, oilseed rape and sugar beet would not choose to grow the varieties containing the same trait in all crops (eg, glyphosate tolerance in all three crops) but would use a mix of herbicide tolerant crops and conventional crops (eg, glyphosate tolerant sugar beet, glufosinate tolerant oilseed rape and conventional wheat). In this way this would contribute to minimizing the onset of weed resistance and problems of herbicide tolerant volunteers.

Convenience effects

One of the main benefits cited by farmers who have used GM crops to date on a commercial basis has been a 'convenience' benefit. Although often difficult to quantify, this category of benefit includes additional management flexibility for choice of crop and husbandry practices used, additional flexibility in timing of operations (eg, when to spray crops), less time spent crop walking and assessing pest or weed incidence, savings in use of machinery (eg, on fuel) and improved production risk management (in other words less worry about whether or not a pest

attack may cause major losses to crop yield and quality or less worry that failure to treat weeds with herbicides at a critical and narrow time window will result in yield losses).

Case study crop: oilseed rape

The parameters suggested to the Strategy Unit for its quantitative (spreadsheet) analysis of potential impact of GM technology on a case study crop of GM oilseed rape containing hybrid vigour derived from GM technology and herbicide tolerance (to glufosinate) are shown in Table f. Details of the rationale for selecting this crop/traits and each parameter and boundary are presented in section 5.

Table f: Herbicide tolerant and GM hybrid winter oilseed rape: parameters for quantitative analysis

Issue/variable	Suggested boundaries for analysis
Likely date of commercial availability to UK farmers	2005-2008
Oilseed rape farm level prices: general	Forecast in five years time +8% relative to 2002/03 levels. Boundaries: no change to + 12%
GM versus non GM price differential	No difference. Boundaries: 3% in favour of GM (cleaner seed and higher oil content) to 3% in favour of non GM (sold into human food uses)
GM market potential	Likely no problem in finding outlets – major markets in non food use sectors (industrial oils, biofuels)
Baseline farm gross margins before assessing impact of technology:	Adjust for price changes (see above) and apply MTR changes to area payments (higher rate/tonne but modulation applicable to year to be examined – eg, 19% for 2013)
Impact of GM technology on yield	Assume +10%. Boundaries: +5% to +15%
Impact on total variable costs of production (excluding price of technology)	Assume no change. Boundaries: a saving of 5% to extra costs of 5%
Longer term possible implications (5-10 years after adoption) of weed shifts/resistance and volunteers	Amend impact on costs of production by 1% (ie, no change becomes +1%). Boundaries no change to total costs of production to +2%
Other impacts: convenience, impact on rotation	Difficult to quantify. Assume no change (a conservative assumption). Boundaries: +1% to revenue to –1% to revenue
Co-existence implications and compliance requirements (on GM producers)	Assume additional costs involved for compliance audit requirements (eg, adherence to SCIMAC type guidelines) at +0.5% to variable costs. Boundaries zero to +1% on total variable costs
Co-existence implications for non GM producers	Assume zero provided that SCIMAC separation distances are complied with. Upper boundary: none suggested
Cost of technology to farmer	Assume +£15/ha on costs of production (or +60% on seed cost). Boundaries: = +10/ha to +20/ha

1 Introduction

The Strategy Unit (SU) of the Cabinet Office is conducting a study into the possible costs and benefits, which might arise from the commercial adoption of GM crops in the UK. As part of its analysis, the SU is looking at the possible costs and benefits which may accrue in the product chain from seed producers, to farmers, wholesalers, processors, retailers, caterers and consumers.

Within this the SU commissioned research (this study), which will inform its work on the possible economic impacts of GM crops on farmers who grow them and, potentially on other farmers.

1.1 Objectives

The main objective of this study was to review and analyse literature on the economic impact of genetically modified crops and to place this within the context of UK arable farming.

Within this overall objective, the study:

- a) Gathered together information on the impact of the growing of GM crops on farmers' profits, focusing on crops, which could be grown in the UK. This was to focus on specific, monetisable costs and benefits and include:
 - Costs arising from seed price differentials between GM and non GM seed and any relevant technology fee;
 - Impacts from changes in pesticide use (timing and type), including changes to costs of pesticides used and impacts on, for example labour, machinery, frequency and timing of spraying;
 - Impacts on yield quantities, quality and reliability;
 - Costs arising from keeping GM crops separate from non GM;
 - Costs arising from respecting separation distances from non GM fields;
 - Changes to income arising from any GM/non GM price differential.

For each aspect the robustness of evidence cited was to be discussed, highlighting areas of consensus and disagreement.

- b) Identified, where possible the most important non-monetisable costs and benefits and assess the degree of consensus on their occurrence and importance (eg, convenience, liability for contamination, impact of volunteers or development of pest resistance) in relation to the UK farmer.
- c) Made recommendations on which crop should be used as a worked example of the potential monetary impact of GM crops on the UK farmer and suggested assumptions for each variable affecting impact (upper and lower bounds).

1.2 Boundaries of the research

In order to meet the objectives detailed above, the following boundaries should be noted:

- a) *Type of GM crops covered.* GM crops fall into two main categories: agronomic traits and quality traits. Agronomic traits mostly target the delivery of farm level benefits such as higher yields and lower costs of production (other improvements such as improved quality of harvested products may also arise). Their adoption may lead to lower real costs of production and lower real prices of output (ie, possible consumer price benefits). Crops containing GM quality traits essentially aim to create new/improved products that may or may not be close substitutes to conventional crops and may not necessarily trade at lower

prices. The rationale for producing crops with GM quality traits is to produce an improved product for which additional value (and possibly a higher price) can be obtained from the downstream supply chain. Although some of the earliest commercially available GM crops were quality traited products (tomatoes with improved processing characteristics and tomatoes with improved shelf life/handling qualities), the majority of the current commercially available GM crops and the majority of those 'in the pipeline' for approval in the foreseeable future (eg, a time horizon of 5-10 years) are agronomic traits like herbicide tolerance and insect resistance. As such, the focus of this research has been on GM crops containing agronomic traits. This is certainly where almost all impact literature can be found.

- b) *UK applicability of research findings*. Clearly as GM crops currently do not have approval for commercial planting in the UK, there is no evidence to draw on as to the farm level impact of GM crops in a UK context. The research has, therefore drawn on findings from other countries where GM crops have been planted (eg, the USA, Argentina, Canada, Spain) and trials data from the UK (where available) in order to make assessments about the potential farm level impact.
- c) *Timeframe for the analysis*. As the research is to provide assumptions that will assist the SU in estimating the monetary impact of GM crops on the UK farmer over the next 5-10 year period, the research has included forward looking analysis. This includes:
- likely future CAP reform;
 - EU accession of up to 10 new member states from 2004;
 - The next WTO Round;
 - the level of demand for non GM products.
- d) *Environmental impact*. The study did not examine possible environmental impacts of the technology or attempt to provide monetary values to such impacts.
- e) *Origins of literature and data reviewed*. During the course of the research, a considerable volume of literature was brought to the authors' attention. In addition, information and views were sought and provided from a range of organizations including government officials, farm advisers, researchers, academics, representatives of biotechnology companies, plant breeders, seed companies, farmer organizations, industry level bodies, trade associations, organic certification bodies, non governmental organizations and environmental pressure groups. In all cases the information and/or literature provided was examined for aspects such as how representative the data or assertions made were, whether assertions were supported by empirical evidence (and whether this is representative) and how transparent analysis has been (ie, whether assumptions used and data sources were clearly stated). In sum, the authors have sought to examine the robustness of arguments (where presented and where conflicting claims have been made) and to draw conclusions based on this. The report is therefore the independent and objective assessment of the authors⁶.

Readers should also note that the data presented about both baseline husbandry practices, input use, yields and economic performance (eg, within the UK), and evidence of the impact of GM crops shows variability. This is normal and reflects the inherent variability of agricultural production. It does, however mean that care has to be taken in interpreting

⁶ The authors take the opportunity to emphasise that, as research consultants they have (at the time of conducting this study) no retainers from any organisation and are independent. The authors have undertaken (published) work in the past that has been funded/purchased by organisations, both with interests in plant biotechnology, and organisations with non GM interests. The material presented in this report is therefore the authors objective analysis of the issues covered in this study

data because the impact of a new technology (like GM) might result in improved performance for one farmer but not so for another. Throughout the report, care has been taken to highlight (where possible) the origins of data used, average/range of performance data and how representative it is. It is hoped that this will assist the reader in understanding the possible impact of GM technology on farm profitability.

- f) *Crop coverage.* It was agreed at the outset of the study that the crop coverage was to be on the leading arable crops grown in the UK, for which there are GM developments, either currently commercially available or which are likely to develop in the next ten years.
- g) *Study output.* This report does not draw conclusions about the possible impact of GM crops (containing agronomic traits) on UK arable farming profitability. Its primary function has been to review evidence and provide objective information and analysis that can help the Strategy Unit of the Cabinet Office in its work.

1.3 Methodology

The research was based on desk research/analysis supported (essentially a literature review), supported by telephone, e-mail, fax and postal correspondence with the range of organizations referred to above. In some sections forecasts are made about likely future developments (eg, the market for non GM products, CAP reform). These are based on the authors' analysis and, where appropriate, the assumptions used are stated.

The study also had to be undertaken in a very short period of time (five weeks).

1.4 Report structure

The report is structured as follows:

Section 1: (this section): introduction

Section 2: GM crops in the UK – context background to arable farming, profitability, policy impact, market developments and the time it takes for new technology to be commercialised

Section 3: Generic issues affecting GM crop growing including demand issues, technology costs and co-existence

Section 4: Possible impact of GM crops on the profitability of UK arable farming: covering wheat, oilseed rape, sugar beet, potatoes and forage maize

Section 5: Case study crop: oilseed rape – suggested parameters to use for quantitative analysis of impact

2 GM crops in the UK - the context

This section provides a brief discussion of general issues and trends in UK arable farming so as to 'set the scene' and place the subsequent discussion of possible GM crop impact in context.

2.1 General background to arable farming in the UK

Since the Second World War, arable farming has become increasingly intensified in the UK. This has been based on a stable policy environment both, before and after, EU accession in 1973 and the rapid development/availability of new technology. As a result there have been substantial increases in the use of fertilisers and crop-protection chemicals combined with much improved cultivars. These have contributed to greatly enhanced yields. For example, wheat yields have increased by 30% from 6.2 tonnes/hectare in 1982 to 8.05 tonnes/hectare in 2002 (Table 1).

Table 1: UK wheat production 1982 - 2002

	1982	1992	2002
Area ('000 hectares)	1,662	2,060	1,989
Yield (tonnes/ha)	6.20	6.82	8.05
Output ('000 tonnes)	10,307	14,042	16,006
Price (£/tonne)	£119.80	£126.92	£58.30
Value (£ m)	£1,234	£1,782	£933

Source: Home Grown Cereals Authority

Over the same period the price of wheat has fallen from an average £119.80/tonne to £58.30/tonne. This decrease in price mainly reflects changes to EU policy in which the level of import protection and the level of domestic price support has been progressively reduced since the early 1990s. Also the last few years have been one characterised by very low world prices for cereals (relative to the average level of prices over the last 30 years).

Against the background of declining prices, the profitability of UK arable farming has also fallen. Thus, net farm incomes⁷ for cereal growers in the Eastern Counties fell in real terms from £283/hectare in 1996 to £38/hectare in 2001 (Table 2).

Table 2: Net farm income by farm type in real terms 1996/97 - 2001/2002 (£/ha)

Farm Type £/ha	1996	1997	1998	1999	2000	2001
Mainly cereal	283	148	88	108	58	38
Mixed cropping	198	170	196	60	87	115
Mixed Farms	256	108	42	91	127	59
Fen Arable	346	160	374	73	199	58

Source: Lang, B (2002)

2.2 General factors affecting farm profitability and choice of production systems

There are several key factors that influence farm-level profitability for a particular cropping system or systems element. These can be grouped into five categories (Pannel, 1999):

⁷ Net Farm Income is calculated on the assumption that all farms are tenanted and that all tenant-type assets are owned by the farmer. It thus represents the return to the principal farmer and spouse for their manual and managerial labour and on the tenant-type capital of the business.

- Short term profit factors (eg, crop yield, output prices, input costs);
- Dynamic factors (short to medium term): these include impacts on subsequent crop yields due to current fertilizer use, weed control, tillage method, crop disease incidence;
- Sustainability factors (eg, pesticide resistance, soil degradation);
- Risk factors (eg, yield and price variability, system flexibility, farmer attitude to risk);
- Whole farm factors (eg, machinery capacity, finance availability and cost, labour, farmer objectives, knowledge and experience).

How these factors impinge on individual farmers ultimately determines the way in which they farm and the farming systems used. In this report we have broadly classified where appropriate the various farming systems used for each arable crop examined as conventional, low input, integrated farming and organic. Not surprisingly, due to variation in the above five factors the economic performance of farms and which of these (four) particular farming systems used can vary widely, both between and within regions. This means that when attempting to examine the potential impact of a new piece of technology (eg, GM cost reducing technology) there is likely to be significant variation in the impact at a local level. This is clearly shown in relation to the identified impact of commercially grown GM crops in North America (see appendix 5).

Also, it is important to recognise that when considering different possible rates of application of farming inputs to a crop, there may be a reasonably wide range of input levels either side of the 'economic optimum' that delivers profit levels that are only marginally different that attained at the optimum (Anderson, 1974). In other words, there can be a reasonable margin for error, and scope for flexibility in choosing input levels, without substantially reducing profits.

2.3 Key policy and market environment

This section provides a summary of the likely direction of the most important and relevant policies that affect arable crop production in the UK. Given that the Common Agricultural Policy (CAP) determines agricultural policy in the UK, the section concentrates in the elements of the CAP that affect arable crop production and how they may change in the light of the current proposals (Mid Term Review (MTR)) to reform the CAP. A more detailed discussion of the CAP, how UK initiatives such as the UK's policy on sustainable development fit within this and the possible effect of changes to other institutional factors (eg, possible changes to World Trade Organisation agreements) is presented in Appendix 1.

2.3.1 The CAP and its Mid Term Review: broad implications for arable crops

The main implications of the MTR proposals for arable crops are as follows:

- *reduction in the intervention price for wheat, barley and maize to €95.35/tonne (ie, a 5% cut in the support price)*. As intervention acts as a floor to the market, any reduction in the level of support price should, in theory, result in a reduction in internal EU prices. However, the potential negative effect of this proposed support price cut on EU cereal market prices relative to mid/late 2002 season price levels is likely to be limited because i) intervention is not available for some grains (notably feed quality wheat), ii) the EU is becoming an increasingly open market subject to greater influence of (fluctuations in) world markets⁸, iii) accession of 10 new member states will add to the net cereal supply balance of an enlarged EU. In sum, the 5% proposed cut in support prices may well not lead to a 5% cut in market prices for cereals;

⁸ The EU has introduced from the beginning of 2003 a return to the use of fixed import duties on cereals, within a Tariff Rate Quota (TRQ) mechanism. The rationale for this came from deficiencies in the variable import duty mechanism that had permitted low priced grain from Eastern Europe/Russia/Ukraine to enter the EU. The return to fixed (but higher levels of duty than applied in 2002) duties has, however resulted in the provision of additional duty-free quotas for the main global cereal exporting nations

- *provision of additional area payments equal to the equivalent of €2.98/tonne.* This would raise the basis on which area payments are calculated from €3/tonne to €5.98/tonne and is equivalent to a 50% compensation for the support price cut referred to above. In theory this should have a negative impact on cereal profitability (assuming prices fall 5%), although the precise effect will depend on how prices adjust. As suggested above, there is a reasonable probability that prices will not fall or fall by only a small amount, in which case cereal profitability might actually rise. For non cereal crops that have their area payments effectively set by the cereal payment level (ie, oilseeds and protein crops), the effect of the increase in the unit value by which area payments are calculated (€5.98/tonne rather than €3/tonne multiplied by average regional reference yields) will improve profitability relative to cereals. Where oilseeds are planted for energy crops the energy crop supplement may also enhance profitability and encourage additional plantings;
- *elimination of the rye intervention price:* this is unlikely to significantly affect the UK market because rye is not widely grown;
- *Degressive modulation:* the net effect will be a reduction in the level of area payments received for all crops on most farms (only exception being small farms). Clearly, the impact will vary according to the ‘trigger’ factors (the €5,000 and €50,000 payment thresholds) and the extent to which arable farmers will be able to offset these losses through gains made via Rural Development Measures (eg, via increased funding for and expansion of schemes that currently operate within the various country-level rural development programmes in the UK). Given that even after the MTR, Rural Development Measures will still only account for about 12%-13% of total EU agricultural spending, the scope for all arable farms ‘clawing back’ most of the degressive modulation cuts via payments from schemes relating to agri-environment improvement or organic expansion⁹ is likely to be limited. The net overall effect will therefore be lower levels of revenue from support payments;
- *Cross compliance/farm auditing:* the net effect will be small as compliance conditions should simply represent good agricultural practice that is currently undertaken – possibly a small addition to total farm costs;
- *Energy supplement.* this will improve the profitability of relevant crops (notably oilseeds) relative to non energy crops and may result in a stimulus to increased oilseed plantings;
- *Set-aside:* - making this non rotational will have implications for farm level rotations. The removal of the 50% maximum area that can be set-aside may lead to an increase in the area being put into set-aside, especially as the degressive modulation process will be reducing the level of returns to almost all farmers;
- *Sugar reform:* - although outside the MTR, sugar reform can be expected (see appendix 1) and we therefore assume that sugar support prices will fall by about 30% (and quota will fall by 25%) over the period 2006-2011. Despite this likely reduction in the level of price support, sugar beet is still likely to continue to be the most profitable arable crop when compared with cereals, oilseeds and proteins. The primary limiting factor on production will therefore continue to be quota levels set by the EU sugar regime. The main variant factors to this will be the extent to which C sugar will be grown and sugar beet for biofuels is developed.

2.3.2 Policy change: relevance to UK arable crop profitability

Drawing on the summary presented above in section 2.3.1 and in appendix 1, the key points of relevance for UK arable crop profitability over the next five to ten year period are:

⁹ Schemes that currently exist such as Countryside Stewardship, Environmentally Sensitive Areas and the Organic Scheme and how they develop according to plans laid down in the UK government’s Sustainable Development Plan and Organic Action Plan

- The UK agricultural sector will be operating within a larger and more competitive internal EU marketplace;
- Levels of support for agriculture will be lower than at present;
- The EU market will be open to increasing levels of competition from world markets. This will apply to all sectors, including sugar production (by 2008/09);
- The UK agricultural market environment will probably be subject to greater variability in prices (reduced role of policy support mechanisms and increased openness of markets);
- New demand for crops in non food uses (notably bio-fuels) can be expected to increase across the EU. Agri-environmental schemes like Countryside Stewardship and the Organic Scheme may become more attractive to some producers, especially if the UK government chooses to channel additional rural development funding from modulation into such schemes. Nevertheless, whilst the relative importance of such schemes will increase, the lion's share of agricultural policy support will continue to be delivered via market measures and direct payments;
- In order to remain as competitive as possible in the EU marketplace, many UK producers are likely to increasingly explore all forms of new technology that can assist them (eg, through yield enhancement, cost reductions) and to explore ways of reducing production and price risk. The planting of GM crops could be an approach taken to contribute to improved competitiveness or reduced risks provided farmers perceive that there is a market for the produce (see section 3.4 for further discussion). Some others may look at other cost reducing technologies or focus on higher value, niche product production, like organics, where cost is less of a market driver. Others may choose to focus more on the production of 'Care' goods (eg, environmental set-aside, membership of agri-environmental schemes that target the delivery of environment and landscape goods for the wider public) and lastly, some others may choose to exit from the sector.

2.4 Underlying market developments and supply chain responses

In recent years a number of important developments have taken place that impact on the production of agricultural produce. On the consumer side these include:

- growing levels of concern amongst consumers about how food is produced and how new technology is applied to food production. This has resulted largely from growing detachment of citizens from agriculture and food production, greater availability of information and time to discuss it;
- diminishing levels of public trust in scientists and technical experts whose knowledge and understanding have been relied upon to determine whether new technologies are safe. The erosion of trust has developed over many years and some high profile failures of health protection and examples of unforeseen side effects from new technologies have come to light. The BSE issue represents a major current issue of the perceived failure of public authorities to protect public health;
- greater levels of awareness and concern about possible adverse impact of agriculture on the environment;
- the growth in demand for products that are perceived to better meet the demands of consumer concerns about the environment, health and production systems. For example the development of markets for organic produce and animal welfare-friendly livestock products. The organic sector has, for example experienced rapid expansion in demand over the last few years, although in the last year or two, there have been signs in some segments of the organic market that demand may have peaked (eg, in the dairy sector, where some organic milk has had to be sold into non organic markets).

On the supply side, the main developments that have taken place, largely in response to the above consumer-related trends include:

- significant development of more sophisticated supply systems that incorporate identity preservation/segregation and traceability. Much more of the food consumed today comes via systems that aim to trace produce back through the food chain to the farm level point of production and to provide consumers with increasing levels of assurance on content, composition and method of production. As a result an increasing number of farmers are now members of independently accredited, quality assurance schemes (eg, the Assured Combinable Crops Scheme);
- a drive in the supply chain to add value to products by altering and improving the inherent characteristics of a product for which a premia may be charged. This aims to strengthen the competitive position of the added value product relative to its substitutable alternatives by differentiating it and/or reducing the cost of processing (eg, developing an oilseed with a higher oil content);
- greater interest in production systems like organic and welfare enhanced;
- a general greater applicability and adoption of husbandry practices that are classified as 'more integrated crop management systems'. For example, less use of prophylactic spray regimes in favour of spraying according to pest and disease thresholds. These integrated systems have tended to become more attractive¹⁰ in the recent years, against a background of lower average farm prices, reduced levels of policy support and a general increase in the level of price risk faced by farmers.

2.5 The time period for the development of new technology like GM crops

In considering the possible impact of GM crops on UK farm profitability, it is important to recognise that new technologies like GM take time to come to the market place. Thus the lifting of any moratorium on GM crop approval in the EU does not necessarily mean that GM crops will immediately be made available to farmers.

In general, the development of a new variety of seed that may contain a GM trait (or in many instances varieties produced without the use of GM) can take several years. Ideas have to be tested first in laboratories before graduating to field trials. Regulatory approval procedures have to be met and these invariably necessitate the collection of a considerable amount of information to satisfy health, safety and environmental requirements. Once regulatory approval for a GM trait has been granted, seed containing a trait has to be put through national variety trials to gain approval and endorsement for use and then a quantity of seed has to be multiplied up to meet perceived commercial levels of requirement. These processes effectively mean that, even if the EU moratorium on the approval of GM crops is lifted in 2003, GM crops are unlikely to be available in commercial quantities to UK arable farmers for at least 2-4 years, even if the technology providing companies decided to market GM crops. Some of the traits examined in this report are also at a fairly fundamental stage of research and therefore such traits are not expected to come to the market place for at least ten years.

Further details about crop-specific GM trait developments are presented in Appendix 2.

¹⁰ When the economic climate becomes difficult the level of attention put to examining ways of reducing costs tends to increase, resulting in greater levels of willingness to consider changes to production practices

3 Generic issues affecting GM crop growing

This part of the report examines a number of generic or common issues relating to the use of GM crops. It includes:

- a) Demand issues – the development of GM versus non GM markets;
- b) The cost applied to using new technology like GM seed;
- c) The issue of co-existence of GM crops with crops grown using different alternative forms of seed;
- d) Possible development of pests and weeds resistance to GM agronomic traits.

These are examined further in the sub-sections below.

3.1 Demand issues: GM versus non GM derived crop product markets

This sub-section summarises the key points of relevance for possible impact on UK farming profitability of using GM crops that arise from developments in the distinct markets for GM versus non GM derived product markets (in the EU). A more detailed discussion of these issues is represented in Appendix 3. The primary sources of information drawn on are Brookes (2001) and Brookes (2002a).

3.1.1 GM versus non GM market developments and features

A distinct non GM market began to develop in 1998 (for ingredients used in human food) and was extended to the animal feed sector from about 2000. It has focused largely on soybeans and derivatives, and to a much lesser extent maize, because these were the first two crops for which approvals for the importation and use of products derived from GM crops were granted (before the introduction of the de facto moratorium in 1999). Key features of the market development have been:

- In the human food sector there has been a switching to using alternative non GM derived ingredients (eg, the replacement of soy oil with sunflower or rapeseed oil). This was relatively easy for a number of food products like confectionery and ready meals, where soy ingredient incorporation levels were low (eg, 1%).. This course of action has been more difficult to take in the animal feed sector because of the importance of soymeal as an ingredient in some feeds (eg, broiler feeds where typical incorporation rates are 25%);
- If the GM crop or derivative could not be readily replaced, non GM derived sources of supply were sought. This focused mainly on Brazil (but not exclusively) and involved the initiation of identity preserved (IP) or segregated supply lines (traditional supply lines use commodity based systems where there is broad mixing of seed in bulk for transportation) to ensure non GM derived supplies to customer-specific tolerances were adhered to;
- GM derived ingredients have largely been removed from products directly consumed (by humans). In the animal feed sector, about 25% of soymeal used is required to be non GM in the EU and in the industrial user sectors, there is little or no development of the non GM market¹¹ (ie, the market is indifferent to the production origin of raw materials);
- It has been reasonably easy for the European buyers to identify and obtain supplies of non GM derived soybeans and soymeal at 'competitive prices'. Where the tolerance applied has been 1% (for the presence of GM material), price premia have tended to be in the range of 2% to 5%, on average over the last two years, whereas when tighter tolerances and a more strict regime of testing, traceability and guarantees are required (eg, to a tolerance of 0.1%), the price premia has been within a range of 7%-10%;

¹¹ This refers to all non food industrial uses and does refer to industrial uses where the raw materials are destined for human food use (eg, maize starch used in food products)

- the additional cost burden of supplying non GM ingredients has largely been absorbed by the supply chain up to the point of retailers (ie, the cost burden has fallen on feed compounders, livestock producers and food manufacturers and has not been passed on to retailers and end consumers).

3.1.2 GM versus non GM market developments: possible influence on GM crop uptake and arable crop profitability in the UK

Drawing on the summary of market developments (see section 3.1.1 above) and the more detailed discussion in Appendix 3, the main points to take into consideration when examining possible impact on UK farming profitability and take up of GM crops are as follows:

- a) Current non GM versus GM price differentials (in favour of non GM) are low and on average within a range of 1% to 5%. The non GM market, in which there is a price differential (in favour of non GM) mainly exists post farm gate;
- b) At the farm level in countries where GM crops are widely grown, there has been and is currently very little development of a price differential. In Brazil, the focus of non GM supplies of soybeans, there has, to date been no evidence of a non GM price differential having developed. In the US and Canada, the farm level price for non GM supplies has tended to be within the range of 1%-3% higher than GM supplies, and this level of differential in favour of non GM crops has had little positive effect on the supply of non GM crops (ie, GM plantings have continued to increase, with the price differential being widely perceived to be an inadequate incentive for most farmers to grow non GM crops like soybeans). In Brazil, trade sources¹² (personal communication with the authors) also suggest that a farm level differential of 5%-10% for non GM soybeans will be required to keep a significant volume of Brazilian soybean farmers growing non GM soybeans if GM soybeans are approved for planting in Brazil. In the EU, where GM crops are currently grown commercially (effectively only Spain), there is also no evidence of a price differential having developed at the farm level;
- c) Assuming that some GM crops (containing agronomic traits) are eventually approved for use in EU agriculture, a key factor influencing whether UK farmers grow these crops will be whether there is a market for the GM crop(s). In other words would farmers be able to sell their crop. The evidence and analysis presented above and in appendix 3 suggests that this depends on the crop, use and market:
 - crops going directly into human food currently have the highest level of requirement for non GM produce and therefore crops with relatively high shares of produce going into the human food chain are likely to be markets in which GM crop take up may be least and slowest¹³ (eg, sugar, potatoes, wheat);
 - In contrast, a significant part of the animal feed and industrial sectors (about three-quarters of the ingredients used in EU animal feeds) are largely indifferent as to whether crops used are derived from GM crops or not. For crops destined for these markets, there is less likely to be a problem in finding outlets for GM crops and hence the crops likely to see the highest level of interest in GM technology take up will probably be in grain maize, oilseed rape, starch potatoes and forage maize. For example, GM maize currently grown in Spain is almost entirely used in the animal feed sector;

¹² With interests in the supply of non GM soybeans

¹³ It is possible that initially there could be no market for GM crops in human food products, if for example, current non GM policies in sectors like sugar were to continue for several years

- The nature of competition in different markets may also affect ‘willingness to accept GM crops’. In markets where (low) price is considered to be the primary driver of demand (this is relevant to both domestically consumed foods and to export markets), access to the lowest priced products and raw materials is the main criteria used for purchasing. In such markets (eg, some mainstream rather than premium range meat products, frozen rather than fresh poultry), GM based feed ingredients tend to be attractive because they are often cheaper than the non GM alternative¹⁴;
 - Lastly, it is also important to recognise the influence of time on the demand for non GM products. As GM crops are unlikely to be available in commercial quantities for UK farmers for 2-4 years, it is possible that the level of demand for non GM produce, and perceived consumer opposition to consuming GM crops may decrease by the time the first GM crops are commercialised in the UK. Equally it is possible that in 2-4 years time the level of perceived consumer opposition to consuming products derived from GM crops may increase. Based on the future market dynamics presented and discussed in appendix 3, the authors of this report perceive that the perceived level of consumer opposition to consuming products derived from GM crops may decrease relative to current levels. This is, however a personal perspective based on assessment of how different variables affecting the markets may change over the next few years.
- d) Assuming that some GM crops (containing agronomic traits) are eventually approved for use in EU agriculture, a key factor influencing whether UK farmers grow these crops will be the potential impact on farm incomes. Farmers will assess whether to grow GM or non GM crops according to the likely impact of the GM crops on factors such as yield and costs of production (and other factors that are more difficult to put a monetary value on such as convenience) and on whether they will be able to find customers for their produce. Within these assessments the level of price differential between GM and non GM crops will play a role in influencing take up. The higher the level of price differential in favour of non GM crops, the less likely GM crop take up is likely to be and vice versa. It is to be expected that any development of a price differential in favour of non GM crops will reflect the relative balance of supply and demand for non GM crops and any cost of production differences that exist between GM and non GM crops. Evidence to date from GM growing countries suggests that the levels of price differential that might occur will only be in the range of 1%-3%. However, this level may not fully reflect the level of cost saving that may accrue to GM crop users. For example, if a GM crop cost benefit is greater than this, then the required price offered for non GM crops will have to be greater than this (1%-3%) to encourage farmers to grown non GM crops. Alternatively, if the GM crop offers little or no cost saving relative to non GM crops then the price differential will not need to rise above these levels to ensure non GM supplies meet demand. Also, the level of consumer demand for non GM products may affect price differentials. The stronger the demand for non GM products, the greater the possible willingness of the supply chain downstream of farmers to pay higher prices for non GM products and vice versa. Overall, it is difficult to forecast how future markets and price differentials may develop.
- e) It is important to emphasise that the GM crop traits examined in this study are essentially intended to be cost reducing. This means that if the majority of global production switches to this technology there will a cost and price reducing effect on the baseline price of the

¹⁴ GM traits like herbicide tolerance are intended to be cost saving. Where such technology is widely adopted and delivers cost savings, it is likely that the real price of the crop (eg, soybeans) will fall. This is not unique to GM agronomic traits and applies to all forms of new technology that target cost savings. As such, the long run decline in the real price of most food products is largely a reflection of increased adoption of cost saving technology

commodity. To date this has probably only occurred in the soybean market. The net effect of this is that any price differential that may develop between GM and non GM products will partly reflect this cost of production differential and may also reflect any costs of segregation/IP of the non GM product. It is therefore incorrect to assume that price differentials only reflect segregation/IP costs. In the soybean sector, analysts such as Moschini (2002) and Qaim & Traxler (2002) have attempted to estimate the impact of GM technology applied to soybeans on the baseline price of globally traded soybeans. Their conclusions suggest that the real price of soybeans had fallen by 1%-2% by the end of 2001 because of the technology.

- f) In the longer term (10 years plus), GM crops containing quality traits (eg, offering possible traits such as lower fat content, food products with improved taste, offering lower processing costs to industrial users) are likely to be commercialised. Whilst consideration of GM quality traits is beyond the terms of reference for this report, it should be noted that this category of GM crop will probably offer farmers price premia to grow such crops. The premia will reflect any additional costs involved in production (eg, possible reduced yield relative to conventional crops) and preserving the identity of the crop to the buyer. Such crops may be attractive to some farmers because of the possibility to produce a specialist crop for a market paying a premium price and/or because producing on contract may contribute to reducing price risk.

3.2 Technology costs

Farmers using any new technology usually have to pay some form of 'fee' for access to the technology. In the case of agricultural inputs such as new seed varieties, the cost of new technology is usually passed onto farmers in form of higher prices of seed (a seed premium). Thus, a new higher yielding variety of seed tends to trade at a premium to existing seeds.

Whilst this is the underlying basis upon which new seed technology is charged for, the advent of GM seed in the USA did result in a variation to this approach. Roundup Ready soybeans, when first introduced in 1996 in the USA were sold via what was known as a technology fee based system. Farmers signed a licence agreement on a per bag of seed fee basis. In 1996 the fee was \$5/lb bag and at that time the licence also required farmers to use only Roundup brand herbicides (ie, sold by Monsanto). This was widened in 1999 to allow the use of other (non Monsanto) glyphosate-based products and from 2002 the technology fee system was changed in favour of a royalty system. The key point to note about this new approach to charging for the GM technology is that under the original technology fee approach used by Monsanto, the technology provider was effectively receiving a fixed fee per bag of seed sold. This contrasts with the way in which the charging mechanism now works (a royalty system), where the technology provider receives a % based share of seed sales and the 'technology fee' has largely reverted to the traditional way of charging for technology; the seed premium. The seed premium route is also the way in which the other main providers of GM crop technology charge for their products. In practical terms, a technology fee is roughly the same as a seed premium, except that sometimes (not always) farmers are required (for technology fees) to agree not to farm save seed and/or to use only products (eg, herbicides) from an approved list (that invariably includes products from more than one supplier).

How much farmers ultimately pay for access to new technology depends on several factors. The technology providers take into consideration a number of commercial factors when determining the price to be charged, including estimates of the possible farm level benefits, the nature of competition and pricing of alternative (eg, non GM) seed. In the crop protection sector, a general 'rule of thumb' approach to pricing new technology is to use a cost:benefit ratio of three/four to one (ie, if the benefit is £60 the technology is priced at £15/£20). The reader should, however note this 'rule of thumb' represents a crude illustration of the base approach to setting 'technology

fees'/seed premium and commercial reality tends to be more complex than this. For example, a technology provider introducing a herbicide tolerant crop has to take into consideration whether to alter (eg, reduce) the price of the herbicide linked to the herbicide tolerant crop and what possible reductions in herbicide prices might be initiated by competitors serving the non GM herbicide tolerant crop market. Lastly, where technology providers sell their technology via other seed companies and/or wholesalers and agricultural merchants, the price ultimately paid by farmers will vary according to the margins added by these links in the supply chain and/or the ability of farmers to gain discounts on list/recommended prices.

The key messages for the reader to take from this are:

- GM technology is largely charged for via seed price premia, in the same way as new conventional seed is charged for. Variations to this approach (the technology fee approach often referred to in respect of Roundup Ready soybeans in the USA) have largely evolved back to the seed premia approach;
- The level of premia charged by technology providers to players further down the supply chain to farmers (eg, seed companies, agricultural merchants) will vary according to a number of commercial factors and market conditions;
- The level of premia paid by farmers for GM seed may vary according to the margin added by their supplier (eg, local merchant) and farmer ability to negotiate discounts on list or recommended prices. This latter factor is important to recognise when examining literature on the impact of GM technology on farmer profitability because the higher the assumed cost of the technology, the lower the benefit and vice versa.

3.3 Co-existence

Co-existence as an issue relates to the economic consequences of adventitious presence of material from one crop in another and the principle that farmers should be able to cultivate freely the agricultural crops they choose, be it GM crops, conventional or organic crops (EU Commission 2003).

This broad definition of co-existence has two main components which comprise adventitious presence from pollen that has introgressed with a non GM crop (ie, cross pollinated) and adventitious presence of pollen on the non GM crop (that has not cross pollinated).

Adventitious presence of one crop with another can arise for a variety of reasons in all cropping systems. These include seed impurities, cross pollination, volunteers (self sown plants derived from seed from a previous crop), from seed planting equipment and practices, harvesting and storage practices on-farm, transport, storage and processing post farmgate.

In relation to GM crops the most frequently quoted issue where literature can be found relates to the economic consequences of adventitious presence of GM crops in non GM crops. However, to focus only on this aspect, would be ignoring a) the issue is not new (it affects many aspects of conventional agricultural production systems) and b) adventitious presence of conventional or organic material in GM crops could also be 'an issue' in the future. As such this section includes consideration of these broader perspectives of co-existence.

3.3.1 Co-existence in conventional agriculture

Adventitious presence of (unwanted) material from one crop in another is an issue widely recognized in the agricultural sector and almost all agricultural commodities are traded in recognition of the fact that some degree of adventitious presence of unwanted material may be found in supplies. This means that the majority of agricultural products are subject to limited

forms of grading, with some products (a minority) subject to more sophisticated forms of identify preservation (IP). In both cases, tolerances are invariably set for the presence of unwanted material because of the impossibility, in any practical agricultural crop product and food processing/handling chain, of ensuring absolute purity of products. Examples in conventional agriculture include:

- a specified grain variety may contain up to a threshold level of other grains (eg, maltsters quality requirements for malting barley include a maximum admixture of 2% of other seeds and varieties). In this case, the threshold recognizes the adventitious presence that would most likely arise during harvest, transport and storage on-farm and further down the supply chain;
- certified seed production systems that recognize different standards of seed according to various purity levels. These operate to tolerance levels for the presence of non pure seed and are based on specified seed separation distances and time intervals between the seed crop and any other crop of the same species grown on a plot, backed up by seed inspection and testing agencies. Failure to meet the purity standards results in seed not being certified and the relevant seed premium being lost to the grower. Compliance with these standards shows that in more than 96% of cases the procedures adopted (isolation, cleaning, rotations, and separation of harvest) are sufficient to meet the stringent purity standards (source: JRC 2002);
- production of specific types or varieties of crops that deliver 'quality traits'. Examples include high oil maize or high erucic acid oilseed rape (HEAR). In the latter case, HEAR varieties have desirable properties for industrial oils. However, the erucic acid is what is known as an anti nutritional in animal feed, therefore it is important that HEAR does not contaminate other oilseed rape (often referred to as double zero varieties) being grown for uses in human food and animal feed. High erucic acid oilseed rape crops tend to be grown on contract to processors with contracts recognizing that there may be adventitious presence of non erucic oilseed rape in deliveries via the establishment of specific tolerances for the presence of non erucic oilseed rape material. The contracts also usually require that only certified seed is used, seed drills have been cleaned prior to use, separation distances of between 100 metres (UK, Germany) and 400 metres (France) are maintained from other oilseed rape crops, all cultivation and harvesting equipment are cleaned before use and post harvest segregation is maintained to minimise admixtures. Prevention of cross contamination is promoted by contract testing and the use of penalties (including rejection of crops) if the set parameters for the oilseed fatty acid content are not met. The threshold for admixture of HEAR in other (double zero) oilseed rape is 2%¹⁵. Evidence cited in the JRC study from Germany suggests that a 100 metre separation distance tends to deliver more than 95% of double zero seed lots with a erucic acid level of below 0.2% and only a few seed lots contain more than 0.5%. Adherence to the contractual requirements and in particular the separation distances, comes (where applicable) by voluntary arrangements between adjacent farmers, although in many instances there is no need to involve other farmers, as separation distances can be adequately dealt with on-farm.

In addition, tolerances play an important role in organic production systems. There are tolerances for the presence of non-organic material allowed in some processed foods¹⁶ derived from and labelled as being made from organic ingredients and tolerances or allowances relating to the presence of non organic material used as agricultural inputs (eg, in animal feed and seed). Also, the current right to market and label produce as organic in the UK (and certified by an independent accredited body as organic) is fundamentally based on the adherence to organic production and husbandry principles rather than on any testing regime of produce (eg, to identify if produce

¹⁵ To breach the 2% threshold for erucic acid in the oil would require a 4% cross pollination of seed

¹⁶ Including possibly products of GM technology like processing aids (Source: Elm Farm Research Centre (2003))

contain x% of unwanted material such as pesticide residues). It is possible that in future, market factors may result more organic produce becoming subject to test-based certification mechanisms.

3.3.2 Co-existence and GM crops: general economic points

The issue of adventitious presence of GM crops in non GM crops has only become an issue because of the development of distinct markets for non GM derived products (see section 3.1). The initial driving force for this differentiation in markets between products derived and not derived from GMOs came from consumers who expressed a desire to avoid support for, or consumption of, GM crops and their derivatives. To fully accommodate this it is important to segregate or identity preserve (IP) non GM derived crops and to label these and derived (food) products throughout the food supply chain. Whilst this, in principle, does not require any fundamental change to trading practices that have been used to segregate and label specific types of conventional, agricultural produce, the nature of some of the specific issues surrounding the GM versus non GM debate have proved novel. In particular, those wishing to avoid GM products:

- want to avoid both products containing GMOs and products derived from GMOs even if it is not possible to detect GM material in the end product. This requires segregation/IP and labelling on a *production process* basis even though, in some cases (eg, soy oil) it is not possible to detect the presence or otherwise of DNA/protein from GM derived crops. The only comparable and existing system to this is related to organic produce;
- want (non GM) products to have no detectible presence of GM material (ie, a zero presence of GM material). This is entirely unique as there are no food products (outside those possibly produced in a laboratory) traded and consumed anywhere that are 100% pure. This practical issue is also not widely known amongst consumers (eg, that the limit of reliable detection is to a tolerance of 0.1%). Therefore, all products traded and consumed operate to descriptions that recognise tolerances for the presence of some other material, and as indicated above, this includes trade in organic produce. For example, in organic agriculture there are tolerances for the use of some non organic ingredients in processed products (5%), non organic inputs (eg, conventional seed until the end of 2003), the use of some GMO derived processing aids are permitted and the *de facto* tolerance for the presence of GMOs in organic produce is 0.1% (the limit of reliable detection)¹⁷.

In addition, some non GM producers, especially in the organic sector, raise the issue of possible negative economic consequences on their sector from co-existence with GM crops (ie, where an organic producer finds adventitious presence of GM crops in his/her crop above a given threshold and, as a result, loses an organic price premia or incurs additional costs on-farm to minimise the risks of adventitious presence of GM). In such a circumstance there is a question of who should bear the cost of the loss or additional cost? Should a 'polluter pays' principle apply?

These general issues relating to co-existence are considered, from an economic perspective, in the sub-sections below.

3.3.3 Co-existence and liability

Whilst this is an issue beyond the terms of reference for this study, the following points should be taken into consideration:

¹⁷ The Commission's March 2003 Communication on co-existence of GM, conventional and organic crops acknowledges that the EU regulation on organic farming (Reg 2092/91) allows for the setting of such a threshold for the adventitious presence of GMOs in organic produce although to date no level has been set

- Regulations, laws, guidelines and standards, which originate from government or industry can also affect the costs involved. These usually set baselines for acceptable behaviour and practice (from the government perspective these are usually founded on health and safety issues but also extend to issues such as competition, equity and reasonableness (of behaviour)). Complying with such regulations imposes costs on producers and failure to comply with them may result in possible legal action (criminal or civil) or market losses;
- All imposition of regulation reflects a need to balance reasonable protection (eg, of human health and safety, the environment) with reasonable cost burden;
- In the context of GM crops, the establishment of any regulatory based compliance requirements (eg, relating to farming practices) on farmers considering growing GM crops will be taken into consideration when weighing up the perceived benefits (eg, from possible yield gains, reduced costs of production) against the costs (eg, seed premium, compliance costs). Consequently, the higher the compliance costs, the lower the incentive to adopt and vice versa. As such, this principle is not unique to GM technology and applies equally to other forms of agriculture (eg, farmers considering switching to organic production systems will weigh up the costs of conversion (eg, impact on yields, costs of production, compliance with organic standards/principles) relative to the benefits of possible higher price premia;
- In most markets for agricultural produce, the burden of costs associated with maintaining the integrity of a product or 'preserving its identity' falls on the sector that produces that product and which is seeking to benefit from its production. For example, producers of quality assured or regional produce, organic produce, quality trait crops (eg, high erucic acid oilseed rape, high oil maize, malting barley, bread-making quality wheat, basmati rice). In all these cases, the respective products tend to trade at a premium to the majority of produce traded and this premia provides the incentive to initiate actions to preserve integrity and identity. This potential allocation of the burden of costs is referred to in the Commission's Communication on co-existence of GM, conventional and organic crops (2003)¹⁸;
- If regulation of GM crops included provision for imposing liability on GM crop growers for possible impact on non GM growers (eg, adventitious presence of GMOs above a given threshold leading to loss of a non GM price premia), this will add to the costs of adoption (eg, by having to take out insurance cover, if such cover were to exist) and may result in less take up of the technology than otherwise. Whilst assessing the impact of such a scenario is beyond the terms of reference for this study (eg, impact on the profitability and competitiveness of UK farming), it is important to recognise that if such a precedent were to be set in respect of GM crops it should on equity grounds also apply to non GM crop producers, whose activities might have an adverse impact on GM crop producers. For example, the hypothetical scenario of a farmer growing a crop with a GM quality trait that loses its (quality trait) price premia because of adventitious presence of non GM material above an agreed threshold.

3.3.4 Co-existence and tolerances

The level at which tolerance thresholds (eg, for the adventitious presence of GM material in non GM crops) are set has economic implications at the farm level. These essentially relate to:

- the costs involved in meeting tolerances (eg, by changing farming practices, initiating on-farm segregation of crops) or;
- the economic consequences of not meeting tolerances (eg, possible loss of non GM or organic price premia).

¹⁸ Page 5

When taken into consideration with liability issues (see above), the cost implications of meeting tolerance thresholds and who bears the associated costs will clearly affect the profitability of UK farming and influence the relative balance between GM, conventional and organic production systems. In turn this will have a 'knock-on' effect on the ability of UK agriculture (in all forms, including GM, conventional and organic) to compete both in export markets and the UK domestic market with imports.

In the sections below, these issues and relevant empirical studies/data are examined further.

3.3.5 Costs involved in meeting tolerance thresholds

a) General principle

There is an underlying principle that the tighter the tolerance, the higher the cost involved in meeting that tolerance. This has general applicability and is not GMO-specific. Within the GM market context, however this principle is clearly evident in respect of the current non GM market premia for soybeans and soymeal (see section 3.1), where the average premium for non GM soybeans and meal, to a tolerance of 1% (presence of GM material), over the last year, has been in the range of 2% to 5%, whilst the average non GM premium to a tolerance of 0.1%, has been 7% to 10%.

b) Costs involved in meeting specific GMO-related tolerances: practice and evidence to date

i) GM crops grown in the UK to date

The main development in the UK that addresses co-existence issues in respect of GM crops, is the Supply Chain Initiative on Modified Agricultural Crops (SCIMAC). These guidelines specify practices to adopt for crop management and harvesting, storage and planting of seed, neighbour notification, monitoring and record keeping and separation distances to be adopted when growing GM (herbicide tolerant) crops. They have to date, only been applicable to the Farm Scale Evaluation Trials (FSEs) and not to commercial practice. There is no current data available relating to the efficiency of these measures in maintaining purity levels of other (non GM) crops or on costs involved, although it is possible that the FSEs may produce some data on this¹⁹. In terms of the costs involved in complying with the SCIMAC guidelines, we are not aware of any formal costing work having been undertaken, although most of the requirements represent the application of good agricultural practices and/or are the type of activities that many farmers in quality assurance schemes already undertake (60% of the growers in the FSEs indicated that the audit procedures were in line with those in other farm assurance schemes: Piersall 2003). This suggests that the 'real' cost of compliance is likely to be fairly low relative to existing farming practices²⁰.

The only SCIMAC-specific cost that would be in addition to the others referred to above, might be the extra costs associated with the compliance audit requirements placed on commercial growers of GM crops. If these are undertaken by industry (eg, agronomists), then the system costs are also likely to be fairly low (eg, operating in a similar way to how agronomic advice is often provided by seed distributors 'as part of the service package' when farmers buy seed). If however, the Government required the use of independent auditing then costs to the farmer would be higher. In the current FSEs we understand that the Central Science Laboratory charges £800/FSE site for the auditing. In respect of the possible charge that might apply under a commercial environment, it is

¹⁹ Evidence from a survey of farmers in the FSEs and from the independent audit of grower compliance shows that the vast majority of farmers have found the guidelines to be very/fairly straightforward. Also, the compliance audit (of eight critical points) found very high levels of compliance (Piersall 2003)

²⁰ Page 5

²⁰ As a consequence if the lay reader were to attempt to quantify the cost of compliance by examining each individual requirement and attempting to compute an associated cost (eg, for segregation of crops in store, cleaning equipment etc), such estimates of the cost would probably significantly over state the cost relative to 'normal' practice

difficult to forecast what the average costs would be. If an independent audit requirement was established and the provision of such services was open to competition, then it is reasonable to assume that the average charge would be lower than the amount currently charged by the CSL.

The only other current 'co-existence' development relates to organic farming where accreditation bodies such as the Soil Association recommend that, to minimise the chances of mixing of GM and organic seed and pollen dispersal, that separation distances should be up to six kilometres depending on wind direction, time of flowering and local topography. The 6 km separation distance is in effect a 'warning limit' with risk of adventitious presence being determined by a risk matrix. Within this matrix the Soil Association have specified separation distances in the range of 3,000 metres to 6,000 metres (oilseed rape including seed 6,000 metres, sugar beet 3,000 metres for organic seed production and 1,000 metres for 'no weed beet' (ie, bolters), maize including seed 3,000 metres, potatoes 500 metres and wheat 500 metres. This means that in most cases where organic production has been found within 6 kms of a FSE site (the Soil Association's web-site states there have been 88), the majority have not been classified at risk because they were less than these separation distances and/or were crops different to the GM crop trials. At the time of writing (end March 2003), we have not yet been supplied with any information about the numbers of organic farms within the 88 sites that have been classified as 'at risk' and/or what actions have subsequently been taken (eg, testing for adventitious presence, possible de-certification of crops).

For further details about the SCIMAC separation distances and ones recommended in a report by MAFF (Ingram J 2000), the Soil Association's guidelines, plus a brief explanation of the principles behind separation distances and possibilities of adventitious presence occurring, the reader should refer to appendix 4.

ii) *Studies examining the possible costs of meeting co-existence related tolerances for adventitious presence of GMOs*

The available literature on this subject is limited and mainly focuses on the report of the Joint Research Council (2002) Co-existence in European Agriculture and recent work from Denmark (Tolstrup et al 2003). Key points relating to these pieces of work are summarised below (for further details see appendix 4):

The JRC study (2002) on co-existence in European agriculture

The main findings of this study were:

- the estimated levels of adventitious presence of GM crops in non GM crops vary significantly depending on the crop and farm type. For example, as much as 2.2% for a conventional intensive maize producer and as low as 0.1% for an organic potato farm. In general the analysis expects lower levels of adventitious presence of GM crops on organic farms because segregation systems are already in place. The notable exception to this was winter oilseed rape for seed production, where organic farms would probably face higher levels of adventitious presence because of problems of controlling volunteers with organic practices;
- The estimations for the expected levels of adventitious presence of GM crops in non GM crops were based on a combination of computer modelling and expert opinion. The authors of the JRC analysis therefore stated that '*the estimations have a strong relative value (ie, are useful in predicting the effect of a change in farming practices) but the absolute figures obtained have to be taken with care since the models are not fully adjusted with field data*';
- The analysis relating to the scope for changing farming practices to reduce levels of adventitious presence and the associated costs of such actions are directly related to the tolerance thresholds applied. The study examined tolerances of 0.1% (all crops), which is about the current limit of reliable detection, 0.3% for the oilseed rape for seed production (a level suggested in EU Commission discussion documents relating to possible

amendments to seed directives and estimated to be a level at which a 0.9%/1% tolerance in final product would be achieved) and 1% for maize and potatoes (the current threshold for labelling of authorized GMOs in the EU²¹). The study concluded that the 0.1% limit would be difficult to meet for any of the farm and crop combinations examined (winter oilseed rape for seed, maize and potatoes);

- All farm types examined in the study would be able to meet the thresholds of 1% for maize and potatoes and 0.3% for winter oilseed rape for seed provided they made some change to the current farming practices assumed in the study. Some farms would probably not have to change practices (notably potato farms and some maize producers, like organic) whilst other would have to initiate changes. Also some changes (eg, relating to changing flowering times for maize) might also require co-operation with adjacent farms;
- Estimates of additional costs associated with meeting the thresholds examined²² were; for meeting a 0.3% threshold for the presence of GM material in non GM oilseed rape crops used for seed, €126/hectare for conventional oilseed rape and €232/hectare for organic oilseed rape, for meeting a 1% threshold for the presence of GM material in non GM maize crops, €55.3/hectare for conventional maize and €92/hectare for organic maize; and for potatoes, the total cost of meeting a 1% threshold for the presence of GM material in non GM potato crops were estimated to be between €107/hectare for conventional earlies and €74/hectare for organic early potatoes.

The Danish Working Group on co-existence of GM crops with conventional and organic crops

This study (referred to as Tolstrup et al 2003), examined three scenarios for GM adoption: 0% in Denmark (but grown in other countries), 10% share of GM crops and 50% GM share. Overall, the study concluded that:

- for several crops, co-existence based on the proposed thresholds for adventitious presence of GMOs in end products (0.9%) was perceived to be possible. However, considerable differences were identified between crops in the extra costs that might be necessary to take in order to adhere to the thresholds (these were not stated in the English language summary version made available to the consultants);
- Little additional change to existing practices was perceived to be required for most of the arable crops suitable for growing in the UK (and examined in the Danish study), with the exception of oilseed rape. This is a crop in which the Danish study indicated there might be difficulties in meeting threshold levels and/or significant costs incurred in changing farming practices to meet the thresholds;
- Farming practice currently in use plays a significant part in influencing the level of additional costs that might be expected. Here organic and specialist farms (notably seed producers) already operate to a set a regulations that largely use the same measures as those specified in the report as necessary to meet the thresholds examined.

Further details about this research are provided in appendix 4.

Key points from these co-existence studies and relevance to the UK context

The analysis presented in the JRC study and the Danish report provides some useful indicators of the possible incidence of adventitious contamination of non GM crops with GM material, of changes in farm practices that might be required to minimise adventitious presence, the feasibility of meeting possible threshold levels and associated costs. However, in drawing on the work it is important to recognise the following key points:

²¹ Also the level proposed in the EU proposal for traceability and labelling (Com 2001 1821) and close to the 0.9% agreed by the Council of Ministers in the autumn of 2002

²² This included costs associated with implementing on-farm segregation, a new monitoring, testing and checking system and taking out insurance to cover short term losses (from possibly having crops downgraded from non GM status)

- The estimates produced in the JRC report relating to the possible costs of changes in farming practices to meet these thresholds should be treated with caution (acknowledged by the authors) and are highly dependent on the assumptions used, especially relating to the tolerances applied;
- The JRC probably overstates the likely real costs. In particular, the monitoring costs included in the analysis account for an important part of all costs. If a monitoring system was established and run by a third party independent body (as occurs for most quality assurance schemes), the likely additional monitoring costs would probably be substantially lower than the values quoted (eg, possibly €27/hectare for winter oilseed rape seed production instead of €107/hectare)²³. Also, where the possible requirements for changes to farming practices include implementing more robust segregation and traceability of produce, there may be an element of double counting to take into consideration. In recent years there has been a general trend towards farmers being required to be members of independently accredited quality assurance schemes (eg, the Assured Combined Crops Scheme in the UK which covers more than half of all arable crops grown in the UK). This requires additional provision of information on traceability and adherence to specific standards in husbandry and storage, which effectively increases on-farm costs. This, largely market driven feature is also a trend likely to continue in the future and will therefore be something that the majority of arable farmers (GM growing or non GM growing) will be faced with. Given this, some of the changes suggested in the JRC/Danish studies as necessary if the assumed adventitious thresholds are to met, may be changes that farmers have to make anyway, simply to meet general market requirements, regardless of whether crops are derived from GMOs or not.

It is also interesting to note that in Australia, where the technology providers of herbicide tolerant oilseed rape are proposing that growers should operate a five metre separation distance between GM and non GM oilseed rape, the Australian Gene Technology Grains Committee has proposed that GM and non GM oilseed rape production systems can co-exist without causing problems of adventitious presence of GM material in non GM seed at this level of separation distance (GTGC 2002).

c) The economic consequences of exceeding GMO thresholds for adventitious presence

i) Non GM producers in general

The incentive for any non GM producing farmer (including those growing part GM and non GM) to implement measures to minimise adventitious presence of GM material in non GM crops will be directly influenced by the relative costs involved compared to the consequences (eg, possible loss of non GM price premia, inability to sell the non GM crop in a given market). Where the consequence of not minimising adventitious presence is significant (eg, a significant non GM price premia, inability to sell produce or where a retailer insists on a very tight tolerance of 0.1% as a condition of supply), then it is likely that farmers will be prepared to change farming practices and incur the associated costs. However, where the non GM price premia is low (eg, 1%-3%) and it is reasonably easy to sell produce that may have to be labelled as derived from GMOs²⁴ (even if the crop is effectively non GM but may have GM presence in it at levels at/near the threshold for labelling), it is probable that most farmers will not feel it necessary to incur costs of monitoring or changing farming practices.

²³ This estimate is derived from discussions with representatives of UK-based advisory services who have experience of the costs involved in setting up and running farm level quality assurance schemes

²⁴ This specific issue remains an unanswered one in respect of the EU legislation. Will non GM crops grown on land next to GM crops and which are either mixed in storage or contain adventitious GM presence above the thresholds (and hence will be required by the labelling regulations to be labelled as being derived from GMOs) also be subject to the same monitoring requirements being established for GM crops?

Where the market (economic) consequences of not meeting the adventitious thresholds are low, the incentive to take out insurance (a cost included in the JRC study, see above) against possible market losses (assuming that the market were to provide such cover), it is unlikely that conventional producers would feel it necessary to take out such cover and therefore, this element of the costs cited in the JRC study may also be an overstatement of possible costs involved. If however, the market consequences are high (eg, there is a large price differential in favour of non GM supplies) then producers are more likely to incur the additional costs and the JRC study cited costs may be more applicable.

ii) The organic sector

Organic certification is currently based on adherence to principles such as not using pesticides or GMOs and organic status is not determined by testing of produce to see if standards have been met. This means that the majority of organic produce are not subject to testing for the adventitious presence of 'non organic' material like pesticide residues. We understand²⁵ that in a small number of cases, some market operators do test organic produce for adventitious presence of pesticide residues and that there has been only the odd incidence of produce having been rejected (ie, lost its organic premia) for showing adventitious presence of pesticide residues. However, the testing by market operators is not the 'norm', with organic farmers judged for their adherence to the principles and standards, not by systematic testing of produce against threshold levels for adventitious contamination²⁶. It is therefore possible that if the same approach is applied in a post GM approved scenario, very few organic farmers would be subject to penalties associated with adventitious presence of GMOs (above the limits of reliable detection: 0.1%), as only a few market operators might initiate tests and reject/downgrade delivery failures, with the majority of organic produce being judged on their adherence to the organic principles.

It is clearly difficult to assess whether this practice would apply in a future scenario where GMO crops could be grown commercially although if a principle-based approach is applied to pesticide residues and a testing based approach is applied to GMOs, this might be perceived by consumers to be inconsistent and therefore could damage the overall integrity of the organic label. Evidence from the USA/Canada, is limited. The Soil Association (2002) cite two examples of elevators specialising in buying organic oilseed rape off farms as having initiated testing of loads entering their plants for adventitious presence of GMOs with one indicating that 5% of loads were rejected and the other indicating that 2% were rejected. It is not known how widespread testing of organic produce for adventitious presence for GMOs is in the USA/Canada, the tolerances applied and how representative these examples are of the organic sector in the US/Canada.

A secondary aspect to take into consideration when assessing the extent to which the organic sector may be faced with risks of GMO presence thresholds being exceeded (and hence triggering possible negative economic effects) is the context of organic farming in the sectors where GM technology is being developed and may be applied in the next 10 year period. Although the sector has experienced rapid expansion, it remains a small part of UK arable crop agriculture. For example, the current area of organic wheat, oilseed rape and sugar beet account for 0.5%, 0.06% and 0.34% respectively of the total UK areas planted to these crops. Even if it was assumed that there was a substantial (eg, fivefold) increase in the UK organic area planted to these crops in the next 5-10 years, the sector would remain small relative to total arable crop production²⁷. The

²⁵ Personal communication from the Soil Association

²⁶ It is possible that in future these market driven factors may result in more produce being classified as organic or not, according to test-based criteria rather than principle-based criteria

²⁷ It is unlikely that the organic area of arable crops like oilseed rape, sugar beet and cereals in the UK will expand substantially. Crops like oilseed rape tend to be of limited interest to organic farmers because of the crop's high nitrogen requirement relative to other break crops and the market for organic oilseed rape is very small (those demanding organic oils prefer alternatives such as sunflower; see section 4). For crops like sugar beet and cereals, which are largely processed before consumption, the UK sector is faced with intense competition from imported sources of (raw material) supply which tend to be more competitively priced (eg, underlying competitive advantages of producing organic sugar cane relative to organic sugar beet, or organic wheat produced in countries like Argentina

number of (organic) farmers possibly affected would therefore be small relative to the total number of farmers in the UK. Many would not be producing crops for which GM alternatives are available (the primary reason why the majority of organic farms found to be within 6 kms of the FSEs were not classified as being 'at risk' by the Soil Association). Also the area classified as being, 'at possible risk', would probably be very low. For example the category of crop identified as having the greatest possible risk of adventitious presence identified in the JRC study is winter oilseed rape seed production. Based on 2002 plantings of oilseed rape in the UK (200-250 hectares), the area of seed required to service this is only 0.5 hectares, which could be supplied by one specialist grower (ie, one field of crop required). It would therefore not be difficult to site such a specialist enterprise in a region where there is limited planting of commercial varieties (eg, Wales, SW England) and hence minimise the possibility of adventitious presence of GMOs occurring. This siting of specialist seed enterprises in remote areas, to deliver crop isolation and maximise seed purity is not new – it is already applied in conventional seed production, most notably in the potato sector.

The authors do nevertheless, acknowledge that the very small context of organic farming 'aspect' would be less applicable in relation to the hypothetical example of GM agronomic traits being commercialised in the UK fruit and vegetable sectors (where the share of UK organic produce is higher than in the arable cropping sector). However, no GM agronomic traits applicable to fruit and vegetables grown in the UK are 'on the horizon' for the next ten years and have therefore not been examined in this study.

3.3.6 Summary of key findings relating to possible co-existence tolerance-related costs

- a) There is an underlying principle that the tighter the tolerance, the higher the cost involved in meeting that tolerance. Within the GM market context, this principle is clearly evident in respect of the current non GM market premia for soybeans and soymeal (see section 3.1), where the average premium for non GM soybeans and meal to a tolerance of 1% (presence of GM material), over the last year has been in the range of 2% to 5%, whilst the average non GM premium to a tolerance of 0.1% has been 7% to 10%.
- b) There is limited evidence available on the possible incidence of adventitious contamination of non GM crops with GM material, of changes in farm practices that might be required to minimise adventitious presence and the feasibility of meeting possible threshold levels (including associated costs). The main sources are the JRC (2002) study a report of a Danish Working Group (2003). Whilst these studies, notably the JRC study provides estimates of possible costs that might affect non GM producers, the data presented should be treated with caution and due note taken of the assumptions used (which are crucial to the findings). In particular the costs cited for meeting tolerances of GMOs in non GM material are probably overstated, especially in relation to monitoring, segregation and traceability aspects. Many of these activities are already part of good agricultural practice and/or part of requirements for farmers who are members of quality assurance schemes²⁸. Therefore the additional cost involved for many farmers could be

relative to the UK). Overall, this suggests that any possible further expansion in the UK organic area (in lines with the aspirations of the Organic Action Plan) will be concentrated in higher value products that have characteristics such as being bulky (raises cost of transport and hence reduces the competitiveness of imports, eg, potatoes), perishable and more commonly consumed without processing (eg, fruit, vegetables)

²⁸ For example, the Assured Combinable Crops Scheme, which covers about 58% of the total combinable arable crop area in the UK has membership charges which vary according to the size of farm and are equal to about £0.44/ha for a 400 hectare arable farm, £0.7/ha for a 200 hectare arable farm and £1.4/ha for a 75 hectare arable farm

fairly low (or none at all) and in line with the fees paid for membership of quality assurance schemes.

- c) If GM crop growers were required to comply with specific conditions (eg, like the SCIMAC guidelines), there could be additional cost involved associated with compliance audit requirements. The current audit charges for the Farm Scale Evaluations (£800/site from the Central Science Laboratory) represent one benchmark cost, although if this independent auditing activity were to be opened to wider competition, the level of audit fees paid might reasonably be expected to fall to levels in line with membership of quality assurance schemes (£0.44/ha to £1.4/ha).

The incentive for any non GM producing farmer to implement measures to minimise adventitious presence of GM material in non GM crops will be directly influenced by the relative costs involved compared to the consequences (eg, possible loss of non GM price premia, inability to sell the non GM crop in a given market). Where the consequence of not minimising adventitious presence is significant (eg, a significant non GM price premia or a significant organic premia), then it is likely that farmers will be prepared to change farming practices and incur the associated costs. However, where the non GM price premia is low (eg, 1%-3%) or criteria for downgrading produce (eg, organic to non organic) are based on adherence to principles rather than regular testing, it is probable that many farmers will not feel it necessary to incur costs of monitoring or changing.

The same principles apply to any farmers faced with possible liability 'claims' from other producers (these could be GM producers facing possible liability claims from non GM producers who have lost non GM price premia or non GM producers facing liability claims from GM producers of crops containing quality traits that have lost quality trait-related premia). The underlying willingness to take actions (eg, changing farming practices, siting of crops, taking out insurance) to minimise adventitious presence of their crop in someone else's will be directly related to their perception of the risk of adventitious presence occurring and the level of liability that might be incurred.

3.4 Possible development of herbicide resistant weeds and weed shifts

This issue is raised in some literature. As this could have a possible impact on farm profitability, the implications are considered below. The extent to which this issue may arise and evidence to date is also examined further in Appendix 5 for specific crops.

The development of weeds resistant to herbicides is not a new development in agriculture. It occurs mostly when the same herbicide(s), with the same mode of action have been applied on a continuous basis over a number of years.

As glyphosate is the primary herbicide used in GM (herbicide tolerant) crops and the planting of GM crops like soybeans may have encouraged increased use of no/low tillage practices (this was nevertheless a trend occurring before herbicide tolerant crops were launched but which may have accelerated since the availability of some GM crops), it is possible that these factors could lead to the emergence of weeds resistant to herbicides like glyphosate and to weed shifts towards those weed species that not well controlled by glyphosate. In addition, it is possible that herbicide tolerant plants could become volunteers in a subsequent crop which cannot be controlled by using glyphosate. This potential for out crossing of herbicide resistant plants with non transgenic seeds is reported to be more likely in oilseed rape than a crop like soybeans. The extent to which these problems, as well as that of volunteer (herbicide tolerant) plants in follow on crops, exists in countries where GM crops have been grown commercially is not known, as there are no current, detailed and representative studies available on the subject.

Whilst it is beyond the remit of this study to examine the incidence of these potential problems (as indicated above appendix 5 places these issues in context by summarising the current state of evidence on these issues on a crop-specific basis), from a farm profitability perspective:

- The development of weed resistance (singularly or stacked) to glyphosate and glufosinate, and problems with volunteers has probably not had any significant impact on the economics of using herbicide tolerant crops to date;
- In the longer term, it is reasonable to assume that some degree of reduced effectiveness of glyphosate and glufosinate against weeds may develop, along with some possible instances of weeds with resistance to more than one herbicide;
- To the extent to which weed resistance may occur, this will add cost to farmers who are required to use additional levels of glyphosate/glufosinate or include low dose applications of other herbicides in their weed control programmes²⁹. For example in Australia, where instances of glyphosate resistant weeds have been found, farmers increasingly use other herbicides like trifluralin as a pre-sowing treatment instead of glyphosate. This may therefore reduce, marginally, the average level of cost saving and profit gains cited in the most recent studies of GM herbicide tolerant crops;
- Similar problems of weed resistance build up to herbicides used on conventional arable crops can also be expected to develop, leading to similar problems and solutions for conventional crop producers (ie, the issue of weed resistance to herbicides is not a GM specific issue). Any assessment of the possible benefits and costs of GM crops should recognise these points because to only examine the possible impact of weed/pest resistance build up in relation to GM crops would not be comparing 'like for like' with the alternative production systems;
- The net impact on profitability of weed resistance, shifts and volunteer problems is likely to be fairly small. Current commercial practice in conventional agriculture is to use tank mixes of herbicides to deal with difficult weeds. Where farmers are faced with the build up of weed resistance to one herbicide, the solution is to add a different herbicide into an existing tank mix that is effective against a particular weed. Additional spray runs are rarely needed and therefore the overall impact on variable costs of production is very low (+1 to +2% for the additional herbicide). This issue is examined further in section 4;
- New technology when introduced tends to deliver a level of benefit to farmers, who decide to adopt or, not based largely on their perception (and eventual experience) of the level of benefit for them. With time and repeated use of a specific piece of technology (eg, a particular herbicide, or seed), the effectiveness of the seed, herbicide etc declines, reducing the level of benefit derived. Eventually the technology is then replaced, itself by newer technology (eg, a new seed containing a different GM herbicide tolerant trait, or a new herbicide that may have broad spectrum applications like glyphosate, or targets the weeds that glyphosate is less effective against).

3.5 Will use of GM crops like insect resistant maize or herbicide tolerant oilseeds hasten the build up of resistance of pests (and weeds)

This is also an issue raised in some literature. In terms of the possible impact on farm profitability the implications are the same as discussed in section 3.4 above (ie, the net impact on farm profitability is likely to be fairly small). The extent to which this issue may arise and evidence to date is presented in Appendix 6.

²⁹ Farmers could also revert to conventional cropping and crop protection practices

4 The possible impact of GM crops on the profitability of UK arable agriculture

In this section we examine the possible impact of GM technology on the profitability of UK arable cropping and forage maize (profitability being examined in terms of the commonly used measure of profitability, gross margins³⁰). For each crop examined, the following has been undertaken:

- An overview of the production base sets the scene;
- Profitability and key inputs used in the most commonly used production systems are discussed (including some comparisons with alternative production systems, where data availability and information permits);
- Drawing on the international literature review of GM crop impact, the possible economic impact of GM technology on the main arable crops grown in the UK, for which GM agronomic traits are likely to be commercialised, is examined.

Within the analysis, care has also been taken (where relevant) to include consideration of the potential impact on profitability over a crop rotation period rather than on a single year. By doing so complementary benefits to the cropping enterprises via rotational benefits (eg, that increase nitrogen availability by growing clover to enhance soil nutrients or by providing better weed control for the follow-on crop) can be taken into consideration.

4.1 Wheat

4.1.1 The importance of wheat in the UK

The UK wheat production base is summarised in Table 3. This table also provides a regional breakdown and shows that three regions, Eastern, East Midlands and Yorkshire & Humberside account for 60% of total UK wheat production. There is very little wheat production in Wales (16,000 hectares and only 7,000 hectares in Northern Ireland). Overall, wheat accounted for 48% of the total UK arable crop area³¹ in 2002.

Total UK domestic consumption of wheat averaged 13.1 million tonnes over the 1997/98 to 2001/02 period, some 1.6 million tonnes below domestic production. However, in 2001/02 total UK production fell to 11.57 million tonnes, some 1.5 million tonnes below domestic consumption. In years of surplus the UK exports wheat onto world markets and in periods of short-term deficit end of years stocks are drawn down. UK domestic consumption is divided broadly equally between human/industrial consumption and usage as animal feed (Table 4).

Table 3: UK Wheat Production 2002

	Area ('000 ha)	Yield (t/ha)	Production ('000 t)
North East	71	8.1	570
North West	29	6.8	184
Yorks and Humbs	247	8.5	2,105
East Midlands	386	8.3	3,195

³⁰ A gross margin refers to the output (market) value from growing a particular arable crop plus any relevant crop specific, area-based payment, less the variable costs associated with the production of the crop. Variable costs are those that are specific to the arable enterprise and vary in proportion to the number of hectares planted. A gross margin does not represent 'full' or net profit figures for each crop. Fixed costs that cannot be specifically linked to a crop such as some farm labour, machinery, equipment and general overheads also have to be taken into consideration before a true net profit can be calculated per farm

³¹ Arable crop area defined as cereals, oilseeds, pulses, sugar beet and potatoes

West Midlands	165	7.5	1,225
Eastern	520	7.9	4,354
South East	261	7.9	2,076
South West	191	7.5	1,446
England	1,869	8.0	15,155
Wales	16	7.6	112
England & Wales	1,885	8.1	15,267
Scotland	97	7.5	739
Northern Ireland	7	6.2	47
United Kingdom	1,989	8.0	16,053

Source: DEFRA

Note: Rows may not add due to rounding

Table 4: UK Wheat supply balance sheet 1997 to 2003 ('000t)

	1997/98 to 2001/02 average	2001/02 estimate	2002/03
Opening stocks	1,772	2,382	1,968
Production	14,724	11,570	16,053
Imports	1,269	1,490	1,100
Total availability	17,765	15,442	19,121
Human and industrial Consumption	6,379	6,382	6,327
(of which home grown)	5,365	5,348	5,413
Usage as animal feed	6,330	6,158	6,531
(of which home grown)	6,093	5,690	6,347
Seed	328	298	300
Other	74	58	80
Total domestic consumption	13,111	12,896	13,238
Balance	4,654	2,546	5,883
Exports	2,878	578	-
Intervention Stocks	9	0	-
Exports / intervention stocks	2,887	578	4,051
Commercial end-season stocks	1,767	1,968	1,832

Source: DEFRA

4.1.2 Conventional wheat crop production

The key variable inputs used in wheat production include:

- Crop protection products; including herbicides to control weeds, fungicides to control diseases; insecticides to control aphids and molluscides to control slugs;
- Fertilisers to provide plant nutrients;
- Seed to provide specific crop outputs (eg, bread-making, milling or feed wheat).

These inputs are used to varying degrees within a crop rotation that drives the optimum utilisation of land each year. As winter wheat has been and is, generally the most profitable combinable arable crop in the rotation it tends to be the dominant crop grown. It performs best when planted after a break crop (eg, oilseed rape, peas, beans, hemp or set-aside) but is often grown on the same

land for two years in a row, although where Take-All disease is above an economic threshold (ie, is considered to be a problem), a second wheat³² will not be planted after a first wheat (first wheat tends to yield, on average 1 tonne/hectare more than second wheats). Over a five year rotation wheat may typically be grown on the same field between two and three times. Typical examples of rotation include:

- East Anglia – first wheat, second wheat, winter barley, winter oilseed rape, first wheat;
- Lincolnshire – sugar beet, first wheat, second wheat, winter beans, first wheat;
- No second wheat – first wheat, set-a-side, first wheat, spring beans, first wheat.

Typical gross margins for wheat grown in the UK are shown in Table 5 according to soil types and Table 6 shows differences in margins according to whether the wheat is first (grown after a break crop) or second (grown after wheat). Overall, average gross margins in 2002 varied widely from £498/hectare for second feed wheat to £607/hectare for first year milling wheat. The share of key variable costs accounted for crop protection was between 34% (milling wheat on light soil) and 42% (feed wheat on heavy soil), although the Velcourt data puts the share of crop protection at between 45% (first feed) and 53% (second feed).

Table 5: Gross margins for UK winter wheat 2002 (£/ha)

	Feed wheat - heavy soil	Feed wheat - light soil	Milling wheat - heavy soil	Milling wheat - light soil
Average yield tonnes/ha	8.05	8.05	7.60	7.60
Price (£/t)	58.03	58.03	68.00	68.00
Area payment	230.00	230.00	230.00	230.00
Sales revenue	467.14	467.14	516.80	516.80
<i>Total revenue inc area payment)</i>	<i>697.14</i>	<i>697.14</i>	<i>746.80</i>	<i>746.80</i>
<i>Variable costs</i>				
Seed	36.80	36.80	39.20	39.20
Fertiliser	85.91	82.80	103.50	100.40
Herbicides	30.10	19.10	30.10	19.10
Fungicides	51.00	51.00	51.00	51.00
Plant growth regulators	6.19	2.19	6.19	2.19
Insecticides	1.50	1.50	1.50	1.50
Other variable costs	0.00	3.96	0.00	3.96
<i>Total variable costs</i>	<i>211.50</i>	<i>197.35</i>	<i>231.49</i>	<i>217.35</i>
Gross Margin	485.64	499.79	515.31	529.45

Source: ADAS 2002³³

³² First wheat means wheat grown on land after a non cereal crop in the rotation and second wheat means wheat grown on the same land that has previously had wheat grown on the land (ie, wheat preceded wheat)

³³ This source of data on profitability is put together each year by ADAS staff as their best estimates of average performance across the UK. It draws on the knowledge of ADAS staff who regularly provide farm business and management advice to UK farmers. The data is widely considered amongst the UK farming community to be representative

Table 6: Winter wheat gross margins 2002 by year of wheat/type of wheat (£/ha)

	First feed wheat	Second feed wheat	First milling wheat	Second milling wheat
Yield (tonnes/ha)	9.83	8.70	8.46	7.87
Price £/t	62	62	74	74
Area payment/ha	230	230	230	230
Sales revenue	609	539	626	582
<i>Total revenue including area payment</i>	839	769	856	812
<i>Variable costs</i>				
Seed	27	42	31	40
Fertiliser	83	106	101	105
Herbicides	42	45	40	47
Fungicides	56	55	55	55
Growth regulators	13	10	12	9
Insecticides	13	9	8	11
Other sprays	2	3	2	3
Miscellaneous variable costs	0	2	0	0
<i>Total variable costs</i>	236	271	249	270
Gross margin	604	498	607	542

Source: Velcourt Group (which farms 38,000 hectares and manages a further 20,000 hectares in the UK, which is equal to 1.4% of the total UK arable crop area)

Seed

UK wheat farmers predominantly purchase varieties that have been trialled and evaluated by the NIAB and placed on the Recommended List. The 2003 Recommended List provides extensive details on 25 varieties from seven breeders/agents. Between 10%-20% of sown seed is farm-saved which can result in a reduction of seed costs by £11.20/ha³⁴. However, by using farmer-saved seed the grower is increasing the risk of disease and lower yields. The average seed rate used is around 160 kg/ha and the cost of seed varies from £220 to £250 per tonne depending upon the variety and if it is purchased with a seed treatment. Plant breeders earn royalties on the sale of seed to growers and from farm-saved seed.

Herbicides

Depending upon the previous crop and the type of soil, herbicide expenditure can range from between £19.10/ha on light soils to £47/ha for second year milling wheat and up to £60/ha where black grass is a problem. The average number of applications therefore varies between two and three (a pre-emergent, followed by a post-emergent and a broad-leaf weed control in the spring). In the UK, there are in excess of 800 herbicide products registered for use on wheat (Crops, 2003) targeted at grass and broad-leaved weeds.

As wheat is a monocotyledon this makes the control of grass (monocotyledon) weeds such wild oats, black grass and broom very difficult and relatively expensive. This compares with broad-leaved (dicotyledon) weeds such bindweed and cleavers which are much easier and cheaper to control. The four leading weeds faced by UK wheat growers and their impact on crop yield are summarised in Table 7.

³⁴ This saving may, however be offset by lower yields that usually occur when farm-saved seed is used (when compared to using bought-in new seed)

Table 7: Lead grass weeds in UK winter wheat

Weed	Yield loss from 1 plant/sq meter	Populations of weeds to cause a 5% yield loss	Incidence	Resistance status
Black grass – Alopecurus myosuroides	0.4% No 1 grass weed as it can occur from hundreds to several thousand per sq m.	12 plants per sq metre. Commonly found at densities of over 500 plants per sq metre. Control target 98%	Widespread in England, particularly on heavy soils. One plant can shed 200 seeds.	Both target site and enhanced metabolic resistance are found
Wild oats – Avena fatua	1.0% No 2 grass weed	5 plants per sq metre. Highly competitive. Control target 95%	Widespread	Target site and enhanced metabolic resistances
Bromes	1.0%		Headlands and edges of the field	None known
Italian ryegrass – Lolium multiflorum	0.6% 25 plants/sq m resulted in 30% yield loss	5 plants per sq metre. Highly competitive. Control target 90%	Widespread, mostly on farms with history of seed crops or pasture	Enhanced metabolism and target site resistance to fops and dims

Source: Crops, 2003

Fungicides

The UK's climate is conducive for the development of crop fungal diseases. Wheat can be particularly susceptible to fungal diseases and these can have a major impact on crop yield and profitability. Average expenditure on fungicides varies from between £40/hectare to £65/hectare and typically requires 2-3 applications per crop.

Wheat suffers from a range of disease that infect different parts of the plant: the ear, leaves, stem or roots (Table 8). These diseases can be airborne, seed or soil transmitted and cause a range of symptoms that can have a major impact on crop yield.

Table 8: The major fungal diseases of wheat

Common name	Species
<i>Leaf and stem diseases</i>	
Powdery mildew	<i>Erysiphe graminis</i>
Yellow rust	<i>Puccinia striiformis</i>
Brown rust	<i>Puccinia recondite</i>
Septoria diseases	<i>Leptosphaeria nodorum</i>
Leaf spot	<i>Mycosphaerella graminicola</i>
<i>Root and stem diseases</i>	
Eyespot	<i>Pseudocercospora herpotrichoides</i>
Take-all	<i>Gaeumannomyces graminis</i>
Sharp eyespot	<i>Pellicularia filamentosa</i>
Brown foot root and ear blight	<i>Fusarium spp</i>
<i>Ear diseases</i>	

Loose smut	<i>Ustilago nuda</i>
Bunt	<i>Tilletia caries</i>
Black/sooty moulds	<i>Cladosporium herbarum</i>

Septoria can cause crop losses of between 20 and 30% if not treated. The Septoria diseases include *Septoria nodorum* and leaf spot *Septoria tritici*, which cause brown irregular lesions on leaves and purple-brown glume blotch. The disease is associated with high rainfall areas, wet summers and high humidity at heading. Septoria is a rain splash and air-borne disease that survives on infected stubble and seed. To control the disease growers currently use varieties that show a level of tolerance, purchase seed that has been treated with broad-spectrum systemic fungicide seed treatment (eg, fuberidazole), or, use one or two foliar applications of a fungicide such as azoxystrobin, flufenconazole, chlorothalonil and epoxiconazole.

Fusarium spp is commonly known as Brown foot rot and/or ear blight. It is a priority fungal disease affecting about 20% of the Western European wheat area. Total crop losses across Western Europe are estimated at £200 million, with £60 million the current total amount spent on fungicides to treat it. The disease causes a brown rotting of the stem base, roots and seedlings especially on cold, heavy, poorly drained acid soils in wet autumns and winters. There is some genetic tolerance to *Fusarium* ear blight and growers can use varieties selected for their resistance. Seed dressings such as fuberidazole and thiabendazole give partial control and a foliar application at late tillering with broad spectrum fungicides will suppress the disease. Control of *Fusarium* is important as it can cause crop losses of between 5%-10% and can cause wheat grain to be down graded by buyers due to discolouration and lowering of the specific weight. The *Fusarium* fungus also produces mycotoxins that can make wheat flour unsafe for human consumption.

The importance of fungicides to enhance yield is illustrated by the Recommended List where each variety is assessed for yield with and without fungicides. Untreated grain yield is some 20%-40% lower than treated yield – this equates to between £90/ha and £250/ha in lost production.

Table 9: Winter wheat recommended list NABIM Group 3 varieties 2003

Variety	Robigus	Deben	Wizard	Consort	Claire	Riband
Scope of recommendation	UK	UK	East	UK	UK	North
<i>Fungicide treated grain yield as % treated control</i>						
United Kingdom (10.3 t/ha)	104	103	101	100	100	98
North region (9.5 t/ha)	108	108	103	105	102	105
Dry (East) region (10.2 t/ha)	107	105	104	101	102	99
Wet (West) Region (9.8 t/ha)	107	106	103	102	104	100
<i>Untreated grain yield as % treated control in comparable trials</i>						
United Kingdom	82	79	69	64	76	60
<i>Disease resistance</i>						
Mildew	9	6	8	6	4	7
Yellow rust	3	9	4	5	9	6
Brown rust	9	5	9	4	8	3
Septoria nodorum	8	7	6	5	7	4
Septoria tritici	7	6	5	4	7	3
Eyespot	5	6	8	7	7	6
Fusarium ear blight	6	6	6	6	7	5

Note: On the 1-9 scales high figures indicate that a variety shows the character to a high degree
 Source: NIAB/HGCA

Plant growth regulators(PGRs) and insecticides

PGRs are used to limit the amount of lodging, which can reduce yield, makes harvesting difficult and results in poor crop quality. Costs vary from between £2.19/ha up to £13/ha. In contrast, insecticides to control aphids are cheap relative to PGRs, with the average cost being £1.50/ha.

Depending upon the soil type, seed-bed and weather conditions slugs can also cause serious crop losses – expenditure can be as high as £20/ha.

Fertiliser

The application of nitrogen, phosphate and potassium (NPK) varies from field-to-field and is subject to soil condition and nutrient status. The typical applications and costs in the UK are given in Table 10 below. Foliar urea is also sometimes used to increase protein content and yield in milling wheat. The optimal use of fertilisers is well documented with growers adjusting total usage on the value of the biological response. As discussed above in response to the fall in wheat prices in recent years there has been a decrease in fertiliser prices and reduced fertiliser use.

Table 10: Typical fertiliser application rates on UK winter wheat.

Nutrient	Kg/ha	Cost £/ha
N	180 –190	55.8
P	60	15.6
K	60	11.4
Foliar Urea	40	17.6
Feed Wheat		71.4
Milling Wheat		100.4

Source: ADAS

The importance of fertilisers on crop yield cannot be under-estimated and is a key factor influencing crop yields in the UK, where the warm and wet climate provides the optimum conditions for the wheat crop to maximize the biological potential of the crop. Average yields in the UK in 2002 were 8.03 t/ha which compares with 7.63 t/ha in France and 6.9 t/ha in Germany.

The sustainability of wheat yields, soil fertility and the economic cost of nitrate pollution are areas of dispute often raised when comparing conventional wheat systems with organic wheat. Some, in favour of organic farming suggest that conventional farming is not sustainable (eg, Rasmussen 1998). However, the Broadbalk Experiment at Rothamsted contradicts this suggestion. The Experiment has been monitoring soil fertility in adjacent plots of land that have operated separately, one to conventional agricultural practices and one to only applying farmyard manures for many years. The Experiment has found no difference between soil fertility levels between the two systems (conventional and organic). Within the Experiment, yields of wheat on plots receiving adequate amounts of inorganic fertilisers were also as at the same level as those produced using only large amounts (35 t/ha/year) of farmyard manure as their source of fertiliser.

It is also interesting to note that studies on nitrate leaching for conventional crop production show levels from conventional farming to be similar, if not lower than, organic crop production systems, when related to production units (tonnes of crop) from the same area of land (Stolze et al, 2000).

Cultivation

In recent years there is increasing use made of conservation tillage/low-tillage/non-inversion cultivation in conventional wheat production systems. This reduces the need to plough the soil after harvest ready for sowing. Ploughing is expensive, energy demanding and time consuming and recent evidence suggests that it is deleterious to soil inhabiting invertebrates (Edwards and Bohlen, 1996). Non-inversion tillage/direct drilling involves drilling directly into the stubble of the previous crop, whereas minimal tillage involves cultivating the soil surface enough to drill. This reduction in physical disturbance is also thought to benefit soil organisms, retain organic matter closer to the surface, reduce soil erosion and prevent leaching of nitrates and phosphates (Stinner and Stinner, 1989; Brown et al, 1996; Fraser et al, 1996; Hutcheon and Illes, 1996). Where these cultivation systems are used, weed control is primarily achieved with the use of herbicides.

4.1.3 Alternative production systems

4.1.3.1 Low-input/integrated arable farming wheat production

Low-input wheat production involves the reduced use of inputs, particularly pesticides, within a more-or-less conventional approach. Integrated Arable Farming Systems (IAFSs) involves the development of optimal strategies for reducing inputs through more sophisticated decision-making and agronomic factors including rotations and cultivation methods.

The Boxworth Project (Greig-Smith, Frampton & Hardy, 1992) and the TALISMAN (Towards A Lower Input System Minimising Agrochemicals and Nitrogen: Young et al., 2001) illustrated that low-input arable systems that reduce pesticide rates are likely to be commercially viable in certain crops, notably cereals. However, profitability is influenced by numerous factors such as the cost of inputs, market value of the crop, rotation system, location, soil type and agronomic factors. Furthermore, a high level of site-specific management and knowledge are of a prime importance.

Against this background, low input systems may become increasingly financial viable or attractive if the current poor historic level of arable crop profitability continues and farmers look at different ways of reducing costs (Wadsworth et al, 2003).

There have been many studies evaluating IAFSs. These include:

- LIFE (Less Intensive Farming and the Environment);
- LINK:IFS (Integrated Farming Systems);
- FOFP (Focus on Farming Practice);
- RPMS (Rhone Poulenc Management Study);
- LEAF (Linking Environment and Farming);
- FWAG (Farming and Wildlife Advisory Group);
- TIBRE (Targeted Inputs for a Better Environment).

Overall, conclusions are difficult to summarise from these studies. In some instances integrated systems can be as least as profitable as conventional systems, particularly if careful consideration is given to the crop rotation and management factors. In other circumstances the economics of IAFs will not be favourable. Integrated systems are likely to be more attractive to farmers when market prices and/or policy driven price supports are lower. The higher level of risk involved in IAFSs (in terms of possible crop yield loss and financial uncertainty) is widely acknowledged as an issue that has to be considered by farmers relative to a policy of using a degree of insurance or prophylactic pesticide treatments.

4.1.3.2 Organic wheat production

Organic wheat production currently accounts for around 10,000 hectares in the UK, equal to 0.5% of the total UK wheat area in 2002. Organic production does not allow the use of synthetic pesticides or inorganic fertilisers.

By their very nature organic farms have a diversity of enterprises and usually have livestock incorporated into the farming system to allow for the production of farm-yard-manure. They therefore need to incorporate crop rotations that include the use of pasture or nitrogen-fixating clovers to maintain and enhance nutrient content.

Key features of organic production systems include:

- Organic wheat can be grown after a grass/legume break crop or a crop such as potatoes/maize where residual fertility from manure applications and weed control can be obtained;
- Tillering and protein levels are reduced in low soil mineral-N conditions;
- Wheat should not be grown more than twice in succession due to declines in soil nitrogen levels, increased risk of take-all and weed competition (Lampkin, 2002);
- Cereal yields are typically 60%-70% of yields from conventional produced crops (Offerman & Nieburg, 2000). In a seven-year study conducted in the UK by the CWS comparing organic farming systems with conventional systems, organic wheat yields were 68% of conventional yields (Leake, 1999).

Data on total costs of organic arable production for 1995/96 put them at 80% of the total costs of conventional systems, with fixed costs at 86% and variable costs at 66% (Offerman & Nieburg, 2000). Lower variable costs are due to the significant lower usage of inputs such as fertilisers and pesticides, although the costs of organic seed are considerably higher than conventional seed (if used – there is a derogation that allows use of non organic seed until the end of 2003). Although fixed costs are generally lower, this can vary according to labour input and the proportion of unpaid family labour. On organic farms where there is a more complex cropping pattern or an inherent higher labour cost, fixed costs would be expected to be higher. Further experience with organic cultivation in the UK will identify whether actual fixed costs are higher or lower than conventional cultivation.

Table 11 illustrates the gross margin for organic wheat based on the 2002/2003 Organic Farm Management Handbook (Lampkin, 2002). Lampkin projected total sales revenues in July 2002 to be £963 based on a yield of 4 tonnes/ha and an ex-farm price of £185/tonne. However, using the 2001/02 price (source: Soil Association) for organic feed wheat of £155/tonne and/or autumn 2002 prices of £135/tonne³⁵, the level of gross margin is lower than the Lampkin figures (Table 11). This decline in prices and margins over the last year illustrates the market forces operating in the sector, where previous high prices stimulated imports and increased production resulting in excess supply over market demand for organic wheat.

Seed costs at £94/hectare are higher than in conventional production systems because of higher seed rates used (200 kg/ha versus 160 kg/ha in conventional wheat) to try and create a higher plant population to smother weeds and higher seed prices (£470/tonne versus £225/tonne) due to the higher seed production costs.

The cost of fertiliser at £35/hectare is based upon farm-sourced manure applied on the previous ley. Lime and rock phosphate are applied on a rotation basis as needed (indicated by soil analysis).

³⁵ Personal communication with Premium Crops March 19th 2003

Table 11: Organic wheat gross margin analysis (£/ha)

	Winter wheat (Lampkin 2002)	Winter wheat – Soil Association (prices 2001/02)	Winter wheat – 2002/03 (prices)
Yield tonnes/ha	4	4	4
Price £/tonne	185	155	135
Area payment	223	223	223
Total revenue	963	843	763
<i>Variable costs</i>			
Seed	94	94	94
Fertiliser	35	35	35
Herbicides	0	0	0
Fungicides	0	0	0
Plant growth promoters	0	0	0
Insecticides	0	0	0
Other	15	15	15
Total variable costs	144	144	144
Gross margin	819	699	619

Source: Lampkin (2002), Soil Association

Analysis of the profitability of organic wheat production relative to conventional systems has previously shown organic returns to be higher than conventional systems (eg, Institute of Rural Studies, 2000). However, to draw a conclusion from this that organic wheat production is in generally more profitable than alternative production system is too simplistic because of the following points:

- the studies referred to above do not take into consideration the importance of crop rotations to maintain soil fertility (a high nutrient demanding crop such as wheat cannot be grown as frequently in an organic rotation compared with a conventional rotation). Hence, organic rotations require the sacrificing of income in the crop rotation when a green manure crop is grown (Padel & Lampkin, 1994). A 'truer' comparison between the systems should take this into consideration. Thus, the margins presented in Table 11 effectively represent first year wheat, which would be grown one year in five in a typical organic rotation compared to two or three years out of a five year rotation with conventional, low tillage or low input systems. This means that the margins shown in the table are not strictly comparable with the margins presented earlier for conventional production. To illustrate the productivity of a stockless organic arable rotation with a conventional rotation see Table 12 below. This shows that wheat may be grown one in ten years, delivering 8 tonnes/h and a revenue of £1,080/ha (2002 prices) relative to the non organic system where the yield is 34 tonnes/ha and a revenue of £2,108/ha;
- the level of profitability for organic wheat is crucially influenced by the organic price premium, which as illustrated above, in relation to prices in the last year are as vulnerable to market variations as the price of non organic wheat. Nevertheless, current organic prices offer a substantial premium over non organic wheat (+78% relative to milling wheat and +133% relative to feed wheat³⁶). If the organic premium were to fall significantly this would have a major negative impact on the profitability of organic wheat. For example, if the premium was to fall below +70%, organic first year wheat margins would become lower than those derived from conventional feed wheat on heavy soils;

³⁶ The substantial recent and current organic price premia largely reflects the relative imbalance between supply (in shortage) and demand

- given the UK's climate and high incidence of weeds and disease, organic wheat production needs to develop crop rotations and agronomics practices that minimise yields losses, due to weeds and the maintenance of soil fertility by the costly practices such as green manure crops which reduce overall profitability of the system. This has to be taken into consideration when examining the break even point for UK organic wheat producers, relative to competitors in other countries (eg, Argentina) where the incidence of pest and weed pressures may be lower and some costs of production (eg, labour) are also lower than the UK.

Table 12: Comparison of the productivity of a theoretical organic stockless rotation versus conventional arable rotation³⁷

Year	Organic arable rotation	Crop output t/ha	Conventional arable rotation	Crop output t/ha
1	Grass/Red Clover	Fertility building	Winter Wheat	9.0
2	Grass/Red Clover	Fertility building	Winter Wheat	8.0
3	Potato	25.0	Potato	42.5
4	Winter Wheat	4.0	Winter Barley	6.4
5	Spring Barley	3.2	Oilseed Rape	3.2
6	Grass/Red Clover	Fertility building	Winter Wheat	9.0
7	Grass/Red Clover	Fertility building	Set-a-side	0
8	Winter Wheat	4.0	Winter Wheat	8.0
9	Spring Barley	3.2	Potato	42.5
10	Potato	25.0	Oilseed Rape	3.2
		Total output over 10 years		Total output over 10 years
Wheat		8.0		34.0
Potato		50.0		89.0
Barley		6.4		6.4
Oilseed Rape		0		6.4

4.1.4 GM traits under development and possible impact on UK farming profitability

During the 1990s considerable research was conducted by the public and private sector using biotechnological methods to understand the plant genetics of:

- wheat protein quality for bread-making;
- starch quality and content for industrial use and enhanced overall crop yield;
- herbicide, fungal and virus resistance;
- novel hybrids to enhance yield;
- the genetic manipulation of nitrogen efficiency; genes encoding enzymes of the photosynthetic carbon reduction cycle, and;
- a reduction in abiotic stress to increase yield.

³⁷ Note: ignores the possibility of growing a high value vegetable crop such as carrots or brassicas on either system. Rotations may vary depending upon soil type, micro-climate, location etc

The main UK applicable examples of GM wheat research and development include fusarium resistance and glyphosate tolerance. These are examined in more detail in the sub-section below after a summary of international evidence and consideration of generic issues.

4.1.4.1 GM wheat: summary of international evidence on impact

a) Fusarium resistant wheat

This technology is still at a very early stage of development (see below) and therefore there is no current available evidence relating to commercial impact or relating to trials.

b) Herbicide tolerant wheat

There is very little literature on the possible impact of herbicide tolerant wheat (see appendix 5). Drawing on this limited literature and comparisons with findings in other herbicide tolerant crops, the technology may offer some farmers yield improvements (farmers with above average weed problems, especially weeds resistant to some herbicides) and may offer cost savings. Key to potential uptake will be the level of technology fee and the level of possible savings that farmers might achieve. Also, given that wheat tends to be the main crop focus for many arable farmers, willingness to move to a herbicide tolerant (wheat) crop will be influenced by whether other herbicide tolerant crops are used in the farm rotation.

4.1.4.2 Generic cost issues: technology costs

The impact on costs and profitability of herbicide tolerant wheat will be influenced by the cost of technology. There are, however no current commercially applicable examples that can be drawn on to estimate what such a cost might be. The Gianessi et al (2002) study in the USA, assumed a technology fee of about £15/hectare for herbicide tolerant wheat. However, the price of the technology, if available to the UK farmer will not necessarily be the same as in North America. Also, commercial factors will determine the pricing, including estimates of the possible farm level benefit and the nature of competition and pricing of alternative (non GM) seed. An example of the possible impacts is presented for herbicide tolerant wheat in sub-section 4.1.4.4 below.

No statements are made in respect of the possible cost attached to fusarium resistant wheat because the technology is many years away from commercialisation.

4.1.4.3 Generic demand issues

As indicated in section 3, issues such as whether there is a market for GM wheat and is there a price differential between GM and non GM wheat will have to be taken into consideration by UK farmers when considering whether to use the technology.

- a) In relation to whether there is a market for GM wheat, the analysis presented in section 3, suggests that (based on perceptions of current consumer attitudes to GM crops) as an important share of wheat usage (just over half) is used for human food and industrial uses (mostly starch and alcoholic drinks), this is likely to be a crop in which GM crop adoption will be potentially be slowest and least (relative to for example oilseed rape). However, nearly half of wheat use is still used in the animal feed sector where demand for non GM ingredients is significantly lower than in the human food usage sectors.
- b) Price differentials between GM and non GM wheat may affect the profitability impact assessments made by farmers considering adoption. Any assessment of the possible impact of this variable on profitability should take into account the limited nature of current farm level price differentials between GM and non GM crops in general and that the price differential is not always in favour of non GM supplies (eg, the literature review presented in appendix 5, identifies examples in North America of both soybean and oilseed rape growers of GM crops being paid premia by oilseed crushers relative to baseline commodity prices for supplying material with lower than average levels of (weed) impurities).

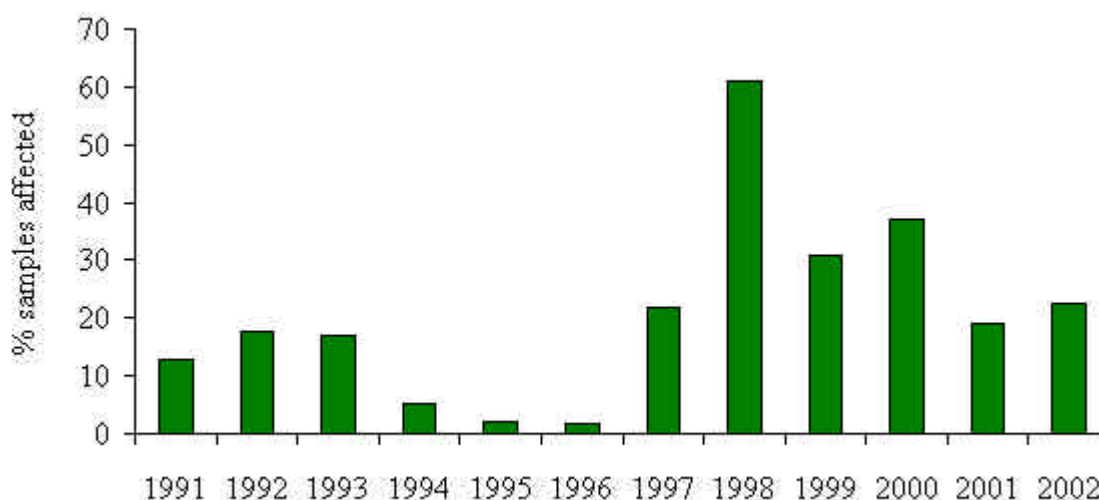
4.1.4.4 *Fusarium* resistance

Syngenta are currently trialling fusarium resistant wheat using a gene of fungal origin conferring tolerance to *Fusarium* pathogens. These trials are being conducted in several countries including the UK in 2002.

a) *Fusarium* problems

As discussed above, fusarium is a major problem to UK growers causing on average between 5% and 10% yield losses, a reduction in crop quality and concerns over mycotoxin levels. There are five major species of *Fusarium* responsible for fusarium ear blight (FEB) on wheat in the UK: *Fusarium avenaceum* (*Gibberella avenacea*), *Fusarium culmorum*, *Fusarium graminearum* (*Gibberella zeae*), *Fusarium poae* and *Microdochium nivale* (*Monographella nivalis* formerly *Fusarium nivale*). Each species is capable of infecting a crop on an individual basis or as part of a complex of species. Figure 1 illustrates the percentage of sample affected by fusarium at growth stage 75 ranging from 1% to 60% over the period 1991 to 2002. Increased disease levels over the last few years are likely to be the result of wet weather at anthesis and changes in agronomic practice.

Figure 1: Incidence of fusarium at GS 75 in England and Wales



Source: CSL

The incidence of wet weather (high humidity) is the most important factor in the development of FEB. The effect of humidity on FEB and mycotoxin production was assessed in trials carried out between 1994 and 1996 by the Central Science Laboratory. Symptom development, ear infection, mycotoxin production and yield loss were assessed under three humidity regimes ambient, medium (>70%) and high (>80%). Control of humidity was achieved using mist irrigation.

In 1994, individual plots were inoculated with one of the four FEB pathogens; *Fusarium avenaceum*, *Fusarium culmorum*, *Fusarium poae* or *Microdochium nivale*. In subsequent years inoculation with *Fusarium graminearum* was also included. Plots were inoculated at early anthesis (GS60).

Yield loss figures were calculated by comparing thousand-grain weights for the individual FEB pathogen treatments to that determined for the ambient uninoculated control. Results for 1995 are shown below. Losses ranged from 3.5% to 8% on inoculated plots at ambient humidity, with *F. culmorum* producing greatest losses. At high humidity significant losses were seen on all plots

including the uninoculated control. Results from ear isolations indicated that the losses of 14.5%, 14.5% and 13.9% on control, *M. nivale* and *F. poae* treated plots respectively could be attributed to infection by *M. nivale*. The losses on *F. avenaceum*, *F. culmorum* and *F. graminearum* inoculated plots, 13.9, 27.4 and 28.4% respectively, were caused in the main by the inoculated species.

Mycotoxins are secondary metabolites produced by some of the FEB pathogens in the UK. It is thought that in some cases the role of the toxin may be to aid infection of the plant by the pathogen. Mycotoxins are of concern due to their potentially harmful effect to both humans and animals. Mycotoxins produced by FEB pathogens in the UK are listed in Table 13.

Table 13: Mycotoxins produced by FEB pathogens in UK wheat

Fusarium species	Main mycotoxins produced
<i>F. culmorum</i>	Deoxynivalenol, nivalenol
<i>F. graminearum</i>	Deoxynivalenol, nivalenol
<i>F. avenaceum</i>	Enniatins
<i>F. poae</i>	HT-2 and T-2 toxins, diacetoxyscirpenol
<i>M. nivale</i>	None confirmed

Source: CSL

The European Commission is currently evaluating the risk posed by a number of trichothecenes toxins produced by *Fusarium* species. These include deoxynivalenol (DON), nivalenol (NIV), T-2 toxin and HT-2 toxin. It has been suggested that action limits for DON be set as outlined below:

- Wheat and cereal products as consumed (bread, pasta, etc.) - 500 ppb;
- Flour used as raw material in food products - 750 ppb.

At ambient temperature mycotoxin levels are not above these action limits but in high humidity conditions without control these levels could be exceeded.

b) Possible impact of GM fusarium resistant wheat

If these trials were successful it would take at least seven years for Syngenta to incorporate the technology into commercial competitive wheat varieties, enter national list trials and multiply seed for commercial release. Given this timeframe and the need for trials to be undertaken, estimating the possible economic impact of the technology on UK farming profitability is highly speculative. Drawing on possibilities for fusarium resistant technology, Table 14 summarises some of the possibilities.

Table 14: Possible economic impact of GM fusarium resistance wheat in the UK

Impact	Issues	Assumption
Reduced use of fungicide	Difficult to estimate as fungicides are applied to control a range of diseases Incidence and prevalence varies from location and by year	A 25% reduction in fungicide use could save the grower between £10/ha and £15/ha based on current usage. Take up by farmers would depend on disease incidence & frequency, cost & effectiveness of current controls and the cost of the technology
Enhanced yield	Some (but not total) control already achieved with fungicide treatments	A 5% yield improvement is suggested as a possibility (reflecting

	Recommended List varieties have varying degrees of resistance from average to good	losses that currently exist even though fungicides are used). At 2002 yields and prices this equates to a 0.4 to 0.45 tonnes/ha increase and a gross revenue improvement of +£23.2/ha to +£26.1/ha
Improved quality	Mycotoxin levels in cereals are a concern and presence outside prescribed limits can lead to downgrading of supplies Improved food safety	Very difficult to evaluate: depends on the current incidence and extent to which supplies are rejected or downgraded

4.1.4.5 Glyphosate tolerance

a) The technology and availability in the UK

Glyphosate (N-phosphonomethylglycine) is a potent and specific inhibitor of 5'-enolpyruvyl-shikimic acid-3-phosphate synthase (EPSPS), which catalyses one of the key steps in the shikimic acid pathway. This pathway is crucial for the synthesis of aromatic acids, which if disrupted causes a massive build up of shikimic acid and the lethal depletion of end-product aromatic acids. Glyphosate is therefore a very effective herbicide and is currently used in UK wheat production at the pre-planting stage to clean fields with severe weed problems.

A commercial level of tolerance in wheat to the non-selective herbicide glyphosate is achieved by the incorporation of a combination of genes. These genes code for enzymes that metabolise glyphosate into two nonphytotoxic compounds, aminomethylphosphonic acid and glyoxylate. The Roundup Ready™ genes have been patented by Monsanto which has filed six world-wide patent applications between 1985 and 1990. By 2010 the intellectual property protection granted to Monsanto will have expired opening up the possibility for other breeders to incorporate the technology without paying a licence fee.

Monsanto also purchased one of the UK's leading wheat breeding businesses Plant Breeding International (Cambridge), from Unilever in the late 1990s with one of the main objectives being to commercialise GM and non-GM technology for the UK wheat farmer. Details on current programmes to commercialise Roundup Ready wheat for the UK have, however been put on 'hold/terminated', although programmes in the USA and Canada have reached the stage of commercial release subject to regulatory approval and market acceptance (see section 3.1). If Monsanto were to re-activate their UK herbicide tolerant (Roundup Ready) wheat development programme it would take at least seven years before commercially competitive varieties (eg, in comparable or higher yielding than competing varieties) could be bred, tested and multiplied.

b) Possible impact of GM herbicide tolerant wheat

As with examining the possible impact of fusarium resistant wheat, it is difficult to forecast the impact of herbicide tolerant wheat because the technology is at least several years away from possible commercialisation in the UK and no UK-based trials (trials that examine possible farm level impacts) have yet been undertaken. Drawing on evidence from existing commercial, herbicide tolerant crops grown in other countries and herbicide tolerant wheat trials/analysis from the USA (see appendix 5), and discussion of current UK wheat production systems and crop protection practices, the possible impact of glyphosate tolerant wheat on the profitability of UK arable crop farming may include the following:

- Premium weed control – especially where herbicide resistant weeds have developed and where difficult weeds are difficult and expensive to control (eg, wild oats, black grass);

- Enhanced weed control over conventional methods – current weed control in the UK is considered to be fairly effective but with reduced expenditure on inputs (due to reduced profitability), yield losses due to weeds may be increasing. A potentially lower cost alternative using glyphosate with better or equivalent weed control relative to current herbicides could contribute to a lower cost production system;
- Added crop flexibility – the control of weed populations could be kept in check by the use of herbicides and crop rotations. Where UK growers have serious weed problems the availability of glyphosate tolerant wheat might allow growers to reduce weed control costs over the rotation by removing difficult weed populations which cannot be commercially controlled with current herbicides;
- Increased use of non-inversion tillage/minimum tillage systems could be more readily adopted by UK wheat growers;
- Possible yield improvements. Based on evidence from other commercialised herbicide tolerant crops like soybeans and maize, yield impact of the technology will probably be neutral, although some users might derive a yield improvement. These are likely to be farmers currently experiencing high levels of weed problems (eg, herbicide resistant black grass) that are adversely affecting yield;
- Reduced variable costs of production from lower cost of herbicides. Depending upon each growers farm conditions, crop rotation and weed problems, the option to control weeds post-emergent with a broad-spectrum herbicide such as glyphosate could reduce the cost of herbicide applications from £47/hectare (the highest recorded average level for second year milling wheat in 2002) to between £10.80/ha and £24.00/ha (based on three applications of glyphosate using two litres per hectare with glyphosate costed at £1.80 - £4.00 per litre depending upon manufacturer and formulation or two applications at a cost of £7.20/ha to £16/ha). This compares with current average herbicide expenditure/ha of £19/ha (light soils) to £30.1/ha (heavy soil) using ADAS survey data or £40-£47/ha using Velcourt data.

c) *Would a possible saving of up to £23/ha and £36.20/ha materialise for the UK farmer?*

The evidence of the current wide range of average expenditures on herbicides suggests that:

- Cost savings from the technology (and its probable main attractiveness to farmers) would be greatest for the more intensive producers (ie, high input: output) farmers and for those located on heavier soils;
- The other crucial factor affecting impact (and take up) will be the technology fee/seed premia to be charged. The Gianessi et al (2002) study in the USA, assumed a technology fee of about £15/hectare. If this level of technology fee was applied in the UK, the net herbicide cost saving³⁸ would be between £7/ha and £21/ha, making the technology of marginal benefit to anyone currently spending less than £24/ha-£39/ha on herbicides. Using the 2002 ADAS survey data this includes most UK wheat producers. Using the Velcourt data, this excludes most wheat producers.

What this brief analysis highlights is the range of herbicide costs currently incurred by UK wheat producers and hence the probable range of responses that may arise if herbicide tolerant wheat were to be commercialised and tried by UK wheat producers. The data also highlights the sensitivity of the analysis to the technology fee assumed to be used – based on the ADAS data, this would suggest that any technology fee charged in the UK would need to be lower than the rate assumed in the Gianessi et al (2002) study and certainly if technology providers were seeking reasonable levels of take up in such a circumstances, it is probable that the technology fee/seed premium charged would be lower than assumed by Gianessi.

³⁸ Assuming no yield benefit or other savings from, for example, lower labour charges or lower fuel costs

Lastly, this analysis assumes that there would be adequate demand and/or a market for GM wheat when it becomes commercially available. If there were to be little or no demand for GM wheat, adoption levels would probably be very low. The technology providers would also probably not bring the product to market in such circumstances.

d) Would glyphosate be effective on a winter wheat crop?

Glyphosate is a translocated phosphonic acid herbicide that needs to be transported around the weed to be effective. The best results are achieved when glyphosate is applied to actively growing weeds with enough leaf to absorb the chemical. Annual weed grasses should have at least 5 cm of leaf and broad-leaved weeds at least 2 expanded true leaves. Perennial grass weeds should have 4-5 new leaves and be at least 10 cm long when treated. Perennial broad-leaved weeds should be treated at or near flowering. Use of glyphosate on GM oilseed rape and sugar beet has not indicated any problems and it would be expected that weed control would be slower compared with warmer growing conditions but as effective.

A post-emergent application in late October/early November and March/April would therefore be potentially practical for the majority of the UK and would probably provide effective weed control. It may be possible in low weed incidence fields to use one application to control both grass weeds and broad-leaved weeds. With glyphosate having broad-spectrum activity against both grass and broad-leaved weeds and being cheaper than alternative products, it may offer as good, if not better weed control than current systems and at a lower cost to the grower.

e) Impact on rotation

Where take-all is not a major problem, UK wheat growers are limited in the cultivation of continuous winter wheat due mainly to the cost of controlling weeds. As discussed above crop rotations are an important part of the wheat growing cycle with wheat grown in rotation with, other, usually less profitable crops than wheat. The availability of glyphosate-tolerant wheat could, therefore offer scope for moving to continuous wheat which, based on current relative crop profitability, would increase total farm profitability.

If glyphosate tolerant wheat were to be used by UK farmers, they would, after harvest, need to use herbicides other than glyphosate to control any glyphosate tolerant wheat volunteers that would germinate from the previous crop. This could, probably be adequately achieved by either using a broad-spectrum product pre-emergent, such as, glufosinate or a low cost grass weed killer.

f) Low tillage/non-inversion

There is already a move towards low tillage crop production in the UK, which might well be reinforced by the availability of a relatively low-cost, broad-spectrum weed control product like glyphosate that could be used post-emergent. To the farmer low tillage crop production is potentially attractive because it improves soil structure, reduces nitrate leaching, lowers energy use and reduces costs associated with ploughing. By facilitating increased adoption of low tillage/non inversion, glyphosate tolerant wheat might therefore be contributing to improved profitability.

4.2 Oilseed rape

4.2.1 The importance of oilseed rape in the UK

In 2002, the UK planted 417,000 hectares of oilseed rape (Table 15), although this area has fluctuated over the last ten years from 458,000 hectares in 1993 to a peak of 501,000 hectares in 1997. The 2002 area planted was equal to about 10% of the total UK arable crop area. Average yields have fluctuated between 2.6 tonnes/ha to 3.5 tonnes/ha although there has been an underlying trend of increasing yields (with the introduction of new varieties, improved use of

inputs and agronomic practices). Over the last ten years, ex-farm prices have fluctuated eg, £175.41/tonne in 1993/94, £143.42/tonne in 2001/02, £150/tonne after the 2002 harvest. This highlights the price variability facing UK farmers with the oilseed rape market open to global competition and world price movements. The estimated value of the UK oilseed rape crop (ex-farm) for 2002/03 is about £223 million.

Oilseed rape is also grown on set-a-side land for non food uses, and in 2002 about 75,000 hectares were planted for such non-food uses. This oilseed rape is HEAR and/or double zero oilseed rape, the latter of which is mostly spring sown. Yields of HEAR are generally lower than double zero varieties, by about 10% if winter sown and –20% if spring sown. Prices for HEAR tend to be slightly lower than conventional double zero oilseed rape (forecast to be an annual average of £125/tonne in 2002/03 compared to the forecast £135/tonne for double zero varieties (source: Nix 2002)). Within the UK crop, the majority of the (non set-aside) crop is winter sown (316,000 ha) with only 23,000 hectares spring sown. England accounts for the majority of the winter cropping area (292,000 ha) with only 26,000 ha in Scotland and 1,000 ha in Wales and Northern Ireland (see Table 16).

Table 15: UK oilseed rape production base 1993-2002

		1993	1997	2001	2002 (e)
UK	Area ('000 ha)	417	473	451	418
	Yield (t/ha)	2.6	3.2	2.6	3.3
	Production (000 t)	1085	1527	1157	1394
Non set-aside	Area ('000 ha)	377	445	404	343
	Yield (t/ha)	2.7	3.2	2.6	3.5
	Production	1029	1444	1038	1202
Set-aside (industrial)	Area ('000 ha)	41	28	48	75
	Yield (t/ha)	1.4	3	2.5	2.5
	Production (000 t)	56	83	119	191

Source: DEFRA

Table 16: UK oilseed rape cropping area 2002

Country	Period	Area ('000 ha)
England	Winter	292
	Spring	19
Wales & NI	Winter	1
	Spring	0
Scotland	Winter	26
	Spring	4
Total non set-a-side area		342

Source: DEFRA

The primary market for oilseed rape is the vegetable oil (from crushing) market with the by-product, rapemeal, generally considered to be the lower value by or co-product and used mainly in animal feed. Rape oil accounted for the nearly 40% of vegetable oil consumed in the UK at around 800,000 tonnes (Table 17). Rapemeal complements other oilmeals used in animal feed, accounting for approximately 20% of usage (580,000 tonnes: Table 18).

Table 17: UK vegetable oil consumption 2002 including non food uses ('000 tonnes)

Vegetable oil	Consumption
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Rape oil	800
Palm oil	700
Soya oil	200
Sunflower oil	100
Other	100
Total UK consumption	1,900

Source: Oil World

Table 18: Oilmeals usage by Great Britain ('000 tonnes) 1992/93-2000/01

	Whole Rape	Rapemeal	Soymeal	Sunflowermeal	Other oilmeals
92/93	78	572	899	350	322
96/97	70	496	1,032	567	468
00/01	56	580	971	457	522

Source: DEFRA

4.2.2 Conventional oilseed rape production

Oilseed rape plays an important part in the conventional UK arable crop rotation along with spring barley and spring beans:

- It does not harbour pests and diseases of cereals;
- It is a good entry crop for wheat allowing for good nutrient carry over and control of some grass weeds (eg sterile broom and blackgrass);
- Integrates well into the cropping system requiring a low labour contribution and the smoothing out of labour requirements due to the early harvest and drilling time. It can be planted in mid August to mid September before or after wheat is sown, or after a spring barley crop.

Oilseed rape tends not be planted on land that has been used for any brassica crop within a four to five year period due to risks associated with canker and clubroot diseases.

Gross margins for winter oilseed rape based on ADAS and Velcourt data range from £514.56/ha to £525.60/ha in 2002. Yields are slightly lower on light soils at an average of 3.3 tonnes/ha compared to an average of 3.5 tonnes/ha on heavier soils.

Table 19: Gross margins for UK oilseed rape 2002 (£/ha)

	Velcourt Group managed farms	ADAS heavy soil	ADAS light soil
Yield (tonnes/ha)	3.41	3.50	3.30
Price/tonne	140.00	145.00	145.00
Area payment	230.00	230.00	230.00
Sales revenue (£/ha)	477.40	507.50	478.50
Total revenue including area payment	707.40	737.50	708.50
Variable costs			
Seed	23.58	24.75	22.00
Fertiliser	95.53	95.20	92.00
Herbicides	45.42	39.75	36.00

Fungicides	14.22	20.70	20.70
Growth regulators	0.00	0.00	0.00
Insecticides	12.03	1.50	1.50
Other sprays	2.06	30.00	30.00
Miscellaneous costs	0.00	0.00	0.00
Total variable costs	192.84	211.90	202.20
Gross margin	514.56	525.60	506.30

Sources: Velcourt Group, ADAS

Seeds

There are currently 23 different winter oilseed rape varieties on the UK's Recommended List supplied by 14 different breeders and agents. Of these, 11 are conventional varieties, eight hybrids and four varietal associations. Conventional varieties are estimated in 2002 to account for 80% of the UK crop area. Conventional varieties are typically sown at between 120 seeds per square metre (4 to 4.5 kg per hectare) whereas hybrids are sown at 70 seeds per square metre. Seed expenditure averages between £22/ha and £24.75/ha. An estimated 40% of UK farmers use farmer-saved seed from conventional varieties to reduce average seed costs by £10.60/ha.

Varieties are selected primarily on their yield performance (eg, Winner and Royal yield 7% higher than the control (average for the main varieties) used at 4.37 tonnes/ha cited from in national list trials). Other traits of importance include yield response to fungicide treatment, resistance to lodging, stem stiffness, shortness of stem, earliness of flowering and maturity and disease resistance.

In England the optimum date for sowing is the last week in August to the first week in September depending upon location and soil type.

Herbicides

Husbandry practices to deal with weed problems in oilseed rape vary across regions and according to the extent of problems. The main weed problems are broad-leaved weeds such as poppies, charlock, mayweed, cleavers, runch, thistles and cranesbill. They are considered to be more costly to control than grass weeds and cereal volunteers if they are not controlled early (eg, fields of poppies in an oilseed rape field are a sign of poor herbicide control in the autumn).

In general, a pre-emergence spray followed by up to two post-emergent sprays appear to be typical practice. The first application post-emergent in early September is with a graminicide such as propaquizafop at an average cost of £18.75/ha rising to £28/ha at the full, recommended application rate. A second herbicide application in November/December is commonplace using herbicides with soil residual activity such as propyzamide for controlling cleavers, chickweed and other broad-leaved weeds and resistant blackgrass, or, metazachlor for pre-emergent control of grass and broad-leaved weeds (with quinmerac the control of cleavers, poppies and mayweed is improved). The cost of the second application is between £24/ha and £50/ha.

Total herbicide expenditure varies from £36/ha to £45/ha but can rise to £78/ha where weed problems are very serious. In limited areas of eastern England weeds have become such a problem that the cost of control is limiting the cultivation of the oilseed rape crop.

Fungicides

Fungicides typically cost between £14.22/ha and £20.70/ha and are applied to control Canker (Phoma), Dark leaf spot (Alternaria), Clubroot and Sclerotinia. Damage to the stem causes lodging and infestation of the seed pods and may result in premature ripening and yield losses. The growing of oilseed rape over the last 20 years has resulted in a build-up of fungal diseases and

hence control of these has become as important as weed control. The key diseases of oilseed rape are summarized in Table 20.

Table 20: Major diseases of oilseed rape

Common name	Species	Cultural control	Chemical control
Canker	Phoma lingam	Four year break	Seed & foliar treatment
Leaf spot	Alternaria spp	Deeply plough stubble	Seed treatment
Sclerotinia	Sclerotinia	Four year break	Seed & foliar treatment
Beet Western Yellow Virus		-	Control of aphids
Clubroot	Plasmodiophora brassicae	Eight year break	Seed treatment

Without disease control yield losses can be very high. These diseases have a major impact on the potential crop area, hence a need to rotate every four years.

Insecticides/Molluscides/Other

Most farmers apply an insurance application of Cypermethrin, costing only £1.50/ha per application to control insect pests such as pod midge, pollen beetle, stem weevil and cabbage stem beetle (Table 21). Field slugs and pigeons can also be a major problem requiring the use of slug pellets at a cost of £10/ha and bird scaring devices.

Table 21: Major pests of oilseed rape

Common name	Species	Cultural control	Chemical control
Field slug	Decoceras reticulatum	Sow heavy soils first	Slug pellets at planting and when damage occurs
Cabbage stem flea beetle	Psylliodes chrysocephala	Isolate plantings from infected area	Granular and foliar treatment
Pollen beetles	Meligethes spp	None	Foliar treatment
Cabbage seedpod weevil	Ceutorhynchus assimilis	None	Foliar treatment
Brassica pod midge	Dasyneura brassicae	Control weevils	Foliar treatment
Pigeon	Columba palumbus	Scaring devices	

Fertiliser

Winter oilseed rape requires higher levels of nitrogen fertiliser than wheat at between 200 to 280 kg/ha. A seed bed application is followed by one to two spring applications to optimise the yield response. Fertiliser costs are around £90/ha to £100/ha.

4.2.3 Alternative production systems: organic oilseed rape production

The UK organic oilseed rape crop was about 200 to 250 hectares in 2002 (about 0.05% of the total UK crop). As weeds are a major problem for oilseed rape and can cause significant yield loss, organic growers need to use land with a low incidence of weeds to minimise weed establishment in the autumn when the crop canopy is not well established. Also as indicated above, because nitrogen is a key factor impacting on yield, this can act to limit interest in the crop – it is often considered better to plant a crop like wheat after a break crop (nitrogen enhancing) because of wheat’s general higher levels of profitability than oilseed rape. These considerations and the

limited potential role of oilseed rape in an organic rotation may therefore be a factor influencing the very low level of organic oilseed rape grown in the UK.

We have not been able to identify any data relating to organic oilseed rape costs of production, margins or yields - the Organic Farm Management published by the University of Wales Organic Advisory service does not include the crop. We have also not identified any market information on organic oilseed rape (eg, prices, which are not recorded in Soil Association market reporting). This lack of information reflects the very limited nature of the crop for UK organic growers.

The market for organic rapeseed oil is very small as a significant proportion of the rapeseed oil used is in the non-food sector where there is virtually no organic market. Also in the human food sector rapeseed oil is widely considered to be an inferior product relative to alternatives like sunflower oil. Therefore organic demand in this sector is mainly serviced by oils other than from rape seed.

4.2.4 GM traits under development and possible impact

During the 1990's considerable research was conducted by the public and private sector using biotechnological methods to understand the plant genetics of:

- Oilseed rape oil quality and content;
- Herbicide and fungal resistance;
- novel hybrids to enhance yield; and
- the genetic control of erucic fatty acid content for industrial uses

The main UK applicable example of GM oilseed rape research and development include the production of high yielding hybrids with tolerance to glufosinate. Further examination of this GM applications is presented below. Additional details on GM crop developments in oilseed rape are provided in Appendix 2.

4.2.4.1GM herbicide tolerant & hybrid vigour oilseed rape: summary of international impact evidence

Detailed examination of the evidence to date about the farm level impact of this technology on farm profitability is presented in Appendix 5.2. The main summary points to draw from this review are as follows:

- most of the empirical evidence relating to impact has focused on glyphosate tolerant spring oilseed rape (the most widely grown GM oilseed rape in North America). Impact on yield varies according to local conditions and there are inevitably instances of negative and positive impact. On the limited evidence available (Canola Council being the only comprehensive study of actual commercial impact), there have been, on average, positive yield gains. As the Canola Council study also suggests that variable costs associated with using GM oilseed rape rose relative to conventional crops, this also points to positive yields benefits having been produced. Otherwise the net value to farmers would probably have been limited and uptake of the technology probably at a lower level;
- in the European context of winter oilseed rape, there is limited data available (the crop is not grown commercially). Estimates of the possible impact of glyphosate tolerant oilseed rape in France in 1998 (Messean) identified a yield improvement of 15%, whilst trials of glufosinate tolerant oilseed rape (with early manifestation of the GM hybrid component) have shown improved performance relative to conventional open pollinated varieties and broadly similar performance relative to conventional hybrids (Booth et al 2002). More recent farm level trials conducted in 2001 and 2002 (containing improved GM hybrid vigour relative to earlier generations of seed) have shown yield gains of 14% for winter oilseed rape and 22% for spring oilseed rape (Bayer CropScience 2003) relative to current

commonly planted varieties. This range of suggested yield gains for Invigor oilseed rape is also consistent with estimates of possible impact in Australia of +10%–+15% relative to open pollinated varieties (Zand & Beckie 2002)³⁹;

- Impact on costs of production and profitability of herbicide tolerant oilseed rape (in the absence of GM derived hybrid vigour⁴⁰) in North America has shown positive and negative effects, although on balance the net impact on profitability has probably been positive. For some farmers costs of production have increased post adoption, mainly because of the cost of the technology, although yield improvements have tended to outweigh the cost increases to produce a net positive return (eg, this is the net impact identified in the Canola Council's 2001 study). There are inevitably instances of some farmers who have made greater levels of savings or profitability improvements and others who have experienced more limited benefits (and possibly net negative impacts). Where farmers have experienced low levels of positive returns these are often farms for which the level of weed problems have tended to be limited. Impact on costs and profitability, in the UK context, have not yet been fully undertaken and published. Trials results to date (eg, Booth et al (1999 & 2002) suggest that use of glufosinate tolerant oilseed rape has financial advantages over a complete conventional herbicide programme, although no further analysis was presented because of a lack of information on the assumed 'technology' fee (cost of herbicide tolerant seed). In Australia, the forecast impact (Nelson 2003) is for a 3% saving on total variable costs (assuming a technology cost of Aus \$25/ha);
- Other benefits are cited, as important reasons for adoption (some of these are intangible). These include increased management flexibility and convenience, increased crop rotation flexibility, reductions in labour, machinery, fuel and harvesting costs. Quantification of some of these has been made in the Canola Council study for Canada (see appendix 5);
- Possible negative impact issues associated with weed resistance build-up, out-crossing and herbicide resistant volunteers have been raised, but there is a lack of data and research into the extent to which these problems are affecting the economics of growing GM (herbicide tolerant) oilseed rape. The current dominance of GM oilseed rape within total oilseed rape production in Canada and the USA suggests that these problems are currently not significant and are not deterring uptake of the technology. In the longer term these issues could become more problematic and hence could have a negative impact on the economics of growing herbicide tolerant oilseed rape in North America. Potentially this issue would also be relevant to UK producers, although as indicated in section 3, the additional cost required to address the problem is likely to be small.

4.2.4.2 Generic cost issues: technology costs

As indicated above, the impact on costs and profitability will be influenced by the cost of technology. The higher the cost, the lower the positive impact on returns and vice versa. Drawing on Canadian experience, the cost of the technology could be in the region of £20–£30/ha⁴¹. It is however, important to recognise that the price of the technology in the UK will not necessarily be the same as in North America, especially as the technology, when made commercially available will contain GM derived hybrid vigour. Commercial factors will determine the pricing, including estimates of the possible farm level benefit and the nature of competition and pricing of alternative (non GM) seed. Some illustrations of possible benefits are presented in the sub-section 4.2.4.4 below.

³⁹ The forecast average yield impact across the Australian oilseed rape crop inclusive of use of both glyphosate and glufosinate tolerant varieties is +8% (Nelson 2003)

⁴⁰ Invigor oilseed rape varieties accounted for about 20% of GM oilseed rape plantings in 2002. This means that studies of impact in North America are largely examining the impact of glyphosate tolerant oilseed rape

⁴¹ It is interesting to note, in contrast that Nelson (2003) assumes a technology cost in Australia of about £10/ha

4.2.4.3 Generic demand issues

Drawing on the analysis presented in section 3, it is evident that issues such as whether there is a market for GM oilseed rape and is there a price differential between GM and non GM oilseed rape will have to be taken into consideration by UK farmers when considering whether to use the technology.

- a) In relation to whether there is a market for GM oilseed rape, the analysis presented in section 3, suggests that because of the significant share of oilseed rape usage in the non food sectors (industrial and feed), there is likely to be a reasonable market for GM oilseed rape, even if GM oilseed rape was to be excluded from markets that service direct human food consumption.
- b) Price differentials between GM and non GM oilseed rape may affect the profitability impact assessments made by farmers considering adoption. It is, however important to recognise that farm level price differentials between GM and non GM crops in general have tended to be very low and not always in favour of non GM supplies. The Canadian Canola Council study, for example found that GM growers were benefiting from harvest yield premia from having less seed rejected or downgraded because of impurities (from weed material). Trials of Invigor oilseed rape in the UK and Australia are also showing higher oil content in the GM crop, which delivers price premia to growers (see below).

4.2.4.4 Glufosinate tolerant and novel hybrid oilseed rape: possible impact in the UK

a) The technology

Glufosinate-ammonium (L-phosphinothricin marketed under the trade name “Basta”, “Ignite”, “Harvest”, “Challenge”, “Liberty” and others world-wide) is a non-selective herbicide. It is a non-residual contact herbicide that acts quickly under warm, moist conditions. The current UK recommendation for glufosinate-ammonium on non-GM crops is 8 litres/ha per year with no single application being greater than 4 litres/ha.

Tolerance to glufosinate is achieved by the incorporation of either the PAT (Phosphinothricin acetyl transferase) gene or the *bar* gene. The PAT gene is a dominant gene and when used in a plant breeding programme crosses normally. The novel hybrid technology works by adding a gene that produces a protein that prevents development of the pollen nutritive layer within the anther (the pollen production organ). This renders the plant male-sterile. The intellectual property to the PAT gene, *bar* gene and novel hybrid system are now owned by Bayer CropScience.

Drawing on the literature review presented in appendix 5, the following possible benefits of glufosinate tolerant hybrid oilseed rape to the UK grower include:

- Lower production costs;
- Yield increases;
- Improved control of weeds resistant to herbicides;
- Increased management flexibility;
- Benefits to subsequent crops;
- Facilitation of conservation/low tillage systems;
- Additional possibilities to plant spring oilseed rape.

Each of these possibilities is examined further below.

b) Possible reductions in production costs

Currently, UK growers spend £36-£45/ha on herbicides via 2/3 applications. This could fall to 1 to 2 applications depending weed types, weed pressure and timing of applications in either post-emergent application in the autumn and/or the spring. Glufosinate is typically applied at between

2-3 litres/ha at a cost of £10.77/litre⁴². Therefore a single application will, on average cost £21-£32/ha and two applications would cost £43-£65/ha. Based on these costs, herbicide cost savings will only materialise if farmers use one application or (if they use two applications) are above average users of herbicides (ie, probably have above average weed problems). It is also important to recognise that the cost of the technology has to be taken into the cost considerations (see below for further discussion). Given this, and based on these assumptions for the volume of glufosinate used and the price of glufosinate, production cost savings would only arise for a minority of growers and interest in take-up of the technology will be driven by other factors (see yield below). This highlights the sensitivity of any production cost impact analyses to the baseline data used for herbicide expenditure, the volume of glufosinate used and the price of glufosinate.

c) Possible yield increases

Drawing on the literature review in Appendix 5 and discussions with the main technology provider (Bayer CropScience), the scope for yield benefits comes from:

- *More efficient weed control.* In the UK weed control in conventional oilseed rape production is considered to be good and net yield losses due to weeds fairly low. Nevertheless, herbicide tolerance may deliver yield enhancements in some regions, on some soil types and some years of particularly bad weed infestation. Where significant weed problems do occur and are not well controlled by herbicides, yield increases in the order of 10%-20% might be expected. In the UK context, this is possibly only relevant to a very small number of growers;
- *A reduction in “knock-back”.* Currently herbicide treatments may damage crop productivity by between 1% and 5% of yield through, for example leaf scorching or later emergence of crops because of the impact of residual herbicides in the soil;
- *Reduced losses at harvest.* Growers experience varying degrees of pod shatter and subsequent crop losses. A combination of a cleaner crop without weeds and a more uniform crop⁴³ may result in higher harvestable yield. Drawing on the Canola Council work (2001) farmers have seen 1.27% less of their harvested yield being subject to discounts by crushers. Based on 2002 oilseed rape prices in the UK (£150/tonne) this is equivalent to a £1.9/tonne or £6.27/ha gain in income;
- *Higher oil content.* Evidence from both Australia (Nelson 2003) and the UK (farm level trials: Bayer CropScience 2003) has found that Invigor oilseed rape is delivering a 1.5%-2% increase in oil content. As farmers are paid premia/penalties by crushers according to the oil content of seed around the baseline of 40%, this increase in oil content may offer another form of revenue enhancement. For example, relative to a base oil content of 40% and assuming a base price of £140/tonne, a 1.5% increase in oil content is worth an additional £3.15/tonne or +2.25%);
- *Hybrid vigor.* The SeedLink technology produces seed with a very high level of hybrid vigour and purity – 97%-98%. This compares with other hybrid systems, which may not produce such a high level of hybrid purity/vigour under commercial scale conditions. This is where the main expected yield gain would derive from. The ability of this GM crop to deliver yield gains relative to conventionally produced hybrids derives from the combination of the GM hybridisation system (known as SeedLink) and the opportunity to use a much wider germplasm base. More specifically, non pollen producing female plants can be more easily selected as they are tolerant to glufosinate and can be more readily crossed with pollen producing male plants. By treating the seed crop with glufosinate, the scope for maximising desirable male and female crosses is increased to a level close to

⁴² Source: Average price in 2002 by UK farmers in the Farmstat panel – this is a panel of about 1,600 arable farmers in the UK that record input use. It is considered by the crop protection industry to be reasonably representative of input use across the UK arable sector

⁴³ A more uniform crop in terms of consistency relates to readiness for harvest rather than one part a crop being ready for harvest before other parts. As a result greater uniformity reduces incidence of pod shatter and loss of seed at harvest

100% because the glufosinate removes unwanted oilseed rape plants. Thus the Invigor technology tends to deliver 97% plus levels of purity relative to lower levels under conventional hybridisation systems – these can be as low as 80% (technically it would be possible to improve the purity of conventional hybrids if the non desirable pollen producing plants can be removed by hand rouging when flowers are visible. However, by this time, pollen is already being produced and it may be too late to remove all the undesirable pollen sources). In addition, the GM-based SeedLink hybrid system also allows the plant breeder to use a much wider population of female lines relative to conventional hybrid systems which tend to be reliant on a few female lines. This widens the genetic base, giving a more diverse range of breeding lines and hence results in greater heterosis (hybrid vigour). In Canada where the combined GM hybrid vigour and herbicide tolerant oilseed rape has been marketed, the magnitude of yield gains cited in empirical work is of the order of 10% (Canola Council 2001). However, this mostly relates to glyphosate tolerant oilseed rape which accounts for the majority of plantings and does not contain the Bayer patented Invigor GM hybrid technology. For the Invigor oilseed rape, yield benefit estimates from farm level trails in the UK (Bayer 2003) are 14% for winter oilseed rape and 22% for spring oilseed rape and a range of +10% to +20% is the forecast impact in Australia. These yield gains are relative to conventional open pollinated varieties in Australia (and which account for about 80% of varieties planted in the UK) and relative to leading conventional varieties (including conventional hybrids) in the UK. In the UK context, the impact on average gross margins of a yield gain of +10% would be equal to an increase of roughly £48/ha (based on an average pre-adoption yield of 3.4 tonnes/ha and a price of £140/tonne) or +9.5%. If the yield gain was 15%, the increase in gross margin would be +£71/ha or +14%.

As indicated above in section 4.2.4.2, the extent to which these possible gross margin gains arise will depend on the prices charged for the technology and the herbicide (glufosinate). It is not known what premium might be attached to the seed. Drawing on Canadian experience, the cost of the technology could be in the region of £20-£30/ha. At this level of cost to the farmer, the net yield gain to the farmer (see above) would fall from £48/ha to £18-£28/ha for an assumed yield gain of 10%, and would fall to £41/ha-£51/ha for an assumed yield gain of 15%. It is however, important to recognise that the price of the technology in the UK will not necessarily be the same as in North America (eg, the work by Nelson in Australia (2003) assumes a cost of only £10/ha). Commercial factors will determine the pricing, including estimates of the possible farm level benefit and the nature of competition and pricing of alternative (non GM) seed. In the crop protection sector, a general 'rule of thumb' approach to pricing new technology is to a cost:benefit ratio of three/four to one (ie, if the benefit is £60 the technology is priced at £15/£20). Thus if we assumed a farmer benefit of £48/ha from yield gain, £6/ha for improved harvested quality and no change in herbicide costs, the net gain equals £54/ha, resulting in a possible price for the technology of £13-£18/ha). The reader should, however note these possible technology fees are presented as illustrations of what might occur. Commercial reality tends to be more complex than this and, for example, the technology provider may also consider reducing the herbicide cost (eg, glufosinate) and have to take into consideration possible reductions in herbicide prices by competitors serving the non GM herbicide tolerant crop market.

d) Improved control of weeds resistant to herbicides

In the UK, resistance to specific herbicides has occurred in several weeds, notably black grass, Italian ryegrass and wild oats. Although the cost to control these weeds has not increased due to the availability of alternative herbicides, growers need to control these weeds and spend more time selecting the best combination to ensure effective control. Control with glufosinate may offer a more effective control at lower cost and limit the spread of resistance weeds. As indicated above, this is likely to be of relevance to farmers with above average weed problems.

e) Increased management flexibility

A significant proportion of growers currently use a pre-emergent spray, which is considered to be more risky than post emergent spraying, is very weather dependent and needs to be carried out at harvest time when labour time is limited. A single application of glufosinate post-emergent could replace the pre-emergent and current post-emergent application at a time when labour resources were more readily available. Local circumstance will determine whether or not this is relevant.

f) Benefits to subsequent crops

This is an area where there may be benefits, especially where herbicide resistant weeds require a dedicated herbicide application in the following wheat crop. As indicated above in section 4.1 above the average cost of black grass treatment in wheat is in the region of £23/ha. A coordinated approach with different broad-spectrum herbicides being used in oilseed rape and wheat may reduce herbicide costs in the crop rotation and support the development of low-input/cost systems.

A glufosinate based programme could reduce the use of residual herbicides which can have a carry-over effect requiring ploughing before the sowing of a follow-on wheat crop.

g) Conservation/low tillage

The availability of a low cost weed control system, based on glufosinate, may facilitate some farmers moving to conservation/low tillage cultivation practices, which would result in cost saving, environmental gains and reduced energy use.

h) Spring oilseed rape

Currently very little spring oilseed rape is grown in the UK (7% of the crop) mainly because of low profitability relative to winter plantings (spring rape has lower yields). The availability of higher yielding hybrid spring oilseed rape varieties (oilseed rape breeders have currently not introduced hybrid spring rape in the UK) combined with a broad-spectrum weed control programme, may therefore, facilitate a move, for some growers, to move back into a spring crop to ease management and labour requirements in the autumn during wheat harvest and sowing. However, spring rape is harvested in September, which may clash with winter wheat sowing.

i) Glufosinate tolerant oilseed rape volunteers, gene escape and weed resistance

Oilseed rape volunteers, although often present in cereals, are not considered to be a significant problem to UK farmers because farmers simply ensure that herbicide treatments in cereals include a herbicide in the tank mix that deals with them. Volunteers can be a problem in subsequent rapeseed crops, in peas, sugar beet and potatoes although as these do not generally follow an oilseed rape crop (it is common practice to follow oilseed rape with winter wheat), the problem tends to be minor. The possible development of glufosinate resistant weed rape problems in these subsequent crops may therefore occur but will probably be a very minor problem/issue. Where necessary an alternative/different herbicide would be used within an existing tank mix, resulting in some minor additional cost⁴⁴ (relative to perhaps the herbicide costs incurred in year one of adoption). Any glufosinate tolerant volunteers would also have to be removed by other herbicides used on set-a-side, again possibly resulting in a small additional cost of using herbicides relative to the baseline, year one costs. However, as glyphosate is the most commonly used 'clean up' herbicide used on set-aside this is likely to add no additional cost.

If some farmers were to require some additional herbicide used in a subsequent crop to deal with these problems, this might add a very small amount to total herbicide costs (eg, an extra 5%, which is equivalent to a 1% increase in total variable costs).

⁴⁴ There would probably not need to be an additional spray application

4.3 Sugar beet

4.3.1 The importance of sugar beet in the UK

Sugar beet in the UK is dependent upon the EU sugar regime, which largely controls production through the use of production quotas. The UK quota is currently 1.138 million tonnes comprising of A quota that guarantees farmers a minimum price, a B quota which also guarantees a price less a levy of 30% to cover some of the cost of export subsidies required to facilitate exports and C sugar which is any crop grown in addition to A and B sugar and which trades at world market prices⁴⁵. As average yields have tended to increase over the last ten years, it has required a reduced area to be planted each year in order to meet the A and B quotas.

The UK's sugar quota, set by the EU Commission is managed by British Sugar, which allocates it to UK growers. Each year British Sugar sets individual farm level quotas on the basis of the EU level determined quotas and contracts directly with UK growers. The British Sugar production contracts with farmers also require farmers to buy their seed from British Sugar⁴⁶. This contractual requirement does not state which seed or variety is to be used, with the choice left to farmers drawing from British Sugar's available list of recommended varieties (in practice this is the NIAB recommended variety list).

Sugar beet plays an important part in the arable rotation in the main regions it is grown (predominantly in Eastern England). Commonly grown in conjunction with wheat, barley or pulses, sugar beet provides a valuable break crop returning organic matter to the soil and preventing the build up of disease.

The UK grower typically achieves an average crop yields over 50 tonnes/ha of clean topped roots with a sugar content averaging around 17%. Farmers are paid a bonus on all roots with a sugar content in excess of 16%.

Key features of the UK production base are:

- There are about 7,200 beet growers (all in England);
- The 2002 crop area was 169,000 hectares (about 4% of the UK arable crop area);
- Annual production is around nine million tonnes of beet and this delivers about 1.4 million tonnes of sugar and 700,000 tonnes of pulp for use mostly in animal feed;
- Sugar beet is and has been the most consistent and, highest profit arable crop for UK farmers;
- Sugar beet growing is a totally mechanised operation with only 50-man hours/ha required to grow a typical crop, compared with 500 man-hours 30 years ago;
- Seed is sown in March and early April;
- The crop is harvested between mid-September and late February;
- Processing begins in September and lasts until late February.

4.3.2 Conventional sugar beet production

Sugar beet production methods have changed significantly in recent years. Rapid progress with mechanisation, together with enhanced crop protection technology, has seen a ten-fold reduction in

⁴⁵ The volume of C sugar produced in the UK varies each year. It has been equal to between 6% and 18% of the total planted area in recent years. C sugar production reflects a combination of a) unintended C sugar where growers plant an area of beet to ensure that they do not under deliver on their A & B sugar quotas (this is possible if yields and/or sugar content are below average) and b) deliberate plantings of C sugar – this intended production depends on the marginal cost of production relative to the world price of sugar

⁴⁶ British Sugar is however not a seed producer or plant breeder but acts as an agent or wholesaler of seed

the labour requirements to grow a typical crop. The volume of crop protection products and fertilisers used has also decreased over the last 30 years, with a:

- 52% reduction in total volume of pesticides used;
- 49% reduction in amount applied per hectare;
- 63% reduction in herbicides;
- 95% reduction in organochlorine, organophosphate and carbamate insecticides.

Since 1970 nitrogen application rates for the sugar beet crop have been reduced by 33% and the crop now has the lowest nitrogen usage of any major arable crop in the UK (averaging 105 kg/ha compared to approximately 190 kg/ha for wheat, oilseed rape and potatoes (Source: British Sugar 2003)).

Preparations for the sugar beet crop usually begin in the autumn prior to sowing when tailor-made fertiliser blends are incorporated into the soil during ploughing. LimeX, a liming material co-product of the sugar refining process, is also frequently applied to assist in balancing soil pH and returning valuable nutrients to the land.

Great emphasis is placed on careful spring seedbed preparation to create the ideal conditions for germination and prevent soil compaction, thereby ensuring the best start for the new crop.

Sugar beet is sown from early March onwards and, with over 10,000 hectares per day being typically drilled during the peak period, is normally completed by early April. The single-seed monogerm pellets are sown in rows, or drilled, 50cm wide, at a typical spacing of 18cm and between 2.5 and 3.0cm deep.

Nitrogen fertiliser is applied to suit specific soil requirements and crop production techniques. The objective is to use the minimum nitrogen possible to achieve target yield, consistent with good environmental practice. Food safety requirements restrict the use of products that can be used while a process of continual assessment seeks to minimise their environmental impact.

Harvesting begins in mid-September, but as the national crop continues to grow at over 10,000 tonnes of sugar per day, progress with root lifting is carefully monitored to meet factory intake requirements, and hence achieve the highest possible yield of sugar. As late season growth declines, the pace of harvesting increases to ensure the crop is gathered in before the end of the campaign. Roots awaiting delivery to the factory are carefully stored to maintain the highest possible quality and sugar content.

The typical inputs and costs of growing UK sugar beet are shown in Table 22. The largest single cost, at £140.30/ha is seed, which is treated with an insecticide imidacloprid to control beet virus yellow vector. A combination of fertilisers is used to provide the necessary plant nutrient, nitrogen accounting for approximately half the total fertiliser costs of £87.50/ha. Nitrogen is applied in the early stages of crop growth to ensure an increased leaf area and hence contribute to higher crop yields. Between five and eight herbicide applications are typically made at a total cost of £72.90/ha. Average total variable costs (excluding harvesting) for these inputs total £321.51/ha.

Table 22: Variable costs of UK sugar beet 2001

			Cost per unit		£/ha
Seed:					
Imidacloprid	1.15	Units	122.00	£/unit	140.30

<i>Fertiliser</i>					
Nitrogen	120.00	kg/ha	0.35	£/kg	42.00
Phosphate	50.00	kg/ha	0.26	£/kg	13.00
Potassium	100.00	kg/ha	0.19	£/kg	19.00
Sodium	150.00	kg/ha	0.09	£/kg	13.50
			Total Fertiliser		87.50
<i>Herbicide</i>					
Chloridazon	4.00	l/ha	5.80	£/l	23.20
Phenmedipham (x 3)	6.70	l/ha	2.20	£/l	14.74
Metamitron	1.25	kg/ha	15.00	£/kg	18.75
Ethofumesate (x 2)	2.50	l/ha	6.50	£/l	16.25
			Total herbicide		72.94
<i>Fungicide</i>					
Sulphur	10.00	kg/ha	0.60	£/kg	6.00
Manganese Sulphate x 2	10.00	kg/ha	0.44	£/kg	4.40
			Total fungicide		10.40
<i>Insecticide</i>					
Pirimicarb	0.28	kg/ha	29.00	£/kg	8.12
Mineral Oil (x 3)	2.50	l/ha	0.90	£/l	2.25
Total variable costs					321.51

Source: ADAS

In terms of gross margins, Table 23 summarises the changes in real margins earned from sugar beet since 1996/97. Over this period the gross margin for sugar beet in the Eastern counties has fallen in real terms from £1,125/ha to £826/ha (Lang B 2002). Revenues have fallen in recent years mainly due to sterling appreciation against the Euro, which has effectively reduced the support price. Against this background, the number of farmers growing sugar beet has decreased by 1,300 since 2001. In current price terms, and using ADAS data (average yield 50 tonnes/ha, price £30/tonne and other miscellaneous cost such as contract drilling, harvesting and haulage of £471/ha), the average gross margin in 2002 was £707.5/ha. Using Velcourt data, the gross margin in 2002 was £988/ha (average yield 63 tonnes/ha, costs of production £853/ha).

Table 23: Sugar beet gross margin in real terms 1996/97 - 2001/2002

Year	Yield	Price (£/tonne)	Gross output £/ha	Total variable costs £/ha	Gross margin £/ha
1996	45.19	38	1,739	615	1,125
1997	53.59	31	1,679	676	1,002
1998	50.55	34	1,734	716	1,018
1999	55.02	30	1,625	728	897
2000	52.03	29	1,528	713	816
2001	47.10	31	1,475	649	826

Source: Lang, B 2002

4.3.3 Alternative production systems: organic sugar beet production

In 2001, British Sugar contracted 28 organic growers (0.39% of all sugar beet growers) to produce 12,000 tonnes of sugar beet grown on 300 hectares. This increased to 18,000 tonnes of beet, 500 hectares and 35 growers in 2002. In 2003, we understand that British Sugar will contract for 20,000 tonnes of organic sugar beet⁴⁷, on 518 hectares.

British Sugar is paying a premium of 55% over the average market price for conventional sugar beet and are also providing organic growers with an additional 15% entitlement on their "A" quota allocation. In addition, British Sugar has been waiving transport charges which can be limiting when moving a bulk product across the UK to a single factory.

The UK Organic Farm Management Handbook states that based on UK experience yields can vary from between 60% and 100% of conventional yields (actual yield levels achieved depend upon the level of soil fertility, weed control and climate). The publication also states that yield data from the first two years of commercial growing should deliver an average yield of 36 to 40 tonnes/ha (72%-80% of average yields obtained by conventional production systems).

The gross margin for the UK organic sugar beet grower is shown in Table 24. The premium price currently paid effectively offsets the lower yield and increased costs of weed control. Weed control is dependent upon the late planting of the crop, mechanical cultivation, the use of flame torching and hand labour. This latter reliance on hand labour is also perceived to be a potential problem for any expansion in the area planted, as it is difficult to find adequate amounts of labour willing to do hand weeding (the requirement is an estimated 60 hours/ha).

Table 24: Gross margin of organic sugar beet 2002

	Tonnes/ha	£/tonne	£/ha
Marketable yield	44	45	1,980
Seed			110
Fertiliser			50
Casual labour – weeding	60 hr	@ £5.30/hr	318
Transport			0
Other			25
<i>Total Variable Cost</i>			<i>503</i>
Gross margin			1,477
Sensitivity analysis			
Marketable yield	-10		-450
Price		-10	-440
Casual labour	10 hr	@ £5.30/hr	-53

Source: Lampkin 2002

The risk associated with growing organic sugar beet is considered to be fairly high and is illustrated by sensitivity analysis of the margin data. A reduction on the yield from 44 tonnes/ha to 34 tonnes/ha reduces the gross margin by £450/ha. To obtain good yields weeds must be controlled in the first eight weeks post emergence. If emerging annual weeds are not well controlled they can reduce yields by 26% to 100% (Schweizer & Dexter, 1987). Inter-row cultivation using up to two passes with a tractor and hand-hoeing and pulling may achieve satisfactory weed control.

⁴⁷ This would produce about 3,000 tonnes of white sugar = 0.2% of total UK sugar production

Possible future expansion of the organic sugar beet crop in the UK is dependent upon demand from the drinks and food industry, which use 1.6 million tonnes (75%) of the total UK sugar beet crop. There is currently no demand for organic sugar beet for the retail sugar in the UK, as this market is serviced by “brown” sugar derived from imported organic sugar cane.

As with other organic crops, the gross margins cited in the Organic Farm Management Handbook probably overstate the actual margins for organic production, because the crop rotation has to be extended to include grass leys and legume crops. Over the cycle of the rotation this would reduce the average farm crop productivity compared with conventional cropping.

4.3.4 GM development in sugar beet

During the 1990’s considerable research was conducted by the public and private sector using biotechnological methods to understand the plant genetics of:

- sugar content and enhanced overall crop yield;
- herbicide and virus resistance;

The main UK applicable example of GM sugar beet research and development is glyphosate tolerance. This is examined further in the sub-sections below and more detailed examination of literature on the impact of this technology on farm profitability is presented in appendix 5. A general description of technical developments in GM sugar beet (traits and trials) is also presented in Appendix 2.

4.3.4.1 GM herbicide tolerant sugar beet: summary of international impact evidence

As GM herbicide tolerant sugar beet is not currently grown commercially, the only available literature relating to impact derives from trials and forecasts. Summarising the literature to date on this (potential) impact (see appendix 5 for further details) on farm profitability:

- Impact on yield will probably be positive and could be within the range of +5% and +15% (May 2003, Dewar et al 2003 and Gianessi et al 2002). Trials in both the UK and the USA suggest that yield gains derive from reduced phytotoxicity problems in the crop (less spraying and a reduced variety of herbicides used) and improved weed control. Yield enhancement is likely to be greatest where farmers experience significant weed problems and have difficulty in maintaining reasonable control. Reduced levels of yield relative to conventional crops may, however arise if the technology is sold (possibly initially) in varieties that are not all leading varieties and where the weed control in the herbicide tolerant crop is left late (ie, after weeds have had time to become established). The latter case scenario may arise when farmers experiment with timing of spraying during early adoption and would probably not occur once experience has been gained;
- Impact on costs of production and profitability would be expected to be positive (see section 4.3.4.4 below for further analysis). This is one of the main benefits predicted to arise from adoption (as has been the case in other herbicide tolerant crops). This will potentially arise from reduced costs of weed control. Clearly the extent to which profitability benefits will occur will depend on the technology fee charged (see below) and the level of cost savings experienced by growers. The greatest savings are likely to be where farmers currently have above average weed problems and control costs and the lowest level of savings will be with farmers with below average weed control costs/problems. In some cases, farmers with good weed control, and lower than average costs of control would probably not derive any benefit after paying the technology fee/seed premium;

- Some of the more intangible benefits cited in herbicide tolerant crops like oilseed rape and soybeans are likely to be important factors affecting adoption by farmers. These include convenience, reductions in crop consultancy costs, gains from switching to minimum tillage and benefits in rotations/follow on crops like cereals, given that sugar beet is often considered to be a 'cleaning crop' in rotations.

4.3.4.2 Generic cost issues: technology costs

As with the application of GM technology to any crop, the impact on costs and profitability will be affected by the cost of technology. Drawing on the only work to date to impute a possible cost of the technology (May 2003), this could be in the region of £20-£30/ha. Some illustrations of possible impact based on this level of technology fee are presented in sub-section 4.3.4.4 below, although it is again highlighted that the price of the technology in the UK will be determined according to commercial criteria at the time of launch and may not be equal to the level assumed in the analysis by May or the analysis below.

4.3.4.3 Generic demand issues

Whether there is a market for GM sugar beet and whether there is a price differential between GM and non GM sugar beet are factors that UK farmers will take into consideration when examining whether to use the technology (see section 3 for more detailed discussion).

- a) Will there be a market for GM sugar beet? The analysis presented in section 3, suggests that (based on perceptions of current consumer attitudes to GM crops) as the vast majority of sugar usage is used for human food, this is likely to be a crop in which GM crop adoption will be potentially be slow and limited (relative to for example oilseed rape). The unique position of British Sugar as the monopoly buyer of sugar beet and the sole supplier of seed will also play an important role in determining adoption. Whilst current British Sugar policy of not wanting to use GM sugar beet operates, there will be no domestic market for GM sugar. Nevertheless, if British Sugar were to change its commercial policy (eg, in the light of increased import competition likely in 2008/09 or to service new non food market opportunities that may well develop (notably bio-ethanol)), it is possible that a market might develop where GM sugar could be sold. In addition, it is possible that, if the demand for bio ethanol were to develop in the EU, export market opportunities for GM sugar could develop, as has recently developed for UK growers of oilseed rape, selling to Spanish manufacturers of bio-diesel).
- b) Price differentials between GM and non GM sugar beet may affect the profitability impact assessments made by farmers considering adoption. As applies to all GM crops, any assessment of the possible impact of this variable on profitability should take into account the limited nature of current farm level price differentials between GM and non GM crops in general and that the price differential is not always in favour of non GM supplies (eg, the literature review presented in appendix 5, identifies examples in North America of both soybean and oilseed rape growers of GM crops being paid premia by oilseed crushers relative to baseline commodity prices for supplying material with lower than average levels of (weed) impurities.

4.3.4.4 Glyphosate tolerant sugar beet: possible impact in the UK

Both GM herbicide tolerant sugar beet and fodder beet have also been extensively trialed in the UK, France and Denmark. However, since the EU moratorium, product approval for commercial cultivation has been stalled

The possible costs/benefit implications of adopting glyphosate tolerant sugar beet are discussed in detail in appendix 5. Drawing on this analysis, the following impacts could occur:

- Reduced number of herbicide applications from an average 4.5 to 2 applications and as a result a reduction on the average level of expenditure on herbicides. May (2003) estimates

that the likely herbicide costs for a farmer using herbicide tolerant sugar beet would be between £13/ha and £27/ha plus an application cost of £13/ha (ie, a total of £26/ha to £40/ha). This compares with the current average herbicide costs (including application at an assumed cost of £29/ha) for conventional sugar beet of £129/ha-£149/ha using May's data, £84-£104/ha using FARM data, £102/ha using ADAS data and £167/ha using Velcourt data. Assuming a technology fee/seed premium of £20-£30/ha (May 2003), this would result in an approximate net saving on herbicide costs of £80/ha based on May's data, £36/ha using FARM data, £44/ha using ADAS data and £109/ha using Velcourt data;

- Based on trials data and existing analysis such as May 2003, Dewar et al 2000 & 2003 and Gianessi et al 2002, an increase in yield is likely. This could be within a range of 5% to 10%. At 5% (relative to an average yield of 50 tonnes/ha) this is equal to an additional £75/ha in gross margin and at 10% it is equal to an additional £150/ha. If we were, in addition to assume that UK sugar prices fell by about 18% (see section 1 and appendix 1 - a possible scenario post 2008/09), the additional revenue would be £61.5/ha at a 5% yield gain and £123/ha at a 10% yield gain;
- Possible additional cost savings from reduced use of crop consultants, greater management flexibility, adoption of minimum tillage practices, improved rotational weed control and reduced stubble control. These possible savings will vary by farm and could be within the range of zero to £32/ha (these boundaries are based on the respective views of FARM and May);
- The possibilities of herbicide tolerant volunteers and resistant weeds developing might add a minor additional herbicide cost relative to current usage/costs (see oilseed rape above, section 4.2). In sugar beet this would probably be even less of an issue than in oilseed rape.

In sum, the analysis above suggests that the overall benefit at 2002 costs and prices of using herbicide tolerant sugar beet would be between £111/ha and £291/ha. At possible 2008/09 prices, the net benefit is between £97.5/ha and £264/ha. This range of possible benefits is clearly dependent upon the assumptions used (as derived from the various trials data/literature on the subject). It also highlights the wide variability in the performance of different growers and hence the range of likely impacts of the technology, if adopted.

Lastly, as highlighted section 4.3.4.2, the cost of the technology/seed premium that might be charged for herbicide tolerant sugar beet will affect impact on profitability. Using the 'rule of thumb' cost: benefit ratio referred to in section 3, and assuming the technology is not commercially available for another five years (ie, using 2008/09 possible sugar prices), the charge for the new technology could be set in the region of £23/ha to £80/ha depending on the commercial criteria used by the technology provider and the nature of competition from conventional seed. The reader should note these possible technology fees are presented as illustrations of what might occur. Commercial reality tends to be more complex than this and, for example, the technology provider may also consider reducing the herbicide cost (eg, glyphosate) and may have to take into consideration possible reductions in herbicide prices by competitors serving the non GM herbicide tolerant crop market.

4.4 Potato

4.4.1 The importance of potato production in the UK

The total area of potatoes grown in the UK was about 162,000 hectares in 2002. This is roughly divided into early crops and main crop, which respectively account for about 20%-25% and 75%-80% of the total area (Table 25). Average yields have fluctuated between 40 tonnes/ha and 50 tonnes/ha for main crop and 24 tonnes/ha to 30 tonnes/ha for earlies.

Prices in recent years have fluctuated from between £147.16/tonnes in 1998 to as low as about £60/tonne in 2002. The number of registered producers has fallen from 27,498 in 1982 to 6,143 in 2000. Specialisation is now key to remaining in the sector and necessitates investment in irrigation, cold storage and marketing.

Table 25: UK potato crop area, yield & production 1982-2001

	1982	1992	2000	2001
Potato area ('000 ha)	161	155	146.2	146.4
Early area ('000 ha)	35	52	58	55.6
Main crop ('000 ha)	123	103	88.2	90.8
Early crop yield (t/ha)	23.3	29.3	29.2	23.9
Main crop yield (t/ha)	40.8	49.2	41.0	44.8
Production ('000 t)	6,539	7,481	5,510	5,397

Source: British Potato Council

Note: Regionally the breakdown of production is 75% in England, 19% in Scotland, 4% in Northern Ireland and 2% in Wales

Total available supplies in Great Britain were 8.3 million tonnes in 2001/2002 of which 6.6 million tonnes were sourced from domestic production. The imports of processed potatoes (eg, frozen) account for 20% of human consumption at 1.27 million tonnes, with limited quantities of ware and new potatoes imported (224,000 tonnes and 195,000 tonnes respectively). Wastage accounted for just under one million tonnes of potatoes in 2001/2002 (Table 26).

Table 26: Summary of supplies and disposals of potatoes in Great Britain ('000 tonnes)

	2001/2002
Supplies	
Home crop	6,410
Carry-over from previous year	192
Imports	
New potatoes	195
Ware	224
Processed (raw equivalent)	1,274
Seed for next crop	37
Total supplies	8,338
Disposals	
Human Consumption	6,300
Seed for next crop	393
Exports	349
Wastage	976
Closing stock	317

Source: HM Customs & Excise, Intrastat, MAFF/DEFRA and British Potato Council

Of the 5.0 million tonnes domestically produced and used for human consumption, 62% is as raw potatoes (of which 64% is consumed in the home and 36% by caterers) and 38% is processed (of which the split is 50:50 between home and catering).

4.4.2 Conventional potato production

The major agronomic disease is potato blight and the key pest is nematodes which limit productivity and require a range of control methods including crop rotation, use of resistant cultivars, fungicides and pesticides.

4.4.2.1 Potato pests and diseases

a) Nematodes

Potato Cyst Nematode (PCN) is an important agricultural pathogen comprising *Globodera rostochiensis* and *G. pallida* (potato cyst-nematodes, PCN) which are often key pests of the potato crop occurring in 64% of potato fields in England and Wales (Minnis et al. 2002). PCN is currently the most important factor limiting the production of potato in the UK and causes an annual yield losses of approximately £43 million based on the mean UK value of the crop from 1990-1995 (Haydock P.J. and Evans K. 1998).

Current control measures include resistant cultivars, rotation and nematicides. The variety Maris Piper has been widely used for nearly 40 years in the UK to provide some resistance to *G. rostochiensis* (Dale and De Scurrah 1998). However, frequent use of Maris Piper has increased the prevalence of *G. pallida*, to which it is susceptible, and this form of PCN species is now the most common in UK potato fields (Minnis et al 2002). Breeding for resistance to *G. pallida* has continued for over 50 years but it has proved difficult to provide a range of agronomically acceptable cultivars.

Rotation lengths for potato cropping are commonly 1 in 5 years (it accepted that longer rotations would be beneficial for PCN control (Haydock, P. 2003) but this causes financial penalties on growers). Fumigants and granular nematicides are important aspects in the control of PCN. Granular nematicides are used on approximately 28,000 ha each year at a cost of over £8M to the growers (Evans K. and Haydock P.J. 2000). The European Council Directive 91/1414/EEC had proposed that the most commonly currently used granular, carbamate nematicide (aldicarb products (Temik®)) should all be withdrawn within an 18 month period, however, the Council of Ministers on the March 19th 2003 adopted an alternative proposal under which aldicarb products will still be withdrawn within 18 months but certain "essential uses" will continue to be authorised until 31 December 2007)⁴⁸. Aldicarb is used on potatoes, carrots, parsnips, onions and ornamentals in the UK and covered by this need for "essential use"⁴⁹. This comes after the carbofuran carbamate nematicides (Furadan®, Yaltox®) were not supported by the European Directive and these products are "subject to phased revocation".

At a recent conference into PCN Research Priorities (Rothamsted, March 2003) the frustration with PCN management was evident as it was suggested that potentially all fields used to grow potatoes be treated. Environmental groups such as Friends of the Earth, are calling for a ban on the use of these endocrine disrupting pesticides and have called for government to provide funding for research into alternatives to chemical pesticides⁵⁰.

b) Potato Blight

Potato late blight is one of the most devastating plant diseases and can cause complete crop loss if not controlled. The disease is caused by a fungus-like organism, *Phytophthora infestans*, which is a specialised pathogen of potato and, to a lesser extent, tomato (another member of the plant family Solanaceae).

⁴⁸ Big Issue South West, No 532, March 24-30 March 2003

⁴⁹ www.pesticides.gov.uk/ec_process/EC_News/aldicarb_Mar03.htm

⁵⁰ www.foe.co.uk/pubsinfo/briefings/html/20020911100949.html

Many approaches have been developed to control it but the search for effective control measures is a continuing challenge - the fungus still poses a major threat, and it has evolved to overcome most of the control measures used:

- *Fungicidal control.* Control of potato blight traditionally relied on copper-based fungicides such as Bordeaux mixture (consisting of copper sulphate and calcium oxide). Organic growers are permitted to use this product, subject to approval from the certifying body, until the 31st December 2005. However, copper is potentially phytotoxic, so disease forecasting was developed to better enable growers to predict when the environmental conditions were highly conducive to spread of the pathogen and thus when the growers needed to spray to protect crops. Forecasting methods for blight epidemics differ in different countries but in Britain they are based on the "temperature-humidity rule" devised by Beaumont (1947). After a certain date (depending on locality) blight was found to develop within 15-22 days following a period when the temperature was not less than 10°C and the relative humidity was over 75% for 2 consecutive days. Radio stations now broadcast warnings of the Beaumont periods or updated versions of these in the early-morning farming programmes. Copper is a broad-spectrum fungicide which acts as a protectant – it must be applied to **prevent** disease. It has been superseded by modern systemic fungicides, which move within the plant and can both protect and eradicate existing infections. These fungicides are much more specific in their mode of action. Chief among these for control of potato blight are the acylalanine fungicides such as metalaxyl and furalaxyl. They act specifically on the RNA polymerase of *Phytophthora* and closely related fungi. However, resistance to them can develop quickly in the pathogen population – it requires only a single gene mutation leading to a minor change in the RNA polymerase molecule. In many parts of the world, *P. infestans* is now resistant to these fungicides. Other products used include the UK include Pencycuron, Mancozeb, Cymoxinal, Fluazinam and Fentin hydroxide;
- *Haulm destruction.* If *P. infestans* gets established on the potato foliage then sporangia can be washed down into the soil to infect the tubers, or the tubers can be contaminated with sporangia during crop harvesting. This can lead to rotting of the tubers during storage, and carry-over of inoculum from one season to the next. In order to minimise these problems it is common practice to destroy the foliage (the haulm) with sprays of sulphuric acid or herbicide 2-3 weeks before the tubers are lifted;
- *Resistance breeding.* The cultivated potato (*Solanum tuberosum*) originates from the Andean region of South America, where there are several other species of the genus *Solanum*. The potato blight fungus is also thought to have its centre of origin in this region and the species *Solanum demissum* proved to be an important source of resistance. By the 1940s/50s conventional plant breeding (crossing and back-crossing) bred this resistance into commercial potato cultivars. Four major resistant genes (termed R genes) were discovered and were introduced successively into commercial cultivars. However, within a few years of each R gene being introduced widely into potato cultivars, the fungus was found to be able to attack these plants – the resistance was overcome by new strains (termed physiologic races) of the pathogen that developed in response to the selection pressure imposed by the specific R genes. Thus, race 1 of the pathogen could cause disease of potato cultivars carrying the R1 gene, and so on. With four R genes there are a possible 16 combinations – you can breed potatoes with, for example, R1 and R2, or R1 and R4, or R1, R2, R3 and R4, etc. But eventually a pathogen race would emerge that had the corresponding virulence genes to overcome all these. For long-term control, this form of resistance breeding based on a few "major resistance genes" seems destined to fail. So, many plant breeders now prefer to develop cultivars that have "polygenic" or "field resistance" to the pathogen. Such plants have combinations of several "minor" genes, none of which gives absolute resistance, but together they slow the rate of development of the fungus and enable the plant to tolerate infection;

- *Emergence of new pathogenic strains through sexual crossing.* The continued genetic variation via recombination of the fungus continues to lead to emergence of new pathogenic variants. This continues to hinder all attempts to control this disease.

4.4.2.2 Costs of production

As highlighted above the market for potatoes is complex with processors seeking potatoes of specific quality for processing and the consumer demanding high quality potatoes for home consumption. Each market requires a different type of tuber, which can be produced using a different variety and production programme. The key types of production are:

- Maincrop “ware” or table production – largest outlet requiring heavy yield of saleable medium sized potatoes free from blemishes. Crop is lifted at full maturity;
- Earlies – planted and harvested early to exploit demand for new potatoes in early summer. The crop continues over the summer with prices falling as production increases;
- Potatoes for processing – generally grown under contract – crisping, chipping, dehydrated and canned potatoes each have specific characteristics in relation to size, shape, dry matter, reducing sugar content and starch.

The dynamic factors that influence potato production on the UK are water availability, varieties, nitrogen availability, weed control, pests and diseases. Table 27 below illustrates a range of costs for main crop, chipping and crisping potatoes.

Seed

Seed costs vary considerably depending upon the age of the variety and the seed rate. For main crop potatoes using the variety Estima at a seed rate of 3 tonnes/ha at £280/tonne compares with chipping potatoes using Maris Piper at a seed rate of 1.97 tonnes/ha at a seed cost of £180/tonne. The supply of potato varieties in the UK include domestically bred varieties and varieties bred in other countries; especially the Netherlands. Farmer-saved accounts for between 15-25% of the UK seed market.

Fertiliser

At current levels of application of between 220-250 kg/ha of nitrogen, 180 kg/ha of phosphates and 300 kg/ha of potassium optimum yield levels are obtained. High levels of nitrogen application do not typically result in higher yields. Fertiliser costs vary from £179-£191.30/ha.

Nematicides

Potato cyst nematodes limit the cultivation of potatoes to once every four to six years. As discussed above PCN can cause considerable crop losses and although growers use varieties with some tolerance to PCN they typically use a nematicide such as aldicarb which is soil applied. Current expenditure is between £235-£294/ha.

Insecticide

To limit crop losses most potato growers plant virus-free potato seed multiplied in aphid-free regions (aphids act as vectors for the spread of potato viruses). In addition growers use a limited quantity of aphicide such as pirimicarb during cropping.

Herbicide

Weeds are not a major problem in main crop potatoes with the crop producing a leaf canopy relatively quickly and growers ridging the crop which disturbs any weeds that may be present. The UK crop typically receives a single treatment of herbicide pre-emergent and one to remove the leaf material (haulm) before harvesting. Costs are around £63.90-£65.0/ha.

Fungicides

Although some varieties have some degree of resistance to potato blight the main control is by the use of fungicides. Growers take no risks with blight and typically make 4-6 applications of fungicides at a cost varying from £109.04/ha up to £152.14/ha.

Miscellaneous costs

These include the British Potato Council Levy of £36.50/ha and cost of marketing and bags at £7.00/tonne, equal to £306.60/ha.

No account has been made for irrigation, transport and storage costs in the gross margins presented in Table 27.

Table 27: Gross margins of UK potatoes 2001/2002 (£/ha)

	Velcourt main crop pre pack cold stored	ADAS main crop cv Estima	ADAS chipping potatoes cv Maris Piper	ADAS crisping potatoes cv Saturna
Yield: tonnes/ha	44	44	-	-
Price £/tonne	100	89	-	-
Total sales value/ha	4,400	3,878	-	-
Variable costs				
Seed	715	840	306	552
Fertiliser	179	191	181	188
Herbicides	65	64	64	64
Fungicides	145	152	109	111
Nematicides	235	294	294	294
Insecticides	16	16	16	16
Other sprays	109	4	8	4
Misc costs	253	307	36	36
Total variable costs	1,717	1,869	1,014	1,266
Gross margin	2,683	2,010	-	-

Source: Velcourt Group, ADAS

Wastage

As highlighted in Table 26 above 976,000 tonnes of potatoes are downgraded due to poor tuber size, diseases losses and damage. During storage tuber loose an estimated 5% of crop weight costing £14.3 million/year and 8% of the crop fails to meet size specification for the processing, pre-pack and baker market costing the industry £24 million/year.

4.4.3 Alternative production systems: organic potato production

The area of organic potatoes grown in the UK has increased from 2,081 ha in 2001 to 2,750 in 2002. This area represents about 1.9% of the UK area and 1.2% of UK production. A key driver for the organic potato sector is price from the retail sector for either early or ware potatoes. There is currently a very limited, if any, market for organic processing potatoes.

In the retail sector, high quality standards are required (largely based on visual characteristics) and as a result organic potatoes tend to suffer more than non organic potatoes in terms of the % of the crop downgraded/rejected. Prices have also fallen recently from £170-350/tonne for main crop potatoes and £400-600/tonne for earlies (Source Lampkin 2002) to £100-200/tonne and £200-

400/tonne respectively (Premium Crops 2003). Another feature of the market has been the influx of imports, attracted by the high prices, which has now contributed to falling prices. Largely as a result of this the UK market is now perceived to be over supplied and domestic growers are now advised to enter into a contract with a retailer to ensure a secure price rather than risk the variability of open market sales.

Yields vary depending upon water availability (rainfall & irrigation), place in rotation and quality (incidence of scab, splits, blight, skin blemishes, tuber size) which can downgrade a significant proportion of the harvested yield. Yields of between 60%-70% of conventional yields are possible resulting in a marketable yield of 25 tonnes/ha for main crop potatoes and 12 tonnes/ha for early potatoes. At £200/tonne the total revenue is £5,000/ha for main crop and £4,800/ha for early potatoes.

Gross margins based on £200/tonne and £400/tonne for main crop and earlies are projected to result in a gross margin of £3,212/ha and £3,035/ha respectively (Table 28).

Table 28: Projected organic potatoes gross margin 2002/03 (£/ha)

	Maincrop	Early
Marketable yield	25	12
Price	200	400
<i>Revenue</i>	5,000	4,800
Variable costs		
Seed	938	1,200
Fertiliser	50	50
Blight control	50	25
Weed control	44	44
Casual labour	621	381
BPC Levy	40	40
Haulm removal	20	0
Other	25	25
<i>Total variable costs</i>	1,788	1,765
Gross Margin	3,212	3,035

Note: Marketable yield is 70% of gross yield. No account of transport costs.

Source: Lampkin 2003.

Seed

The derogation on the use of non-organic seed ends at the end of 2003. Organic potato growers will therefore need to budget for purchasing organic seed that retails at a premium over conventional potato seed of around £150.00/tonne⁵¹. The high seed cost reflects the high costs of organic potato seed multiplication. Organic growers also need to select varieties that are high in resistance to blight and nematodes and establish rapidly to limit weed control costs. Seed costs in 2004 may therefore rise by over £100-155/ha from £938/ha to over £1038/ha.

Fertiliser

The main soil nutrients are provided by farm yard manure applied at a rate of 25 tonnes/ha. Lime is applied after potatoes to avoid scab. Potassium sulphate may also be applied on lighter soils (prior approval required).

⁵¹ Personal communication with Specialist Potatoes Limited 2003.

Crop protection

As indicated above, organic growers can use permitted copper preparations to control blight at a maximum rate of 8 kg copper/ha/year until the end of 2005. With the majority of organic potato growers using protective copper fungicides alternative strategies are being evaluated (Zarb et al 2002). Due to the aggressive nature of potato blight, satisfactory levels of control are unlikely to be achieved through improvements/development of just one component of the blight management strategy (Tamm et al 1999). Control systems for late blight in organic production therefore increasingly have to rely on the appropriate integration of different control strategies such as avoiding excessive crop nutrient supply, preventing incidence of primary inoculum sources and preventing tuber blight by early foliage removal. Average cost of these actions are £50/ha.

Weed control

Normal practice is to use chain harrows, ridgers or purpose built weeders ten days after planting. The number of passes depends on weed competition. Other practices include inter-row post-emergent weeding and flaming. Average cost of weed control is £44.00/ha.

Nematode control

The main methods of control are use of resistant varieties and seven year rotations. Recently converted organic ground not previously used for potatoes will usually be low in nematode levels.

4.4.4 GM developments in potato

During the 1990's considerable research was conducted by the public and private sector using biotechnological methods to understand the plant genetics of:

- Carbohydrate metabolism (targets improved quality);
- Fungal resistance;
- Virus resistance;
- Herbicide resistance;
- Metabolic change;
- Insect resistance;
- Marker gene development;
- Nematode resistance.

The main UK applicable example of GM potato research and development is nematode resistance. This is examined further in the sub-sections below (virus resistant and herbicide tolerant potatoes are also briefly considered). A more in depth examination of literature on the impact of this technology is presented in appendix 5. A general description of technical developments in GM potatoes (traits and trials) is also presented in Appendix 2.

4.4.4.1 GM potatoes: summary of international impact evidence

There is very little literature on the possible impact of GM potatoes in the UK context. GM technology developments of relevance to the UK are at least several years away and are still in the early stages of development (nematode resistance). Drawing on the limited literature, the technology may offer some farmers yield and quality improvements and may offer cost savings, most notably in reduced use of fungicides and insecticides. Applicability of the technology to the UK is discussed further in the sub-sections below.

4.4.4.2 Generic cost issues: technology costs

The impact on costs and profitability of any GM potato application will be affected by the cost of technology. The higher the cost, the lower the level of possible benefit is likely to be, and vice versa. As relevant technology applicable to the UK is at least several years away, no analysis is presented of possible different levels of cost.

4.4.4.3 Generic demand issues

Whether there is a market for GM potatoes and whether there is a price differential between GM and non GM potatoes are factors that may affect take up of the technology (see section 3 for more detailed discussion).

- a) In relation to whether there is a market for GM potatoes, the analysis presented in section 3, suggests that (based on perceptions of current consumer attitudes to GM crops) as a major share of potato usage is used for human food, this is likely to be a crop in which GM crop adoption will be potentially slow (relative to for example oilseed rape). Also, given the market-led rejection of the technology (virus resistant and herbicide tolerant potatoes) in the US in 2000/01, GM potatoes are not currently high up the priority list for commercialisation by the biotechnology companies and potato breeders. However, some potato use is for non food uses (eg, starch) where users are generally indifferent to the technological origin of potatoes – this is also the sector that is currently pursuing regulatory approval for potatoes containing a GM quality trait (potatoes with high amylopectin levels) which will add value to the potato starch used in the paper sector.
- b) Price differentials between GM and non GM potatoes may affect the profitability impact assessments made by farmers considering adoption. Such assessments should take into account the limited nature of current farm level price differentials between GM and non GM crops in general and that the price differential is not always in favour of non GM supplies.

4.4.4.4 Nematode resistant potatoes: possible impact in the UK

Transgenic resistance to potato cyst nematodes has been achieved but has yet to be commercially deployed. Several distinct approaches are under development. The strategy based on the expression of inhibitors (cystatins) targeted against nematode digestive cysteine proteinases is most advanced (eg, research at Leeds University). A series of small-scale UK field trials funded by SEERAD has demonstrated that expression of a cystatin in potato confers partial resistance to PCN on cv Desiree. These field trials together with containment glasshouse trials have established effective resistance against many nematode species (eg. PCN on potatoes $79 \pm 9\%$, *M. incognita* on rice $83 \pm 5\%$). Cystatins are highly biosafe; they are neither allergens nor toxins to mammals. Cystatins are present in common foods (maize and rice seeds; chicken egg white) and part of the normal diet of people in the UK. Cystatins are environmentally biosafe and they do not harm non-target insects such as aphids or leafhoppers when expressed constitutively in potato. In addition there is no evidence of adverse effects on aphid parasitoids. Promoters are available which restrict expression of the protein to the feeding sites of PCN, further supporting the biosafe use of cystatins. This approach results in minimal expression elsewhere in the plant including the tubers. Current work has established that expression of cystatins either constitutively or mainly at PCN feeding sites does not harm the soil microbial community or earthworms.

This demonstrates that it may be possible to develop a GM nematode resistant potato, however this research is still at a fairly fundamental level and is at least ten years away from possible commercialisation. We do not provide any analysis of possible impacts on the UK potato grower because there is no data ‘to work on’ from trials, as no field scale trials examining impacts on yields, costs of production etc have yet been established. The only relevant benchmarks to consider are that currently farmers spend an average of £235/ha-£294/ha on nematicides (this accounts for roughly 15% of total variable costs of production) and the main method of current control used (aldicarb) is scheduled for withdrawal from use post 2007.

4.4.4.5 Other GM potatoes: insect, virus resistant potatoes and herbicide tolerant potatoes: possible impact in the UK

These potential applications of GM potatoes in the UK are reviewed in appendices 2 and 5. GM potatoes have been marketed and consumed in the USA and Canada and have demonstrated the

opportunity for growers to reduce pesticide usage and costs. However, there is little prospect of these products coming to the market in the UK over the next few years because a) the original technology provider, Monsanto has withdrawn from the potato sector, b) Colorado Potato Beetle is not a problem in the UK, so there would be no market and c) weeds are not a major problem to UK potato growers (relative to nematodes, viruses and fungal diseases).

4.5 Forage maize

4.5.1 The importance of forage maize in the UK

The area of forage maize in the UK is about 100,000 hectares, having increased from about 20,000 ha in the early 1990s. The UK only grows 2,000 hectares of grain maize which includes sweet corn in the south of England.

Forage maize is an important crop to the UK dairy industry, providing about 1.2 million tonnes of dry matter, equal to 600,000 tonnes of wheat, to supplement livestock rations over the winter. Silage produced from forage maize is normally grown by individual farm enterprises for 'home' or local consumption, and usually for cattle feed. In dry conditions maize produces more forage than ryegrass and with the introduction of new varieties the crop may be grown on a wider scale if warm, dry summers become more common.

Maize has a different and more effective mechanism of photosynthesis from all other major crops in the UK which means that it is most effective at warm temperatures. In an average growing season in the UK, despite rapid advances in plant breeding, maize only just receives sufficient degree-days and solar radiation to produce viable yields. UK growers are therefore recommended not to grow the crop above 500 feet and not further north of Liverpool and Cheshire. The crop is vulnerable to adverse weather conditions in its establishment stages where cold weather can slow down establishment and allow weeds to become dominant.

A comparison of the total cost of producing forage for silage by growing forage maize relative to whole wheat forage (approx, 10,000 ha grown) and permanent pasture illustrates the economic importance of forage maize to the UK dairy industry (Table 29).

Table 29: A comparison of forage maize versus whole wheat and permanent pasture 2003 (£/ha)

	Forage Maize	Whole Wheat	Permanent Pasture ⁵²
Seed	111.15	49.40	0.00
Fertiliser	54.34	108.68	123.50
Sprays	66.69	123.5	7.41
Cultivation, spray, fertilizer spreading	123.50	140.79	0.00
Foraging and clamping	111.15	98.8	271.70
Total cost before IACS	466.83	521.17	402.61
IACS	-69.16	-239.59	0.00
Production cost with IACS	397.67	281.58	402.61
Fresh Weigh yield (t/ha)	37.05	29.64	24.70
Dry matter (%)	32%	35%	25%
Dry yield (t/ha)	11.86	10.37	6.18
DM Cost with IACS (£/t DM)	33.54	27.14	65.20

⁵² Assumes 3 cuts of silage and no value for late season grazing

DM cost with no IACS (£/t DM)	39.38	50.24	65.20
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Source: Kelly P (2003)

Approximately 80% of forage maize is grown on IACS land and is therefore eligible for arable area payments. The cost of producing one tonne of forage maize dry matter with IACS is around half the cost of permanent pasture at £33.54 compared with £65.20/tonne. Without IACS area payments forage maize is still very price competitive £39.38/tonne/dry matter (DM) compared with whole wheat at £50.25/tonne and permanent pasture at £65.20/tonne/DM. Whole wheat forage requires higher levels of fertilizer, crop protection products and application costs. Permanent pasture is more expensive as it requires three cuts of grass, harvesting and transportation, followed by three fertiliser applications to optimize grass production.

A comparison of the nutritional value of forage maize compared to grass silage and whole also illustrates the importance of the crop to the dairy farmer (Table 30). The data are typical values achieved over the last two years from dairy farmers in the South West. Quality varies depending upon growing conditions and climate. The average maize silage dry matter was 32% compared with 35% for whole wheat silage and 25% for grass silage. Metabolisable Energy (ME) levels are very similar with protein levels for forage maize and whole wheat being lower than grass silage. However, both forage maize and whole wheat also provide a good source of starch which is not available from grass silage.

Table 30: Nutritional values of forage crops

	Maize silage	Grass silage	Fermented whole wheat
DM%	23-44	17-45	30-50
ME (MJ/kg DM)	10.3-11.7	9.6-12.7	10.7-11.5
Protein %	6.5-10	9.5-17	5.5-11
Starch %	10-38	-	8-35

Source: Kelly (2003)

4.5.2 Conventional forage maize production⁵³

About 50% of the UK forage maize area is cultivated continuously for a 4-5 year period, the remainder is cultivated annually in rotation. The ground is usually ploughed to incorporate slurry and farm yard manure (FYM) with sowing at the end of April-early May. The grower has a wide selection of hybrid varieties to select forage maize best suited to the farm conditions and rotational constraints (for example follow-on planting of winter wheat).

Forage maize seed costs £111/ha compared with zero cost for permanent pasture. The growing of forage maize allows the dairy farmer the opportunity to utilize slurry and farm yard manure in early spring at a rate of between 20-50 tonnes/ha. The incorporation of FYM by ploughing into the soil/seed bed minimizes manure run-off which can occur when FYM is applied to permanent pasture. Typically the forage maize grower will apply one application of fertiliser to top-up the nutrient demands of the crop to optimize yield at £54.34/ha compared to three fertilizer applications on permanent pasture, after each cut, at a cost of £123.50/ha. Applying slurry and farm-yard manure for silage production on permanent pastures can also downgrade the silage with contamination.

To control weeds an estimated 95% of growers typically use an application of atrazine, which is a soil residual broad-spectrum herbicide, either pre- or post- emergent (the split is estimated at 50:50 rising to 70:30). Depending upon soil type, the incidence of difficult weeds such as black

⁵³ Source: Mostly from Kelly 2003, personal communication

knightshade, and the rate of establishment of a crop canopy, a second application of either pyridate or bromoxynil is made. A second application is estimated to be applied on 20%-40% of the crop area. To ensure good weed control without the need for a second application post emergent, about 20-30% of growers are using a single application (mixture) of two residual herbicides atrazine and pendimethalin.

4.5.3 Alternative productions systems: organic forage maize

The area of organic maize in the UK is estimated to be about 500 ha all of which is forage maize⁵⁴. The cost of production is estimated at £360/ha (excluding manure application) - £140/ha for contract harvesting, £135/ha for seed, £35/ha for mineral fertiliser and £50/ha for manual, mechanical and/or thermal weed control (Lampkin 2002). These costs are very similar to conventional forage maize with the exception of weed control where manual labour replaces the cost of herbicide and spray costs. Weed populations may become very high in early May resulting in high demands for labour and mechanical cultivation which may increase weeding costs considerably.

No details are available on yield but given that both organic and conventional systems use farm yard manure and slurry they may be very similar. However, organic growers are unlikely to use their farm yard manure on forage maize if it is required on other cereal crops for soil fertility building to maximize grain yields. The lack of availability of labour to control a flush of weeds in mid-late May could also result in lower yields.

4.5.4 GM developments in maize

During the 1990's considerable research was conducted by the public and private sector using biotechnological methods to understand the plant genetics of:

- Herbicide tolerance;
- Insect resistance;
- Male sterility /novel hybrids;
- Enzyme production and digestibility;
- Fungal resistance;
- Enhanced protein production;
- Abiotic stress resistance (drought tolerance);
- Carbohydrate metabolism (starch quality and content).

The main UK applicable example of GM maize research and development has been glufosinate tolerant forage maize. This is examined further in the sub sections below. A general description of GM developments in maize is given in appendix 2. Analysis of findings on the commercial impact of GM traits in maize (for herbicide tolerant grain maize and insect resistant maize) is presented in appendix 5.

4.5.4.1GM herbicide tolerant (to glufosinate) forage maize: summary of international impact evidence

We did not identify any published work on the possible impact of herbicide tolerant forage maize. (it is not currently commercially available to farmers and no trials data were identified). The analysis presented in sub section 4.5.4.4 draws on findings relating to the possible application of other glufosinate tolerant crops and examination of how the technology might apply to current practice.

⁵⁴ Soil Association "in April 2002 there was 500ha of organic maize being grown in the UK (from our 'Food and Farming Report 2002'). All of this land area would be producing maize for forage." Personal communication 2003

4.5.4.2 Generic cost issues: technology costs

The eventual impact on costs and profitability will be influenced by the cost of technology. The higher the cost, the lower the positive impact on returns and vice versa.

As we have not identified any research that has examined the possible impact and/or imputed a possible technology cost, this element of analysis has not been undertaken in sub section 4.5.4.4 (we have no basis on which to impute a possible cost).

4.5.4.3 Generic demand issues

Issues such as whether there is a market for GM forage maize and is there a price differential between GM and non GM forage maize may affect use of the technology.

- a) In relation to whether there is a market for GM forage maize, the analysis presented in section 3, suggests that because all of the crop is fed to livestock, there is likely to be a reasonable market for GM forage maize, even if GM (grain) maize and sweet corn were to be excluded from markets that service direct human food consumption.
- b) Price differentials between GM and non GM forage maize may, in theory, affect the profitability impact assessments made by farmers considering adoption. However, as the majority of the crop is consumed on-farm, the crop is not often traded, making this issue largely redundant in any assessment of whether to adopt or not.

4.5.4.4 Glufosinate tolerant forage maize: possible impact in the UK

a) The technology

A summary of the technology is presented in section 4.2.4.4. Drawing on the information presented in appendices 2 and 5, the possible impacts of using glufosinate tolerant forage maize to the UK grower include:

- Possible cost savings;
- Possible yield increases.

These are discussed further below.

b) Possible reduction in production costs

Current levels of herbicide expenditure in the UK are fairly low at an estimated £6/ha for a single application with atrazine plus £9/ha application cost. Where atrazine is used in combination with pendimethalin herbicide total costs rise to £24.81/ha plus an application cost of £9/ha (Table 31). Where a second, post emergent application with bromoxynil is applied after atrazine only, the total cost is £24.20/ha plus £18/ha for application costs. The range of current costs is therefore £15/ha to £42.2/ha. The likely cost under the glufosinate tolerant crop is either one application of glufosinate post-emergent which would cost the grower between £16-£21.44/ha plus an application cost of £9/ha (ie, total cost of £25/ha to £30.44/ha) rising to between £54-£60.88/ha for two applications based on 2 litres/ha (based on £8 to £10.77/litre for glufosinate).

However, the use of atrazine is becoming more restrictive and may be banned in the near future. A recent opinion by the EU Standing Committee on Plant Health in January 2003 did not accept some of the UK's calculations for predicted environmental concentrations of atrazine and its metabolites in groundwater and concluded that the available monitoring data does not demonstrate that concentrations of the active substance or its breakdown products will not exceed 0.1µg/l in groundwater. The future for atrazine in the UK therefore appears limited.

If atrazine were to be banned growers would need to select alternative herbicides which would increase cost. For example, if pendimethalin was used pre-emergent followed by bromoxynil post-

emergent the total herbicide cost would rise to £37.01/ha plus £18/ha for application costs (total costs of £55.01/ha). The glufosinate tolerant option would compare at anywhere between £25/ha and £61/ha.

On the basis of these costs, glufosinate tolerant forage maize would provide the largest cost savings on herbicide use for farmers who currently use two sprays and could revert to one application of glufosinate (also it would be attractive if atrazine were to be banned). Where farmers would need to use two applications of glufosinate the cost savings would be significantly reduced and may be marginal.

If glyphosate tolerant forage maize was used, the likely cost of herbicides would probably be in the range of £13/ha to £27/ha plus application costs of £9/ha-£18/ha (ie, total cost of £22/ha-£45/ha). This suggests that glyphosate tolerant forage maize would potentially be more attractive to farmers from a cost saving perspective.

The authors do however, highlight that this analysis is not based on trials results and the UK's Farm Scale Trials may provide more information on the dose rate and the number of treatments likely to be used. This analysis also takes no account of any seed premium/technology fee that would be charged for the herbicide tolerant crop.

Table 31: Herbicide expenditure on forage maize

Herbicide	Rate l/ha	Unit cost per litre	£/ha/application of herbicide (excluding application costs)
Atrazine	3.0	£2.00	£6.00
Pendimethalin	3.3	£5.70	£18.81
Bromoxynil (sometimes in mixture with prosulfuron)	2.0	£9.10	£18.20
Glufosinate-ammonium	2.0	£8-10.77	£16-21.44

Derived from various sources

c) Possible yield increases

The application of atrazine post-emergent can cause yellowing of the crop and is estimated to hold back the crop by 5-8 days. Pre-emergent application with soil residual herbicides may also slow down the rate of seed germination which reduces the total number of sunlight hours the crop absorbs solar energy and therefore crop yield. Detailed data is not available on this impact but the use of a post-emergent contact broad-spectrum herbicide, such as glufosinate-ammonium or glyphosate, that does not “knock-back” the plant and delay germination could increase yields by between 10% and 20%. A 10% increase in yield this would equate to an additional 1.19 tonnes of maize dry matter which costs £46.70 (based on £39.38/t X 1.19) to produce.

Given the limited nature of the possible cost saving benefit identified above (ie, for some farmers who currently only use one application of herbicide or in cases where the spray regime for the herbicide tolerant crop requires two applications), take up of this technology in forage maize will probably depend on its ability to deliver yield benefits to the levels suggested above. If it does not deliver reasonable yield gains then after taking into consideration a need to charge some form of technology fee or seed premium, the benefits to be derived by the UK forage maize farmer will be limited to only some farmers. It may necessitate a fairly low technology fee and/or be accompanied by a reduction in the herbicide price (eg, of glufosinate) to facilitate take up.

The reader should, however note that there is very little data available (eg, trials data) on the possible impact of herbicide tolerant forage maize (and none was supplied to us in the course of

this study, other than personal communications). The analysis presented above is therefore speculative and not based on empirical evidence of herbicide tolerant forage maize grown in the UK (or elsewhere).

4.6 Herbicide tolerant crops in the rotation

In the sections above, we have reviewed the possible impact and adoption of a number of herbicide tolerant crops in the UK. One point not examined in the crop-specific sections is the possible role of herbicide tolerant crops within the whole arable farm context. It is likely that farmers faced with the option of, for example herbicide tolerant wheat, oilseed rape and sugar beet would not choose to grow the varieties containing the same trait in all crops (eg, glyphosate tolerance in all three crops) but would use a mix of herbicide tolerant crops and conventional crops (eg, glyphosate tolerant sugar beet, glufosinate tolerant oilseed rape and conventional wheat). In this way this would contribute to minimizing the onset of weed resistance and problems of herbicide tolerant volunteers.

5 Impact on profitability: a case study (oilseed rape)

In this section, the analysis presented in the earlier sections has been drawn upon to suggest assumptions that the Strategy Unit of the Cabinet office might use for its quantitative analysis of the potential impact of GM crops on UK farming profitability. In essence this also acts as a form of summary and conclusions for a case study crop, applicable to the UK context.

The case study assumptions and boundaries suggested are presented as a table supported by notes relating to each assumption.

The summary table below provides an overview of the parameters that might be used by the Strategy Unit for its quantitative (spreadsheet) analysis of potential impact of GM technology on a case study crop. The GM crop and trait(s) suggested for undertaking the quantitative analysis is GM oilseed rape containing hybrid vigour derived from GM technology and herbicide tolerance (to glufosinate). This crop case study is suggested for the following reasons:

- Oilseed rape is an important arable crop in the UK, accounting for about 10% of the UK arable area⁵⁵;
- GM oilseed rape has been grown commercially in North America since 1996 and therefore there are studies and analysis available about the commercial impact of the technology;
- These are probably the first GM trait(s) that will be available commercially to UK farmers.

Table 32: Herbicide tolerant and GM hybrid winter oilseed rape

Issue/variable	Suggested boundaries for analysis
Likely date of commercial availability to UK farmers	2006-2008
Oilseed rape farm level prices: general	Forecast in five years time +8% relative to 2002/03 levels. Boundaries: no change to + 12%
GM versus non GM price differential	No difference. Boundaries: 3% in favour of GM (cleaner seed and higher oil content) to 3% in favour of non GM (sold into human food uses)
GM market potential	Likely no problem in finding outlets – major markets in non food use sectors (industrial oils, biofuels)
Baseline farm gross margins before assessing impact of technology:	Adjust for price changes (see above) and apply MTR changes to area payments (higher rate/tonne but modulation applicable to year to be examined – eg, 19% for 2013)
Impact of GM technology on yield	Assume +10%. Boundaries: +5% to +15%
Impact on total variable costs of production (excluding price of technology)	Assume no change. Boundaries: a saving of 5% to extra costs of 5%
Longer term possible implications (5-10 years after adoption) of weed shifts/resistance and volunteers	Amend impact on costs of production by 1% (ie, no change becomes +1%). Boundaries no change to total costs of production to +2%

⁵⁵ The only crops with greater shares of the arable area are wheat and barley. These are not selected as case studies because a) in the case of barley, there is no on going GM research that is likely to deliver GM traits in foreseeable future and b) in the case of wheat, GM products are at least several years away from possible commercialisation in the UK and there is very limited data available on possible impact

Other impacts: convenience, impact on rotation	Difficult to quantify. Assume no change (a conservative assumption). Boundaries: +1% to revenue to -1% to revenue
Co-existence implications and compliance requirements (on GM producers)	Assume additional costs involved for compliance audit requirements (eg, adherence to SCIMAC type guidelines) at +0.5% to variable costs. Boundaries zero to +1% on total variable costs
Co-existence implications for non GM producers	Assume zero provided that SCIMAC separation distances are complied with. Upper boundary: none suggested
Cost of technology to farmer	Assume +£15/ha on costs of production (or +60% on seed cost). Boundaries: = +10/ha to +20/ha

Notes

1. **Date of commercialisation**. This assumes the moratorium is lifted in late 2003 to late 2004 and allows time required to complete regulatory approvals process, seed trials and bulking of commercial quantities of seed. In total 3-5 years from 2003. See appendix 2 for further details.
2. **Oilseed rape farm level prices**. Prices in five years time based on forecasts for changes in world prices (ie, increasing from current historic low levels because of increases in global demand for oilseeds). See section 2.5 and appendix 1 for further details.
3. **Price differential between GM and non GM**. Range includes positive differential in favour of GM due to provision of cleaner seed (+1% to price) and higher oil content (+2% to price) to a small farm level premia for non GM (oil) material used in the human food sector. See section 4.2 and appendix 5. Net effect would be as follows, take current price = 100, add 8% for world price changes to 2008 and then either deduct 1% (to 7%) if GM oilseed rape sells at a premium or add 3%, if non GM oilseed rape trades at a premium
4. **Market potential for GM oilseed rape**. As the majority of oilseed rape is used in the non food sectors (industrial oils and animal feed), where there are lower levels of demand for non GM supplies (relative to the human food use sectors), it is not expected that there would be any significant problems in finding outlets for GM oilseed rape. See section 3.1 and appendix 3.
5. **Baseline gross margins before assessing the impact of GM technology**. The baseline data is for 2002 and is taken from section 4.2. These margins should then be adjusted to reflect changes in the assumed price (see above) and changes to the level of area payment that may arise from the Mid Term Review reform proposals (see section 2.3 and appendix 1).
6. **Impact of GM technology on yield**. Boundaries and average yield improvement assumptions are based on the reviews of impact literature in North America, Australia and UK-based trials. The UK based trials demonstrate the highest yield gains and therefore represent the upper boundaries used. The lower boundaries and average reflect findings from other countries, although given that some of this impact is related to herbicide tolerant oilseed rape without the benefit of the GM derived hybrid vigour, it is possible that the lower boundary may be a conservative figure (ie, the lower boundary could be a higher yield gain). See section 4.2 and appendix 5 for further details.
7. **Impact on total variable costs (excluding price of technology)**. Boundaries and average suggested based on the review of international literature (see appendix 5) and analysis of possible impact in the UK context (section 4.2).
8. **Longer term cost implications – possible development of weed resistance and volunteer problems**. This is a possibility to take into consideration for 5-10 years after adoption. The lower boundary suggested (no change) reflects the possibility of no impact on farm costs (ie, no problems with volunteers or resistance and/or the solution for addressing the problems do not incur additional costs). The average and upper boundaries reflect varying degrees of additional problems but in both cases add only marginal extra

costs. This reflects the existing practices for weed control on most farms whereby weeds problems (including existing problems with weed resistance and volunteers) are dealt with through the use of tank mixes of different herbicides. Any additional requirement to add another or different (possibly more expensive) herbicide will have limited impact. See section 4.2 and appendix 5.

9. **Other impacts such as convenience, impact on rotations** . Suggested boundaries are based on the international literature review (appendix 5) and are conservative. This reflects the limited nature of empirical evidence that has quantified these benefits. These are also often difficult to value.
10. **Co-existence ‘compliance’ costs for GM growers** . These assume that some form of guidelines for GM crops must be complied with (eg, SCIMAC) and that there may be costs involved in meeting these requirements. Given that most of the guideline requirements relate to good agricultural practice and the type of measure already undertaken as part of a quality assurance scheme (eg, Assured Combinable Crops Scheme), the additional costs will, on average be related to compliance audit costs only. The boundaries used are based on existing fees charged for membership of schemes for which independent inspection to confirm compliance of conditions is undertaken (see sections 3.3 and 4.2, and appendix 4). It is also possible that these inspections might be undertaken as part of the farm audits proposed in the Mid Term Review. If so, the costs involved might also be wholly, or partly covered from CAP funding.
11. **Co-existence ‘costs for non GM growers** . The zero cost assumes that the SCIMAC guidelines for separation distances are a condition of use (50 metres for non GM crops and 200 metres for organic crops). No upper boundary is suggested because these separation distances possibly have significant ‘margin for error’ built into them. For example, in Australia, co-existence is considered to be deliverable with non GM crops at a 5 metre separation distance and Ingram (2000) recommended that a 1.5 metre separation distance would ensure that a 1% tolerance for cross pollination could be met. Also, there is no empirical evidence available to suggest that adventitious presence of GM material in non GM crops will be a problem at these separation distances. See sections 3.3 and 4.2, and Appendix 4.6 (notably work by Rieger et al 2002).
12. **Cost of technology** . Boundaries used are based on a simple rule of thumb (see sections 4.1 and 4.2) that relates the cost charged for the technology relative to the possible farm level benefit. Commercial realities may differ significantly from this and therefore the cost of the technology could be higher or lower than the range suggested.

Appendix 1: Future policy and market environment likely to be faced by UK farmers

This appendix provides an overview of the likely direction of the parts of the Common Agricultural Policy (CAP) that have direct relevance to arable crop production in the UK together with discussion of other market and institutional factors that will affect UK arable crop farming.

The rationale for providing this discussion is to help frame the upper and lower bounds for the possible adoption and impact of GM crops in the UK that the Strategy Unit of the UK Cabinet Office is undertaking.

A 1.1 CAP policy

A 1.1.1 General

The foundation for the CAP in the next few years will be the nature of the regime set by Agenda 2000 plus what is ultimately agreed in respect of the provisions of the Mid Term Review (MTR) proposals of January 2003 (Com 2003, 23 Final). The policy context below assumes the MTR is adopted as proposed for cereals, oilseeds and pulses. Section 4.1.4 offers our views on the likely changes that may occur in sugar policy.

A 1.1.2 Cereals

Key support mechanisms relevant to the UK

- Intervention support prices for common wheat, barley and maize set at €5.35/tonne from 2004/05;
- Area payments payable on cereal crops based on relevant (existing) regional reference yields multiplied by €5.98/tonne less any penalties applied for overshooting maximum guaranteed areas;
- Degressive modulation of the above area payments will occur. All member states are required to modulate progressively at rates that vary according to the level of direct payments received. For farmers annually receiving under €5,000 per year, no direct aid reduction will apply, for farms receiving between €5,000 and €50,000 per year, cuts begin at 1% in 2006, increasing progressively to 12.5% by 2012 and for farms receiving over €50,000 in direct payments per year, the aid cuts applied will begin at 1% in 2006 and progressively rise to 19% by 2012. This modulation money is to be used to fund additional rural development measures;
- The base rate for set-aside is 10% - set for a minimum period of 10 years, is non rotational and known as environmental set-aside.

Changes implemented as a result of the Mid Term Review

- Reduction in the level of intervention price for wheat, barley and maize by 5% (based on the pre Agenda 2000 level) – the intervention price therefore falling from €101.31/tonne by €5.96/tonne to €5.35/tonne;
- Abolition of intervention for rye;
- Compulsory degressive modulation introduced on area payments – a possible 19% cut applicable on all farms receiving more than €50,000/year by 2012 (starting in 2006/07).

A 1.1.3 Oilseeds and protein crops

Key support mechanisms

- No provision of intervention support for any crops;
- Area payments payable on oilseeds (rapeseed, sunflower, soya, linseed/flax) and protein crops at the same rate as cereals for cereals (€65.98/tonne) and using cereal reference yields. Protein crops to receive an additional €9.5/tonne (set at €55.57/ha) supplement;
- Degressive modulation – see cereals above;
- The base rate for set-aside is 10% (see cereals).

Changes implemented as a result of the Mid Term Review

- Increase in area payments in line with cereals (as a result of the lowering of the cereal intervention support price);
- Removal of oilseed-specific maximum guaranteed areas (strictly speaking not part of the Mid Term Review but as a result of the alignment of oilseed area payments with cereal area payments⁵⁶);
- Set-aside land can no longer be used to grow oilseeds for energy (biofuel) crops – an additional aid (not crop-specific) of €15/ha is however available up to an EU maximum guaranteed area of 1.5 million hectares for plantings on non set-aside land;
- Compulsory adoption of degressive modulation – see cereals.

A 1.1.4 Other crops

Although strictly falling outside the Mid Term Review, the sugar regime is likely to have begun implementation of reforms in the next few years. Proposals for reform are likely to be proposed in July 2003 (after the Mid Term Review has been agreed) and will be scheduled for implementation from 2006/07 onwards. In the sugar sector, the reforms are likely to result in (these are personal views expressed by the authors):

- Cuts in the A and B production quotas possibly equal to 5% per year over a five year period to 2011/12;
- A 30% cut in the intervention support price for sugar and the minimum prices paid to farmers for A & B sugar – to be implemented over the same five year period. For example, the A Quota price paid to farmers would fall from €47.01/tonne (current) to €32.91/tonne in 2010/11;
- provision of direct (area) payment compensation for these support price cuts phased in over 5 years based on a target of the cereal rate (proposed at €66/tonne but currently €63/tonne) payable at the cereal reference yield. Based on average EU sugar beet and cereal yields the provision of area payments would be roughly equal to 48% compensation for the cuts in price support;
- eligibility to plant sugar for non food (biofuel) purposes.

As Agenda 2000 has effectively set the area payment rate at a uniform level for most arable crops (supplements for durum wheat, rice and protein crops excepted), the MTR proposes to decouple direct payments and to make as a condition for receipt of payment, compliance with mandatory environmental standards (based on respect of statutory 'good' management practices). Details of how these elements of support delivery administration may work have not yet been put forward.

Overall, the measures proposed in the MTR will, if adopted, move more of the agricultural budget out of commodity-based support (known as market measures and direct payments) and into rural

⁵⁶ The EU Commission assumes that the alignment of the cereal and oilseed area payments frees the EU from its Blair House obligations to limit support to the oilseed sector, as limited by the oilseed-specific MGAs. It is assumed that this is not challenged by the US government.

development. Potentially this should make additional provision of funds for agri-environmental and organic development measures at the national and local level according to national and regional priorities. However, the bulk of agricultural support payments will continue after the MTR to be based on market measures/direct payments. Thus in the 2003 EU agricultural budget of about 45 billion euros, 90% was accounted for by market measures and direct payments. This share would fall, if the MTR proposals are adopted, to about 87%-88%.

A 1.2 Trade environment

There are three key trade environment issues of relevance:

- a) *EU accession of possibly 10 new members in 2004*: countries such as Hungary and especially Poland have significant agricultural sectors and, in general, their respective agricultural sectors operate to a lower average cost base than counterparts in the EU. An almost inevitable consequence of the EU expanding to 25 countries will be increased levels of competition within the enlarged market.
- b) *WTO – the Millennium Round*. It is uncertain when this Round will be finalised and agreed for implementation. A reasonable suggestion is implementation from (July) 2005/06. All measures agreed are likely to be implemented over a six year implementation period (as was the Uruguay Round). For the purposes of this project the most important and relevant provisions we assume are likely to be agreed are:
 - A further cut in the value and volume of mainstream commodities on which export subsidies can be paid each year (total elimination is a possible outcome). These cuts to be made relative to the original base used in the Uruguay Round Agreement. Additional provisions to limit the use of export credit/guarantees, the provision of exports as food aid and activities of State Trading Enterprises are also likely to be agreed;
 - A further cut (base = the origin bases used for the Uruguay Round) in the level of import duties. In cereals this is not likely to have a major impact because of the mechanism and level of duties applied in recent years and the volume of import free or reduced duty cereals that can enter the EU. In five years time, the EU is likely to be importing broadly similar volumes of cereals as in 2002/03 and any further import duty cuts agreed in the next WTO are unlikely to have a significant impact on EU cereal markets – the same will apply to oilseeds which effectively trade at world market prices already and which are subject to zero import duties currently. Therefore this measure has most relevance to the sugar sector (see also c) below);
 - A commitment to further reduce the level of Aggregate Measurement of Support (AMS);
 - Probable retention of the designation of ‘Blue box’⁵⁷ for direct payment support measures (ie, the direct payments mechanisms that now form an integral part of the CAP) or classification of degressive modulation as ‘Green Box’. Either way this would mean that these support measures will continue ‘not to count’ against AMS reduction commitments. However, countries like the EU retaining such measures will commit to reduce the level of support to Blue Box measures over the period of implementation of the Round (probably an agreement to reduce by

⁵⁷ Blue Box payments do not currently ‘count’ against the requirements to reduce AMS. The main classification of Blue Box payments are the direct payments paid in the EU and these are being targeted by some WTO partners for re-classification as Amber Box payments which would count against AMS calculations. Green box payments, mainly relate to what are sometimes referred to as production neutral support mechanisms (including notably agri-environmental schemes) and do not count against AMS calculations

15%-20% to 2012) in line with the degressive modulation provisions in the Mid Term Review.

- c) *Everything but Arms Agreement*. This agreement will have a major influence on the EU sugar market because it will, by the marketing year 2009/10, permit the duty-free importation of sugar into the EU from the 48 least developed countries of the world. In the interim period, starting in 2001-02, a duty/tariff-free quota (starting at about 197,000 tonnes of sugar and rising by 15% per year) has been established for sugar imports from these countries and starting in 2006-07, the 'generally applicable' import duty on sugar from these countries is to be reduced in successive stages of 30% in 2006-07, 50% in 2007/08, 80% in 2008/09, culminating in duty-free access in 2009/10.

A 1.3 Prices

Table 33 summarises our price projections for key arable crops grown in the EU in five years time based on a combination of market forecasts (eg, USDA, European Commission) and forecasts of changes to the EU support mechanisms, where these play an important role in influencing internal EU price levels (notably for sugar). The following assumptions have been made:

- The €to \$ exchange rate is assumed to be parity (ie, it has fluctuated significantly over the last year but is assumed to be parity largely for simplification of the analysis);
- The US Farm Bill of 2002 (the Farm Security and Rural Investment Act - FSRIA) sets the base for US support prices operating in 2008. In turn, as the US is a leading exporter of wheat, maize, barley and soybeans, these support prices have an impact on world prices. In sum, the 2002 US Farm Bill is likely to result in support levels for cereals grown in the US rising relative to the level of support for soybeans. It is assumed that this will contribute to US plantings and production of cereals being higher than otherwise and plantings/production of soybeans being lower than otherwise (ie, if the pre-2002 Farm Bill support regime operated). In turn these changes to production will contribute negatively on world prices for cereals and positively on world prices for soybeans⁵⁸;
- EU proposals for requirements on the share of bio-fuels in total fuel usage are assumed to be largely adopted 'as proposed' in 2001 but not on a compulsory basis. This is assumed to boost demand for oilseeds, notably rapeseed and provide a small, positive contribution to internal EU oilseed prices;
- Intervention for rye is abolished so that intervention is no longer an attractive and regular 'target' market for farmers – this will contribute to a significant fall in internal EU prices for rye;
- The sugar regime is finally subjected to reform and support prices are to be reduced by 30% over a five year period starting in 2006/07.

Table 33: Forecast farm level market prices in five years time (2008) - % differences relative to 2001/2002 prices

Crop	EU 15 countries
Soft wheat	0
Feed barley	-1
Grain maize	+1
Rye	-15
Oilseed rape	+8
Sugar beet	-18

⁵⁸ US domestic policy changes will affect the world markets for wheat, barley, maize and soybeans (and other oilseeds) because of the importance of the US as a global exporter of these commodities

Note; All changes take into account forecast changes in world prices, implementation of the Mid Term Review, EU accession effectively from 1.1.2005 and sugar reform implemented from 2006/07

A 1.4 Biofuels

The EU Commission put forward a proposal in 2001 that, if adopted, will require all Member States to target biofuels accounting for 2% of total petrol and diesel used by road transport in 2005. This share of the fuel market is expected to rise by 0.75% per year up to 5.75% in 2010. In 2008/09, the requirement would be 4.25% of total road transport fuel derived from biofuel sources.

To achieve these goals, a number of measures are proposed (notably the provision of tax incentives), including the 'encouragement' of the EU agricultural sector to grow suitable crops for the manufacture of biodiesel (sugar beet, cereals (notably maize) and oilseeds (notably rapeseed). The MTR proposes an energy crop supplement payable of €45/hectare. As such, these measures are likely to encourage additional plantings of suitable arable crops.

Appendix 2: GM technology developments in arable crops of relevance to the UK

A 2.1 Oilseed rape

Rapeseed (*Brassica napus*) has a diploid chromosome number of 38 and is self-fertile, with about 80% of the seed arising from self-pollination. Historically, breeding programmes have emphasised recurrent and mass selection for particular agronomic or biochemical traits. Crosses among the various *Brassica* species have been widely used to broaden the genetic base. Over the last ten years breeders have introduced top cross, restored and composite (variety associations) hybrids. The first successful composite hybrid was introduced onto the UK market in 1996 and the restored hybrids from 1997. Hybrids have been moderately successful and now account for 12 out of 23 varieties on the UK Recommended List, but only account for 20% of the UK crop area as farmers prefer to have the option of farmer-saved seed which is not possible with hybrids. The conventional variety Winner introduced in 2002 is very competitive with hybrids and has the added advantage that farmers can produce farmer saved seed.

The typical period to breed a new variety is three to five years from the initial cross to entering official list trials. National List trials and multiplication will require an additional three years. When introducing a new gene using genetic transformation a breeder will require an additional two to four years to allow for gene stability and expression testing and field evaluation before back-crossing or pedigree breeding to produce a new variety. The cumulative time period from initial gene insertion to the commercial grower is therefore between eight and ten years.

The introduction of hybrids has made the oilseed seed market more attractive to plant breeders, although with an estimated EU farm level retail value of about €135 million, it is equal to only 10%-12% of the EU maize seed market (and hence is a less attractive market to seed companies). Historically individual varieties have obtained substantial market shares and have remained competitive over several years. However, with the introduction of hybrids there is now a quicker turnover of varieties, resulting in lower market shares and variety-life.

By far the most important agronomic trait under development in the EU has been herbicide tolerance, followed by the development of novel hybrid rape (Table 34). The main herbicide tolerance traits have been glufosinate followed by glyphosate and to a very limited extent, oxynil. Work on fungal resistance and lipid metabolism has remained at a fundamental level with no serious effort to develop commercial GM varieties in Europe.

The rapid slow down in new trials across Europe in 2001 and 2002 has resulted in a near termination of GM oilseed rape development. Bayer CropScience are persevering with their glufosinate and novel hybrid technology but they have also withdrawn from a number of trials. Monsanto are currently not requesting approval for cultivation of their glyphosate tolerant oilseed rape in Europe (Table 35).

Table 34: Oilseed rape traits trialed in the EU 1998-2002

<i>Trait</i>	<i>Total</i>
Herbicide tolerance	97
Male sterility	39
Fungal resistance	13
Lipid metabolism	11
Development	10
Metabolic change	7

Marker gene	3
Fruit ripening	2
Insect resistance	2
Carbohydrate metabolism	1
Protein production	1
Total traits	186
Total trials	125

Source: PG Economics

Table 35: Oilseed submission under 2001/18 Part C (as at 17 February 2003)

GM trait	GM Event/Applicant/Use
Glyphosate tolerance	Monsanto: GT73 – import and food use but not for cultivation in Europe
Seedlink InVigor hybrid + glufosinate	Bayer CropScience: Ms8 x Rf3. Import, use and cultivation
Glufosinate tolerant	Bayer CropScience: T45 Import and use only
Glufosinate tolerant Falcon	Bayer CropScience: GS40/90pHoe6/Ac. Import, use & cultivation
Glufosinate tolerant Liberator	Bayer CropScience: Liberator pHoe6/Ac Import, use & cultivation

Source: EU JRC

In 1994 the UK considered GM rape known as 'MS1RF1' tolerant to the broad spectrum herbicide 'Liberty' (glufosinate ammonium) and producing hybrid seed, from the company PGS (now Bayer CropScience) in an application for a Part C approval under Directive 90/220 for seed production. After due consideration and agreement by member states, the UK issued consent in 1996. A further application under Part C was made through the French Authorities for general cultivation and animal feed. Approval was given by most member states in 1997, although the French Authorities did not issue the consent. UK National List seed trials for a variety of this rape were complete and the oil is approved for food use. The moratorium, however blocked the final approval of this line. It has subsequently been superseded by MS8RF3, which does not use an ARM (antibiotic resistance marker).

In October 1998 MS8FR3 was in the final stages of the Part C process and National List trials in the UK. However, concerns about the environmental impact resulted in the Event being blocked by the moratorium. It is not known if the varieties developed back in 1998 are of limited commercial value today as they would have been incorporated into parental lines which have subsequently been superseded by other hybrid and conventional varieties.

Bayer CropScience has branded its novel male sterility + glufosinate "InVigor" hybrid rape. Commercial material is marketed in the USA and Canada, and Bayer CropScience is seeking approval in Australia. To coordinate its global marketing strategy Bayer CropScience is planning to use the MS8xRF3 Event in all new varieties. By February 2003, Bayer had applied for import, use and cultivation for Event Ms8 X Rf3 (which has superseded the old event Ms1 X Rf2 which used an antibiotic marker). Bayer CropScience is also seeking import, use and cultivation approval for glufosinate tolerant oilseed rape using Event pHoe6/AC.

It is worthy of note that Monsanto has not yet submitted an application for cultivation of glyphosate tolerant oilseed rape in the EU, only for import and use. This may be a commercial decision, which takes into consideration glyphosate's use as an oilseed rape desiccant and the need to remove volunteers (possibly glufosinate tolerant) in the oilseed rape-wheat crop rotation.

A.2.2 Sugar beet

Almost all sugar beet seed used in the UK is now genetic mono-germ. Varieties are hybrids (either diploid or triploid) and a complex system of male sterile and restorer lines is used to produce seed. Plant breeders usually maintain close control of parental lines and seed production.

Using conventional techniques, the development of new sugar beet varieties requires 10-12 years from the initial cross to commercial release. This time period can be shortened by two to three years by producing two generations a year in greenhouses and bulking up large quantities of seed prior to acquiring official recommendation on national lists.

GM traits can be incorporated into elite parental lines by back-crossing, entering into field trial evaluations and comparisons with other hybrid combinations. With official national list trials taking an average of three years in Europe it is estimated that, from initial transformation to variety release, takes six to nine years.

By far the most important agronomic trait under development has been herbicide tolerance (Table 36). The main herbicide tolerance traits have been glyphosate followed by glufosinate. Work on other traits has been of a fundamental nature with no serious effort to develop commercial GM varieties.

The rapid slow down in new trials in 2001 and 2002 has resulted in a near termination of GM sugar beet development.

Table 36: Sugar beet traits trialed in the EU 1998-2002

Trait	Total
Herbicide tolerance	109
Virus resistance	15
Marker gene	9
Fungal resistance	3
Carbohydrate metabolism	2
Male sterility	2
Stress resistance	2
Insect resistance	2
Nitrate metabolism	1
Total traits	145
Total trials	119

Source: PG Economics

An application from Monsanto to market GM fodder beet tolerant to the herbicide 'Round-up' (glyphosate), was made through the Danish Authorities in 1997. Both GM herbicide tolerant sugar beet and fodder beet have also been extensively trialed in the UK, France and Denmark. The moratorium resulted in EU product approval (Part C) for commercial cultivation for glyphosate tolerant sugar beet being stalled in early 1999. Monsanto also applied for novel foods approval for foods and food ingredients derived from Roundup Ready sugar beet. The initial assessment report is still pending.

Monsanto have also worked closely with sugar beet breeders who have incorporated glyphosate tolerance into their elite germplasm. The submissions that have been made by Monsanto in collaboration with Syngenta and KWS are for import, use and cultivation and relate to Events H7-1 and T9100152.

Table 37: Sugar beet - EU regulatory status (as at 17 February 2003)

Trait	Regulatory approval date
90/220 <i>Environmental release</i>	
<i>Pending (Part C)</i>	
Glyphosate tolerance/fodder beet	Monsanto/DLF/Danisco - 1998 Production of seeds and roots, animal feed (Stage 5 of Part C)
258/97 <i>Novel foods</i>	
<i>Pending</i>	
Glyphosate tolerance	Monsanto – Foods and food ingredients
2001/18 <i>Part C</i>	
Glyphosate tolerant (RoundupReady)	Monsanto - T9100152. Import, use & cultivation
Glyphosate tolerant (RoundupReady)	KWS SAAT, Monsanto H7-1 Import, use & cultivation

A.2.3 Potato

Genetic transformation of potato is relatively straight forward, although the time required to breed new varieties and multiply commercial quantities of potato seed is extensive and expensive. Traditional potato breeding requires 12 to 15 years and due to the inability to back-cross breeding lines to remove undesirable effects the advent of genetic engineering offers the breeder an attractive technical proposition as an additional tool. The Netherlands and the UK are the main breeders and multipliers of potato seed in Europe due mainly to climate, location and infrastructure.

In the 1990's the technology providers were working with breeders with established varieties and adding single/multiple gene Events. The time from transformation to the market, including trials and seed multiplication, is in the region of 10 years.

Breeders earn royalties based on the area of seed certified and seed retailers on margins resulting from the contracting of seed multiplication and sale to farmers. Co-operatives play a major role in the seed trade across the EU. There are also a large number of small 'hobby' breeders. Single varieties can be successful and dominate the market (eg, Bintje in the Netherlands for French fries).

By far the most important agronomic trait under development in Europe has been alterations to carbohydrate metabolism. The two main targets have been high amylopectin potatoes and improved processing potatoes. Other traits have been evaluated but none seriously for the development of commercial varieties (Table 38).

As the potato is a good model crop for the molecular biologist it was used extensively in the early 1990s to evaluate GM technology (eg, for virus resistance using coat protein technology). However, with the development of robust gene transformation and regeneration protocols in other crops and the imposition of the moratorium, the number of field trials has fallen at the same rate as trials for maize, oilseed rape or sugar beet.

Table 38: Potato traits trialed in the EU 1998-2002

Trait	Total
Carbohydrate metabolism (targets improved processing quality)	53
Fungal resistance	10
Virus resistance	9
Metabolic change	8

Insect resistance	4
Marker gene	4
Development	3
Nematode resistance	3
Bacteria resistance	2
Inducible gene expression	2
Nitrate metabolism	2
Amino acid metabolism	1
Stress resistance	1
Total traits	102
Total trials	95

Source: PG Economics

Three major companies account for 38 out of 95 trials, the remaining 57 trials being conducted by 32 different organisations, of which 38 trials were conducted by public organisations (eg, universities, institutes undertaking fundamental research).

Table 39: Potato - organizations involved in EU field trials 1998-2002

	Total
Bayer CropScience	15
Syngenta	13
Amylogene HB, Svalöf Weibull AB / BASF	10
Max-Planck	8
IPK Gatersleben	5
INRA	4
Advanced Technologies Limited	3
Swedish University of Agricultural Sciences	3
BBA	2
BZK	2
Danisco Biotechnology	2
Germicopa S.A.	2
Metapontum Agrobios Srl	2
Scottish Crop Research Institute	2
Technische Universität München	2
CIMA	1
AVEBE Research & Development	1
Bioplant, Biotechnologisches Forschungslabor GmbH	1
Boreal Plant Breeding Ltd.	1
Coöperative Telervereniging voor de Afzet van Landbouwproducten "De Z.P.C." B.A.	1
DLF-Trifolium A/S	1
Eberhard-Karls-Universität Tübingen	1
Georg-August-Universität Göttingen	1
GSF-Forschungszentrum für Umwelt und Gesundheit GmbH	1
HZPC Holland BV	1
Instituto de Tecnologia Quirrica e Biológica	1

Instituto of Sustainable Agriculture	1
Monsanto Company	1
Plant Research International BV	1
PlanTec Biotechnologie GmbH	1
Solavista GmbH & CO KG	1
The National Institute of Agricultural Botany	1
Universitat Pública de Navarra	1
Universität Hohenheim	1
University of Leeds	1
Total	95

Source: PG Economics

Although there have been a large number of field trials only one submission has been made by Amylogene under Part C of 90/220 for industrial starch varieties with altered starch (high amylopectin) composition. In July 2002 this application obtained a favourable opinion from the EU Scientific Committee. In February 2003 the company re-submitted under the requirements of the amended Directive 2001/18. No submission has been made under the Novel Foods Directive as the extracted starch will be identity preserved and used only in the paper industry.

Table 40: Potato - European regulatory status (at 17 February 2003)

Trait	Regulatory approval date
90/220 Environmental release	Pending Part C
Altered starch composition	Amylogene – 2002 (Part C Stage 5)
2001/18 Part C	
Altered starch composition	EH92-527-1 Amylogene. Industrial use, cultivation

A 2.4 Maize

Maize is a cross-pollinated crop that can be easily controlled by breeders to produce hybrids. The simple process of flower or silk removal is the basic principle behind the development of hybrid maize. Breeders develop parental lines which, when crossed, produce hybrid seed. The technique is labour intensive but the increase in crop yields is considerable (a multiple of 3-4 compared to non-hybrids). The time from initial cross to commercial release can take several years, but with higher multiplication rates and detailed information on parental lines it is possible to introduce a new variety in 4-6 years, though normally the expected time period is 7-9 years.

In addition to this period is the time to undertake gene transformation and expression trials required to get a foreign gene stably introduced into elite breeding germplasm that can then be used in a variety development programme. From initial gene transformation to the commercial farmer can therefore take between 7-10 years.

The EU maize seed market (including forage maize) is estimated to be worth around €1,200-€1,300 million and is characterised by relatively high margins on seed sales. It is highly competitive with many organizations working with seed multipliers and distributors to introduce new and improved varieties. For example, in France there are hundreds of varieties listed and between 50-100 new varieties launched each year. The commercial life of a variety is therefore very short (5-7 years) with new varieties offering slightly better characteristics (eg, yield, time of flowering/harvest, disease tolerance, drying costs, stem content). Given these dynamics and the need to develop varieties for different locations no single variety can usually expect to obtain greater than 2%-4% market share.

An overview of the importance of different traits can be summarised by analysing the EU's SNIF database of GM field trial applications. Using each reference as a single trial (eg, herbicide tolerance and insect resistance are listed as two separate traits) there have been 290 traits trialed over 218 separate trials between 1998 and 2002.

Herbicide tolerance and insect resistance dominate, accounting for 52% (153 trials) and 35% (103 trials) respectively of the European maize traits evaluated in field trials. The dominant herbicides are glyphosate and glufosinate. The other traits of importance with near term prospects are novel male sterility being developed by BioGemma (Limagrain) and improvements in digestibility.

Table 41: Maize traits trialed in the EU 1998-2002

Trait	Number of trials
Herbicide tolerance	153
Insect resistance	103
Male sterility	7
Metabolic change	5
Enzyme production	4
Fungal resistance	4
Protein production	4
Stress resistance	4
Carbohydrate metabolism	2
Endotoxin expression	1
Frost tolerance	1
Marker gene elimination	1
Virus resistance	1
Total traits	290
Total trials	218

Source: PG Economics

Table 42 below lists 35 organizations that have undertaken the 218 GM maize trials across Europe in the 1998-2002 period. The major players are Monsanto, DuPont, Syngenta, Limagrain and Bayer CropScience. The two lead technology providers Monsanto (Glyphosate) and Bayer CropScience (Glufosinate) have worked closely with the lead breeders to maximise the possibility of getting their traits incorporated into a range of varieties required for the different agronomic conditions across the maize growing regions of Europe.

Monsanto has been concentrating its 'collaborative' efforts with the leading French maize breeders – Limagrain, Coop de Pau, Maisadour and Syngenta which account for around 40% of the seed market. Bayer CropScience has agreements with Pioneer, Syngenta, Limagrain and other maize breeders across Europe.

The importance of the relationship between the technology providers and the breeders cannot be under estimated, as without it, the technology provider will not obtain the breadth of exposure in the germplasm base to obtain good market penetration.

Table 42: Maize - organizations involved in EU field trials 1998-2002

Applicant	Total
Monsanto	45
Du Pont/Pioneer	33
Syngenta	33

Limagrain	22
Bayer CropScience	21
Meristem Therapeutics	6
Asgrow	5
RAGT	5
Association Générale des Producteurs de Mais (A.G.P.M.)	4
Dow	4
EMILSEMA	4
Instituto Sperimentale per la Cerealicoltura-Sezione di Bergamo	4
Maisadour	4
SENASA	3
Agrar Semillas S.A.	2
KWS	2
Pau-Euralis	2
Verneuil Semences	2
Consiglio Nazionale delle Ricerche	1
Coop de Pau	1
GEVES	1
Hellaseed S.A.	1
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria	1
CNR Istituto per lo Studio degli Ecosistemi,	1
Istituto Sperimentale per la Patologia Vegetale di Roma	1
JP Sampoux Pau Semences (Groupe Pau Euralis)	1
Koipesol Semillas, S.A.	1
Mai's Angevin	1
ORSEM Hybrides	1
Pausemences Avenue Gaston Phoebus - BP29 -	1
Rustica Prograin Genetique	1
SDME	1
Selia	1
Seminis Vegetable Seeds Iberica S.A.	1
Universität Hohenheim, Institut für Phytomedizin	1
Total	218

Before the moratorium was imposed the technology providers and breeders were rapidly advancing the commercialisation of GM maize in Europe. Table 43 below illustrates the breeders and traits that are the subject of EU environmental and market release regulations.

Due to the moratorium and the introduction of the Novel Foods Regulation (EC) 258/97 only one maize line developed by Syngenta – Bt-176 – obtained full environmental and marketing approval and is currently marketed in Spain. In addition, in 1995 Bayer CropScience (AgrEvo) applied through the French Competent Authorities for EU-wide product (Part C) approval for import, cultivation and animal feed use for T25 maize tolerant to the herbicide glufosinate ammonium (trade name 'Liberty'). After due consideration by member states consent was granted by the French in August 1998. However this variety has yet to be marketed as it has not been entered on the EU Common Catalogue.

The introduction of the Novel Foods Regulation resulted in the other GM maize lines pending approval and waiting for the lifting of the moratorium. The majority of which have been withdrawn due to the elapsing of time and the need to remove antibiotic resistant markers (ARMs).

As of the 17th February 2003 seven Events have been re-submitted and placed on the EU's JRC central database, although some other Events that were pending have been submitted to Competent Authorities by the 17th January 2003 but have not yet been forwarded to the Commission (eg, Bt 11 in maize, re-submitted in France).

Table 43: Maize - EU regulatory status

Trait	Event/Applicant/Regulatory approval/date
<i>90/220 Environmental release Approved</i>	
Glufosinate tolerance	T25 (Bayer) – 1998 – import & cultivation
Corn Borer resistance (Bt)	Bt-176 (Syngenta) – 1997 – import & cultivation Mon 810 (Monsanto) – 1998 – import & cultivation
Glufosinate + Corn Borer (Bt)	Bt-11 (Syngenta) – 1998 import and processing – no cultivation
<i>Pending (Part C)</i>	
Glyphosate tolerance	GA 21 (Monsanto) 2000 (Stage 5 of Part C)
Corn Borer resistance (Bt)	MON 809 (Pioneer) 1998 (Stage 6 of Part C)
Glufosinate tolerance + Corn Borer resistance (Bt)	Bt-11 (Syngenta) 2000 (cultivation only) (Stage 4 of Part C) T25 + MON810 (DuPont/Pioneer) 1999 (Stage 4 of Part C)
<i>258/97 Novel foods Pending</i>	
Glyphosate tolerance	GA 21 (Monsanto) – 2002
Corn Borer resistance (Bt)	Bt-11 (Syngenta) – 2002
MaisGard/Glyphosate	Monsanto – 2000
Glufosinate tolerance + Corn Borer resistance (Bt)	T25 + MON810 (DuPont/Pioneer) – 2000
Glyphosate tolerance	Line NK603 (Monsanto) 2001
<i>Notified as substantially equivalent to the Commission</i>	
Corn Borer resistance (Bt)	Mon 810 (Monsanto) – Food and food ingredients produced from maize 1998
Glufosinate tolerance	T25 (Bayer CropScience (AgrEvo)) – Starch and oil etc from maize
Corn Borer resistance (Bt)	Bt-11 (Syngenta) – food etc from maize
Corn Borer resistance (Bt)	Mon 809 (Pioneer) – food ingredients
<i>2001/18 Part C</i>	
Glyphosate tolerance	NK603 (Monsanto) – import & use only
Glyphosate tolerance + Bt	NK603 + mon810 (Monsanto) – import for all maize uses (no EU cultivation)
Insect resistant (Bt) & glufosinate tolerant	Event 1507, Pioneer Hi-bred, Mycogen Seeds. Import & use only
Roundup Ready (glyphosate tolerant) & insect resistant (Bt)	Events GA21 & MON 810. Monsanto. Import and use only
Insect resistant (Bt) & glufosinate tolerant	Event 1507. Pioneer Hi-bred, Dow AgroSciences, Mycogen Seeds. Import, use and cultivation
RoundupReady (glyphosate tolerant)	Event GA21. Monsanto. Import & use only
Insect resistant (Bt)	Events MON 863, 810. Monsanto. Import & use only

Of the seven submissions only one is for cultivation in the EU, the other six cover Events that are/being developed in other countries. Event 1507 confers insect resistance and glufosinate tolerance and has been submitted by Pioneer, Dow and Mycogen. The same Event has also been submitted for import and use only.

In addition breeders need to demonstrate that any new varieties are suitable for agronomic use (VCU) and are distinct, uniform and stable (DUS). Breeders can submit new varieties to national authorities which will trial the lines against specific criteria over a two year period. If they are entered onto a National List they can then be placed on the European Common Catalogue for marketing across Europe. However, the moratorium has resulted in new GM varieties waiting for entry onto the European Common Catalogue. As considerable time has elapsed these varieties are unlikely to now be competitive and we are aware that seven have now been withdrawn.

In addition two Bt maize varieties 'Compa CB' and 'Jordi' developed by Syngenta are on the Spanish National List and one glufosinate tolerant line Chardon LL is on the Netherlands National List. However, all these varieties have not been placed on the European Common Catalogue because of the Moratorium.

The UK has also undertaken national list trials on two glufosinate lines developed by Syngenta 'Chardon LL' and 'Sheridan'. They are waiting to go onto the UK National List but are also held up by the moratorium. Before they are released onto the market they will need to be re-submitted under 2001/18 with extra information on post-marketing monitoring, labelling and agricultural impact.

Appendix 3: GM versus non GM derived crop product markets in the EU

This appendix examines the development of distinct markets for non GM derived product markets in the EU to date and their possible future development. The analysis focuses mainly on the markets where soybeans and derivatives are consumed and to a lesser extent on the market for maize. This is because these markets are the mainstream markets in which some GM derived crops and derivatives have been permitted for import and use in the EU and hence have been the focus of developments in recent years.

A3.1 The EU market for non GM soybeans and derivatives

A3.1.1 Background⁵⁹

Soybeans

- The EU produces about 1.1 to 1.2 million tonnes of soybeans (about 5% of total consumption). This is mostly found in Italy (70%) and France (26%);
- Imports in 2001 were about 17.35 million tonnes, up significantly on 2000 when the volume of imports was about 14.5 million tonnes. The EU exports negligible volumes of soybeans.

Soymeal

- In 2001 the EU used about 29 million tonnes of soymeal (28 million tonnes in 2000). In terms of supply availability, this is derived roughly 52% from imported meal and 48% from EU crushings. As with bean imports, the volume imported in 2001 was significantly up on 2000 when about 14.8 million tonnes were imported;
- The EU exports annually roughly 1.5 to 1.9 million tonnes of soymeal, mostly to adjacent countries in Central Europe.

Soyoil

- There are negligible imports of soyoil into the EU, with the vast majority of consumption (1.84 million tonnes) being derived from domestic crushings of beans;
- Exports of soyoil were about 1.1 million tonnes in 2001 – marginally higher than 2000 when 1.08 million tonnes were exported.

The UK uses about 0.19 million tonnes of soy oil and 2.11 million tonnes of soymeal (2001 usage data).

Soybean/meal supply

Soybean supply is dominated by Brazil and the USA, which in 2001 accounted for 9.5 million tonnes (55%) and 6.14 million tonnes (35%) respectively of total EU imports. The balance came from Argentina. In addition, domestic EU production accounted for about 6% of total supply availability or the equivalent of 7% of imports. A comparison with 1998-2000 shows that US exports have been within the 6 to 7 million tonnes range, whilst supplies from Brazil have risen significantly from about 5.5 million tonnes in 1998 to 9.5 million tonnes in 2001. In respect of the additional import volumes that have occurred since 2001 (post meat and bonemeal use ban), almost all of this has come from Brazil.

In relation to soybean meal imported directly into the EU (as distinct from the product of beans crushed in the EU), Brazil and Argentina account for the vast majority of imports with 49% and

⁵⁹ Base statistical sources include Oil World, Eurostat and USDA

46% respectively of total imports. The balance came mostly from the US and India with 3% and 0.5% respectively of total imports.

Both Brazil and Argentina have increased the volume of exports to the EU since 1998.

Overall, the EU used (2001) the equivalent of 35 million tonnes of soybean equivalents.

Uses

- About 0.2 million tonnes of wholebeans/roasted beans are used in food products and 1.5 to 1.8 million tonnes of beans are used in animal feed across the EU (mostly as full fat soy used in compound feeds);
- Refined soy oil is mostly used for food uses of which the main ones are margarine, shortenings and as a cooking oil. About 80% (1.47 million tonnes) of total EU soy oil (2001) is probably used in the food industry, about 10% (0.18 million tonnes) is used in animal feed and the balance of 10% used in industrial products;
- The primary use of all soybean (protein) meals is as a protein source in animal feed rations and about 95% plus of all soybean meal in the animal feed sector.

A 3.1.2 GM versus non GM market developments in soybeans and derivatives⁶⁰

GM versus non GM ingredient use in the human food sector

This largely began in 1998 and the initial focus was on the use of soybeans/derivatives in human food. Here the European food industry, largely driven by European retailers developed strategies based on:

- a) Where possible, switching to using alternative non GM derived ingredients (eg, the replacement of soy oil with sunflower or rapeseed oil). This was relatively easy for a number of food products like confectionery and ready meals, where soy ingredient incorporation levels were low (eg, 1%). Also in products like margarines and shortenings where least cost formulation principles are used, much of the soy oil used was replaced by rapeseed oil. Hence, the GM issue resulted in some switching away from soy derivative incorporation in food products even where the DNA/protein from GM soy could not be detected (eg, soy oil);
- b) If soy or derivative usage could not be readily replaced, non GM derived sources of supply were sought. This focused mainly on Brazil (but not exclusively) and involved the initiation of identity preserved (IP) supply lines (traditional supply lines use commodity based systems where there is broad mixing of seed in bulk for transportation) to ensure non GM derived supplies to customer-specific tolerances were adhered to. In turn this brought increasing attention to the issue of segregation/identity preservation (IP) and the associated costs. Probably 50%-80% of all soy oil used in the EU is currently derived from non GM beans. This does, however, not necessarily mean that all of the users specifically request that supplies are derived from non GM sources of supply.

Empirical evidence to date suggests the additional cost initially involved has been within a very broad range of as low as +2% to as high as +150% of the farm-gate price of soybeans. Over the last 2-3 years this has fallen and remained consistently in a range of 1% to 20%

Where IP sources of non GM derived soya were used, the supply chain (from farm and up to but not beyond food manufacturers) has largely absorbed any additional costs (of the IP trails). This

⁶⁰ The main references used for this section are Brookes (2001) and Brookes (2001a)

preparedness to do so has mainly occurred because soya ingredient incorporation in most human foods is very low (eg, less than 1% for soya lecithin in a chocolate bar) and hence any additional on-cost of obtaining non GM derived supplies has been small relative to total production costs. Also in the case of products like margarine the relative cost of switching to rapeoil was not significant in 1998/99, although in the last year, increases in the price of rapeoil relative to alternatives has probably made this move more difficult for the manufacturers of margarine and other soy oil based foods.

To date, the net effect at the consumer level has been no change in the price of end products.

GM versus non GM ingredient usage in the animal feed sector

Over the last 2-3 years, the focus of attention surrounding the markets for GM derived and non GM derived soybeans and meal, in the EU, has moved onto uses in the animal feed sector.

The market for non GM derived versus GM derived soybean meal in the European animal feed sector has, to date, largely followed the same route of the market associated with food uses (see above). Thus:

- Those demanding livestock products from animals fed a diet containing non GM derived protein material have focused on sourcing soymeal from countries that currently do not (legally) permit the planting of GM soy varieties. This has concentrated on Brazil and to a lesser extent other non GM sources such as India;
- Much of this demand has been based on the use of what is known as 'soft IP' systems, in which the non GM derived beans or meal have been sourced and certified as coming from non GM growing regions within Brazil (officially a non GM growing country), but are often not subject to testing verification procedures or are accompanied by guarantees/certification as to the precise non GM status (ie, no tolerance levels for possible contamination (adventitious or otherwise) is given by the supplier). Clearly the use of 'soft IP' systems⁶¹ have much lower levels of cost associated with them (2%-5% price differential) than 'hard IP' systems in which there is strict IP of non GM soybeans or meal from point of production through the supply chain, the setting of strict tolerance levels for adventitious presence of GM derived material (eg, 0.1%) and regular testing through the supply chain to ensure that supplies meet buyer specifications (average price differential in 2002-03 8%-20%). The highest price differences relate to the tightest tolerances and provision of strict (hard) IP requirements (especially servicing the organic sector) and during the end season period for Brazilian origin meal (November-February). The lowest price differentials occur immediately post harvest in Brazil (March-June) and where soft IP systems are used (in some cases the additional cost involved amounts to little more than testing by suppliers who then add a margin before selling onto the EU feed sector).
- It has been reasonably easy for the European buyers to identify and obtain supplies of non GM derived soybeans and soymeal at 'competitive prices' – in other words at similar or no more than a 5% price differential relative to commodity traded soy (ie, non segregated that may contain GM derived soy). This has been mainly because of a) the use of 'soft IP' systems and b) the total volume required in the EU has been significantly below the supply availability in the non GM producing countries such as Brazil and India;
- The additional costs involved in securing supplies of non GM derived soybean meal for use in the livestock sector, have so far, largely been absorbed in the supply chain. Thus in the example of some of the UK's leading supermarket chains announcing in early 2001 of their move to require a number of livestock products to be from animals fed on a diet on non GM derived feed material, they have been quite explicit in stating that any additional

⁶¹ The standard for identity preserved non GM soybeans and meal set by the British Retail Consortium and the Food and Drink Federation facilitates both soft and hard IP systems. It lays down guidelines for practice and documentation to demonstrate to the Competent Authorities that they have taken appropriate steps to comply with the 1% threshold

costs will not be passed onto consumers and that suppliers (presumably in the livestock and feed sectors) will not have to bear any additional costs. Unpublished industry based research undertaken in mid 2002 does, however show that most of the this extra cost has fallen on the supply chain up to but not including the large retail chains;

- some of the producers of relatively high value livestock products such as Roquefort cheese or Quality Label (eg, La Belle Rouge) chicken in France have been sourcing non GM derived soy direct from EU soy growers. In this latter case, price differentials of up to 20% relative to commodity-based, GM derived soy have been reported. Despite the payment of such premia, the producers of these high value livestock products have largely absorbed the additional costs themselves, with the willingness to do so mainly reflecting the lower importance of feed costs in total costs of production relative to mainstream livestock production systems;
- overall, the estimated size of the EU market for soymeal used in livestock feed accounted for by non GM derived meal is 20%-25% of total usage (5.8-7.25 million tonnes of meal). The main sectors of use for non GM meal are poultry and layer feed and 'high value' livestock product 'niche' markets (eg, Roquefort cheese producers).

A 3.2 The EU market for non GM maize

A 3.2.1 Background

The EU annually produces about 38 million tonnes of maize and consumes about 39 million tonnes (2001-02). Imports and exports are limited (ie, the EU market is broadly in balance each year). The primary use is, as an animal feed (78%) followed by starch manufacturing (16%) and human food (6%). Imports account for the equivalent of only 6% of total usage.

a) EU production

Maize is the third largest cereal crop grown in the EU after wheat and barley⁶² with 38 million tonnes produced in 2002. The main corn growing countries in the EU are France and Italy, which accounted for 42% and 27% respectively of total EU production in 2002. The other significant producers are Spain, Germany, Austria, Portugal and Greece, which accounted for 12%, 9.5%, 4%, 2% and 2% respectively of total production.

b) EU maize imports

The EU imports annually about 2.4 to 2.6 million tonnes (in 2001 imports were 2.4 million tonnes). The majority of these imports are into Spain and Portugal, which accounted for about 80% of total imports in 2001. This domination of imports by these two countries largely reflects the existence of an import duty concession for up to 2.5 million tonnes of maize that can enter Spain and Portugal⁶³ at reduced import duty levels relative to imports into other member states.

The third most important importer of maize in the EU is the UK, which imported nearly 0.25 million tonnes in 2001. A significant proportion of this maize is flint maize⁶⁴, largely used in the breakfast cereal sector.

c) Source of imports

The main sources of supply are Argentina and Brazil, which accounted for 58% and 35% respectively of total imports in 2001. The majority of imports are of dent maize, although

⁶² In 2002 the EU produced about 94 million tonnes of soft wheat and 47.9 million tonnes of barley

⁶³ The concession is for 2 million tonnes entering Spain and 0.5 million tonnes entering Portugal

⁶⁴ As distinct from the more commonly grown dent maize, which accounts for the bulk of global grain maize production and trade

important volumes of flint maize (for the production of processed maize products like breakfast cereals) and waxy maize (for higher quality starch derivative production) are also imported.

A 3.2.2 GM versus non GM market developments in maize

The commercialisation of GM (Bt) maize has contributed to, but not been a major influence on the market development of GM versus non GM derived products (as indicated above, soybeans have been the main driver of this market).

Market developments relating to GM versus non GM maize have followed a similar path to the developments discussed above in relation to soybeans/derivatives:

- The food industry targeted removal of all GM derived ingredients from products, including maize or;
- non GM derived sources of supply were sought. This was relatively easy and focused on domestic EU origin sourcing, where the approval and commercial adoption of Bt maize has been very limited. The need to initiate identity preserved (IP) supply lines has also been limited because of the absence of GM maize material in the vast majority of EU supplies. Only in Spain where 20,000-25,000 hectares of Bt maize have been grown annually for the last 4-5 years has a (potential) need for greater attention to segregation/IP been relevant and even here, there have been limited problems; the majority of Bt maize grown in Spain is concentrated in a few regions and is supplied to the local animal feed compounding sector, where there is little demand for non GM ingredients;
- the demand for non GM material is mostly found in the food sector. In the animal feed sector about a quarter of ingredients are required to be of non GM origin (see above);
- as non GM maize has dominated the supply of maize in the EU, the development of clear price differentials between GM and non GM derived maize has been less marked than in the market for soybeans. Where users of maize (notably in the food and starch sectors) have specifically required guaranteed non GM maize (to the same tolerances as non GM soy of mostly 1% and some to 0.1%), price premia for non GM derived maize have tended to be in the range of 1% to 3%;
- the cost burden (where applicable) of using non GM derived maize has generally been absorbed by the food chain.

A3.3 GM versus non GM market developments: the future

This section examines possible future developments in markets for GM versus non GM products. It focuses mostly on the market for soybeans and derivatives, where the differentiation has been most marked. The other main arable crops grown and used in the EU, for GM crops that are currently widely grown on a global perspective are then considered (ie, maize and oilseed rape).

A 3.3.1 The current state of markets - soybeans and derivatives

Drawing on the information presented above, it is possible to broadly quantify the nature of current global soybean/meal and oil traded supplies into products that are derived from GMOs and products that are not. Table 44 overleaf summarises the key statistics and highlights the following:

- Based on the percentage of each major exporting country's crop that is planted to GM varieties, 55% of globally traded soybeans/meal are GM derived and 45% are non GM (in soybean equivalents). However, unless active segregation of IP systems are initiated in the main GM growing countries of Argentina and the US, the 'commodity' nature of global trade in soybeans/meal (which inevitably results in co-mingling of

GM and non GM derived products) means that all exports from these two countries may contain GM material. Using this assumption, 63% of globally traded soybeans/meal are GM derived and 37% are non GM derived;

- Comparing these available volumes of GM derived versus non GM derived material against demand in the EU and Japan (the two markets in which the market for non GM material is probably most developed), this suggests that the supply of globally available non GM material (39 million tonnes in bean equivalents) is more than adequate to meet the current level of demand for NGM material in these countries (about 12 million tonnes bean equivalent);
- Given this relative balance of NGM supply relative to demand, it is not surprising that price differentials between GM and non GM derived soybeans/meal have remained at roughly the same level (and range over seasons) over the last 2-3 years – in other words at fairly low levels of 1%-5% at the import/export level in the supply chain.

Table 44: Main global supplies (exports) of GM derived versus non GM derived soybeans and soymeal 2002/03 (million tonnes)

Exporters (suppliers)	Soybeans	Soymeal	Total bean equivalent	Estimated GM %	GM derived volume (bean equiv)	Non GM derived (bean equiv)
<i>GM growing countries</i>						
United States	25.30	5.44	32.19	75%	24.14	8.05
Argentina	6.41	16.95	27.87	98%	27.31	0.56
Total in GM growing countries	31.71	22.39	60.06		51.45	8.61
<i>Non GM growing countries</i>						
Brazil	16.15	12.30	31.72	15%	4.76	26.96
India	0.00	2.40	3.04	0%	0.00	3.04
Paraguay	2.34	0.6	3.10	30%	0.93	2.17
Others	1.42	4.98	7.72	10%	0.77	6.95
Total non GM growing countries	19.91	20.28	45.58		6.46	39.12
Total GM & NGM derived supplies					57.91	47.73
<i>Key importers</i>				<i>NGM %</i>		<i>NGM vol</i>
EU	17.35	16.47	38.20	25		9.55
Japan	4.90	1.00	6.17	40		2.47
Total requirements	22.25	17.47	44.37			12.02

Source:PG Economics, derived from USDA & Oil World

Notes: GM planting % assumptions based on 2002 in USA and Argentina and trade source (agriculture & seed) estimates of illegal plantings for Brazil⁶⁵ and Paraguay, other countries = arbitrary 10%

A 3.3.2 The current state of markets - maize

The development of a distinct global market for GM versus non GM maize has been much less marked than in soybeans. This can clearly be seen by examining the relative importance of GM maize in globally traded maize and the nature of demand for maize in countries where there is a strong demand for non GM material:

- Only 18% of globally traded maize (about 13.8 million tonnes) is derived from GM maize (based on the % of exports from each country being classified as GM according to the share of GM maize in total domestic production⁶⁶) using countries;
- The market with the strongest demand for non GM material, the EU is virtually self sufficient in maize, importing only 2.4 million tonnes in 2001 (equal to only 3% of global trade in maize). Although GM maize (Bt) is permitted for planting in some EU countries, its share of total EU production is only about 0.6% of total production.

A 3.3.3 Oilseed rape

Market developments for oilseed rape have been similar to maize. Global exports of rapeseed and meal (in seed equivalents) were equal to about 8.95 million tonnes in 2001/02, of which about 32% was probably derived from GM seed⁶⁷. Demand for non GM seed/meal is probably highest in the EU, where use of rapeseed is annually about 8-9 million tonnes. The vast majority of this is derived from EU production (no GM oilseed rape is currently permitted for commercial planting in the EU).

A 3.4 Future market dynamics for GM versus non GM soybeans

How the markets for GM versus non GM derived soybeans/derivatives will develop is essentially determined by how the balance of supply and demand of each category of product develops.

The balance of supply and demand

At present the level of demand for non GM soybeans/derivatives is significantly below the available supply. Global demand for non GM soy is about 12 million tonnes of bean equivalents relative to global supply of about 48 million tonnes – global demand can also relatively easily be serviced by available supplies from Brazil alone (27 million tonnes of bean equivalents). In this circumstance, the price differential for GM versus non GM soybeans/derivatives is small.

If demand for non GM material was to rise substantially (eg, a doubling of demand in the EU coupled with increases in demand in other regions like South East Asia), it is possible that a market situation could arise in which the demand for non GM derived soybeans/derivatives begins to reach the level of available global stocks. Based on 2002-03, this would require a probable threefold increase in the level of global demand for non GM material.

On the supply side, the scope for the narrowing of the gap between global supply and demand for non GM soybeans/derivatives can also occur via a reduction in the available supplies of non GM

⁶⁵ The Brazilian government has recently estimated that about 10% of the crop is to illegally planted GM varieties. Agricultural and trade sources suggest that this is a significant under estimate and the true level could be anywhere between 20% and 40%

⁶⁶ For example, 24% of US maize was planted to GM varieties in 2002 and 24% of US maize exports is 11.52 million tonnes

⁶⁷ Global exports are dominated by Canada, which accounts for 46% of global exports. Canada is also the leading user of GM oilseed rape where 65% of the 2002 crop was planted to GM varieties. Applying this % share of the oilseed rape area to exports from Canada produces an export share of GM rapeseed of 2.68 million tonnes

soybeans. Given the lack of farm level price premia for non GM soybeans and the popularity of Roundup Ready soybeans (because of the farm cost savings obtained) amongst soybean farmers in the US, Argentina and more importantly, in Brazil (and Paraguay) where illegal plantings now account for significant shares of total production, it is probable that the availability of non GM derived soybeans/derivatives from the current main supplying countries of non GM material could fall. Forecasting the availability of non GM soy material over the next 1-3 years, from for example, Brazil is however complicated by the rapid expansion in plantings and production of soybeans in Brazil over the last few years that have made an important contribution to increasing the global availability of non GM material *per se* (as distinct to representing planting of non GM material that has specifically targeted the non GM market). Overall, on the supply side, the availability of non GM soybeans is largely a function of the price paid (ie, premia paid relative to non GM soy) in regions where farmers can freely choose between the two alternatives although the availability of herbicide tolerance in leading varieties, suitable for growing in each region is also an important factor of influence. Thus in countries like Brazil where there is still currently a legal ban on the commercial planting of herbicide tolerant soy, farmers located in regions with similar climatic conditions to adjacent GM growing regions/countries like Argentina have greater scope for planting (illegally obtained from adjacent countries) GM soy than farmers in more distant and geographically dissimilar regions, where leading varieties containing the herbicide tolerant trait are not currently available.

Narrowing of any gap between supply and demand for non GM material

The implications of rising demand for non GM derived soybeans/derivatives relative to static or, possibly declining supply of non GM derived material, from 'cheaper' sources like Brazil (considered to be reasonably cheap sources of non GM material by many because 'soft IP' systems can be used to support the non GM derived status in regions where GM varieties are not available; eg. Northern Brazil) are initially, likely to be a tightening of supply and a possible need to source volumes of non GM material from regions where there is greater likelihood of co-mingling of GM and non GM material. An important consequence of this will be a probable need amongst a greater number of buyers of non GM derived material to initiate the use of 'hard IP' systems for sourcing. In turn this will contribute to increasing the cost of obtaining the non GM derived soybeans/meal, although economies of size in servicing greater volumes of non GM derived material through the supply chain should counterbalance some of these additional costs.

Prices

As indicated earlier, the price differential between GM derived and non GM derived soybeans/meal has been fairly stable over the last 2-3 years (1% to 5% at the import/export level). This differential would widen under the following circumstances:

- When global demand gets near to or exceeds the short term global available supplies;
- Additional costs of initiating 'hard IP' systems to ensure that supplies of non GM material meet buyer specifications. For those previously operating 'soft IP' systems, this will represent an extra cost, whilst for those already operating 'hard IP' systems, economies of size associated with the supply of greater volumes of supply (probably using dedicated supply lines) will contribute to lowering the average unit cost of IP systems. The net overall effect on the average cost of delivering identity preserved non GM derived soybeans and meal is probably higher⁶⁸;
- The cost reducing impact of GM agronomic (herbicide tolerant) technology on the price of GM derived soybeans/derivatives. To date this has already probably contributed to reducing the real price of soybeans/derivatives. This is difficult to quantify but one piece of work from the US (Moschini 2000) suggests by 0.5%-1% to 2000 and that this could increase to anywhere between 2% and 6%⁶⁹ as the global level of adoption increases.

⁶⁸ Mainly because the use of soft IP systems accounts for the majority of non GM supplies to date

⁶⁹ Depending on assumptions used

Work by Qaim & Traxler (2002) estimates the impact of Roundup Ready soybeans adoption on global soybean prices to have been -1.96% by 2001.

Who bears any additional cost of supplying non GM material?

At present, it has been the EU livestock production sector (essentially the poultry sector) that has had to absorb the additional costs of non GM derived feed ingredients. However, if the price differential between GM derived and non GM derived widens (eg, to 10%-15%), this ability to absorb the additional costs will decrease because of the adverse implications for profitability. This points to one of two alternative outcomes:

- The additional cost is passed onto retailers and consumers in the form of higher prices of meat and other livestock products. To date, almost all incidence of additional cost associated with using non GM derived ingredients have not been passed onto consumers and most retailers are reluctant to take this course of action;
- The additional costs are forced onto the supply chain upstream of the retailer (through feed producer and livestock producer). Whilst the supply chain upstream of retailers was prepared to absorb such costs in the case of soy/derivatives used in human food, mainly because of soy's low incorporation rates, the position on the livestock side differs. As indicated earlier, the animal feed compounding industry and most livestock production organizations operate on relatively low margins, and feed accounts for a significant part of total production costs for meats such as pork and chicken (Table 45). Faced with potential cost increases, it is difficult to see how the supply chain upstream of (European) retailers could absorb any higher costs of using non GM derived feed ingredients;
- Due to the market power of most large retail chains relative their suppliers in the livestock sector this points to the majority of any additional cost burden of using non GM derived feed being pushed back down the supply chain onto slaughterers, processors, egg packers, pig and poultry farmers and feed compounders. The likely consequence of this would be reduced output by some European producers rather than produce at a loss. In turn this could result in shortages of non GM derived livestock products for retailers, necessitating either a re-think of paying higher prices or a relaxation of their stance on using non GM derived products (eg, widening tolerances, applying the requirement to premium product rather than mainstream products).

Table 45: Impact of paying premia for non GM soymeal on poultry production margins (UK basis)

	Non GM premia 3%	Non GM premia 10%
Soymeal incorporation rate in feed	30%	30%
Impact of NGM premia on feed cost/tonne	+1%	+3.2%
Impact on variable costs of production to poultry producer	+0.78%	+2.6%
Impact on poultry producer gross margin	-10%	-33%

Source: based on broiler production data: UK (Nix Pocketbook 2002)

Notes/assumptions

1. Baseline feed cost £150/tonne purchased from a compounder which operates on a margin of about 5%
2. Variable costs = feed, heat, lighting and cost of chick. Excludes labour and housing costs. Feed accounts for 81% of total variable costs in baseline
3. Baseline farm gross margin is £0.06/bird on a sales price of £1.127/bird (ie, margin over sales revenue is 5.3%)

Prices and planting of non GM material

If the price differential between GM derived and non GM derived soybeans/derivatives widens, this may affect the planting decisions of soybean farmers (provided the differentials reach the farm level). Some will consider switching back from growing GM to non GM varieties and some others thinking of planting GM varieties may decide to remain with non GM varieties. Their willingness to grow non GM varieties will, however depend upon the financial incentives offered to do so and the associated costs of initiating any segregation/IP systems. Drawing on US examples, where the production cost benefits to US farmers of GM soy are widely perceived to be of the order of \$15-\$25/hectare (\$5.77-\$9.61/tonne or 3.5%-5.75% of the average 2000/1 US farmgate price) and IP costs can add anywhere between 5% and 30% to the cost, it is likely that the non GM soybean price would have to trade at a premia of at least 10%⁷⁰ and possibly as high as 30% relative to GM varieties⁷¹. In relation to this it is interesting to note the low level of premium offered to farmers to plant non GM varieties in the US. For example the large US-based crusher ADM offered a premia of 4.4% (itself up 50% on ADM's offers from the previous year) in 2001, yet take up was reported to be very low.

Key factors affecting the future market

Drawing on the discussion presented above, the future development of the market for non GM soy will be influenced by the following key variables:

- the most important variable is likely to be a decision to legally permit the planting of herbicide tolerant soybeans in Brazil. This will act as a major incentive to plant GM soybeans in Brazil, especially if herbicide tolerance is available in leading varieties and varieties more suited to growing in the Northern half of Brazil. Take up of this technology can be expected to be rapid because of the cost savings (and hence income benefits) that most farmers in the adjacent Argentina appear to have achieved. The more intangible benefits associated with additional management flexibility and convenience, are also important factors affecting take-up. The earlier the date for legalisation of GM soy planting in Brazil (eg, for the 2004 harvest) will speed up the likely decline in available non GM supplies and any delay, perhaps beyond 2005 will result in the current market balances (where supply of non GM material is more than adequate to meet demand) continuing to operate largely in equilibrium;
- the level of price differential for non GM soy relative to GM soy at the farm level. Currently there is little or no differential at the farm level in Brazil and hence, little or no farm level incentive to grow non GM soy, if GM soy is freely available as an alternative. The development of a clear market for non GM soy with a positive price differential at the farm level will be important if supplies of non GM soy are to be maintained at or near current levels, once GM soy is legally permitted for sale in Brazil;
- the level of price differential for non GM soy relative to GM soy at the import/export level. Once this differential goes consistently above 10% it will probably cause significant difficulty to the feed and livestock sector in the EU unless they are able to pass on some of the additional cost to retailers (Table 45). This is also a likely trigger point for re-evaluation of non GM policies amongst some of the European retailers (if forced to face the reality of bearing some of the additional cost or a tightening supply availability of non GM derived products from EU suppliers). Sustained price differentials in excess of 10% could lead to reduced demand for non GM derived products by European supermarket chains (in the short term attempts to force the additional cost on EU suppliers may lead to supply difficulties and retailers may end up having to source additional volumes of (poultry) products from outside the EU). In turn potential bad publicity about this (eg, adverse impact on the EU feed and food supply chain, employment etc) and difficulty in

⁷⁰ A premia of \$18-\$20/tonne (about 11%-12% of the 2000/1 average US farmgate price of soybeans) was cited as a minimum premia required by soybean farmers in Minnesota (May 2001: source D Schmitz of Schmitz Grain Inc).

⁷¹ This also does not take account of the intangible benefits derived from greater convenience – which has been cited as one of the most important benefits of adoption for GM varieties.

checking the 'non GM' credentials of non EU suppliers may lead to compromise between EU retailers and EU-based suppliers – the net effect would probably be reduced demand for non GM derived products. Our assessment is that if this 'trigger' comes in 2004/05 (if Brazil legalizes planting of GM soybeans for the 2005 harvest), although if Brazil legalizes the planting of GM crops in 2004, this 'trigger' will occur a year earlier in 2003/04⁷² ;

- EU legislation on traceability and labelling of GM derived products. Current EU proposals passed by the Council of Ministers (and awaiting approval by the European Parliament) will require feed containing GM derived ingredients to be positively labelled. Also products like soy oil that are derived from but do not contain any detectible presence of the DNA/protein will have to be labelled as being GM derived. This legislation can be expected to be passed in late 2003 but, in our view, is unlikely to have a major impact on the demand for non GM products in the EU. As indicated above, there has already been a movement away from using soy oil in favour of alternatives and this new legislation will probably result in only a small increase in demand for non GM derived oils. On the feed side (meat derived from animals fed with GM derived feeds will not have to be labelled as GM derived), the impact on demand will probably be limited – the main issue will be of enforcement and the scope for fraud concerning products derived from GM soy but for which it is not possible to detect presence of DNA/protein from the GM trait.

A 3.5 Future market dynamics: GM versus non GM markets for other crops

As with the markets for GM versus non GM derived soybeans/derivatives, how the respective markets for maize and oilseed rape will develop will be determined by how the balance of supply and demand of each category of product develops. Nevertheless, because of the largely self sufficient nature of the EU markets for maize and oilseed rape, as distinct to soybeans/derivatives which are much more dependent on imports, the EU markets for these products, and the importance or otherwise of the GM versus non GM issue is more heavily influenced by the extent to which GM maize and oilseed rape might be planted in the EU over the next few years.

In relation to planting of some new GM maize and oilseed rape varieties in the EU, this largely depends on the lifting of the moratorium and hence may allow for new approvals in 2004. Nevertheless, requirements for obtaining regulatory approval, national variety listings and placement on the EU Common Catalogue for approved GM varieties (ie, GM traits in leading varieties), as well as 'bulking up' reasonable quantities of seed for commercial sale are likely to limit the widespread availability of seed until 2005-2007. Hence, we foresee little change in the supply of GM maize and oilseed rape within the EU in the next 3 years (some increase in Bt maize plantings in 2003/4, based on use of existing technology/seed varieties approved in 1997/98).

The net effect of this will be that the supply of non GM products will continue to dominate supplies over the next 3 years and EU farm level price differentials in favour of non GM maize and oilseed rape would continue to operate at very low levels (1%-3%), due to the continued abundant supply position relative to levels of demand.

⁷² If GM crops are not legally permitted for planting in Brazil until 2006 then this delays the 'trigger' to 2006/07

Appendix 4: Co-existence

A 4.1 SCIMAC and MAFF recommended separation distances

The SCIMAC separation distances are based on current legislation, established practice (eg, for HEAR), knowledge of pollen distribution and cross-pollination, practical experience of growing certified seed crops to high levels of genetic purity and ‘best’ available current scientific knowledge are shown in Table 46.

Table 46: SCIMAC separation distance for same species

Crop type	Non-GM crops	Certified seed crops	Registered organic crops
Oilseed rape	50 metres	200 metres	200 metres
Sugar beet	6 metres	600 metres	600 metres
Forage maize	200 metres sweet corn 50 metres forage maize	200 metres	200 metres

Notes: The non GM crops are effectively working to a threshold of 1%, whilst certified seed and organic crops operate to tighter thresholds (eg, no detectible residue for organics which is in effect 0.1%)

The SCIMAC separation distances compare with ones recommended in a report for MAFF (Ingram J 2000) on the separation distances required to ensure cross pollination is below specified limits in non-seed crops of sugar beet, maize and oilseed rape. These are shown in Table 47.

Table 47: Recommended separation distances to ensure cross pollination is below specified limits in non seed crops of sugar beet, maize and oilseed rape

	Threshold levels of cross-pollination		
	1%	0.5%	0.1%
Oilseed rape (B. napus and rapa)	1.5 metres	10 metres	100 metres
Maize grain	200 metres	300 metres	Insufficient information to make a recommendation
Maize silage	130 metres	200 metres	420 metres
Sugar beet	0	0	0

Source: Ingram 2000

Note: A limited area of maize grain (maximum of 2,000 ha) is grown in the UK. All maize seed is imported.

These separation distances show that:

- For oilseed rape, the recommended separation distance required to meet 1% threshold (close to the likely 0.9% that will be set in the EU labelling and traceability regulations) is 1.5 metres, although for varietal associations and partially restored hybrids (that account for about 5% of total plantings), the recommended separation distances are 100 metres. For meeting a 0.1% threshold the recommended separation distance is 100 metres. SCIMAC guidelines are 50 metres. For certified seed and organic crops the SCIMAC guidelines are 200 metres;
- For silage maize, the recommended separation distances are 130 metres (1% threshold) rising to 420 metres (0.1% threshold). SCIMAC guidelines are 50 metres for silage maize and 200 metres for sweet corn;
- For sugar beet there are no recommended separation distances, as the crop is usually harvested before flowering. The only caveat to this is in relation to bolters, which can occur at a rate of 1% - here it is good agricultural practice to remove them and such action is

recommended. The SCIMAC guidelines are separation distances of 6 metres and 600 metres for seed production and organic production.

A 4.2 Soil Association's separation distance guidelines

The Soil Association's 6 km separation distance is a 'warning limit' with ultimate risk of adventitious presence being determined by a risk matrix. Within this matrix the Soil Association have specified separation distances in the range of 3,000 metres to 6,000 metres (oilseed rape including seed 6,000 metres, sugar beet 3,000 metres for organic seed production and 1,000 metres for 'no weed beet' (ie, bolters), maize including seed 3,000 metres, potatoes 500 metres and wheat 500 metres). These matrix guidelines are based on information supplied by the National Pollen Research Unit and relate to the distance by which pollen can travel by wind and insect vectors and are assumed to result in the receptor crop (eg, non-GM or organic crop) being down-graded or re-classified as GM. The estimated separation distances assume no (absence of) minimum acceptable level of contamination. However, some level of contamination or a threshold does exist because of the limits of reliable detection (this is effectively 0.1%). The National Pollen Research Unit recommendations are therefore based on what they classify as 'very low risk distances'. We do not know if these imply 0.1% or tighter.

A 4.3 Principles behind separation distances and possibilities of adventitious presence occurring

For the reader seeking to fully understand the principles behind separation distances and possibilities of adventitious presence occurring, the following points are of relevance (Ingram 2000):

- Pollen availability and transmission. The chances of pollen from a GM crop pollinating with a non GM crop (ie, introgressing) is a function of the quantity of pollen emitted from the GM crop and its delivery to the stigma of a non GM plant. This is influenced by the factors such as wind speed and direction, presence of insect vectors to deliver the pollen, rainfall and barriers to pollen movement (eg, trees, hedges and topography);
- Degree of cross-pollination once pollen from a GM plant reaches the receptor, non GM crop. Here timing of flowering of the receptor (non GM) crop needs to co-incide with the GM crop, the GM pollen must still be viable for fertilisation and it has to compete with fresher pollen produced by the non GM plant itself and/or pollen from other non GM crops in the vicinity that will be available in greater quantities;
- Factors affecting gene expression in the receptor crop. After cross-pollination the genetic material is incorporated into the seed and may influence the characteristics of the resulting seed crop. It does not impact on the integrity of the parts of the non GM crop, other than the seed (eg, in the case of oilseed rape, any introgression of GM material will show up only in the seed and will not be present in the rest of the plant);
- Inheritance considerations. If the GM trait is a dominant gene only half of the emitter (GM plant derived) pollen would contain the GM trait. Therefore half of the pollen produced will not contain the GM trait.

A 4.4 The JRC study on co-existence: key findings for the three case study crops examined

The main objectives of this study that are relevant to this research were:

- to identify and analyse the causes of, and probabilities of, potential contamination of conventional and organic crops with GM crops at the farm level;

- to identify and propose changes in farming practice in order to minimise gene flow and adventitious mixing of GM and non GM crops;
- to estimate and analyse the different costs associated with the proposed changes in farming practices;
- to identify implications of adventitious contamination and estimate the associated financial losses for conventional and organic farms.

The study was based on three crop case studies, winter oilseed rape for seed production, grain maize for feed production and potatoes for food production. These crops represented different biological characteristics and all three are of relevance for GMO-based, conventional and organic production systems. The study:

- considered for each crop two different possible contamination thresholds. These were 0.1% and 0.3% for winter oilseed rape for seed production and 0.1% and 1% for grain maize for feed production and potatoes for food production;
- examined two scenarios for GM crop adoption in the EU; 10% and 50%;
- studied a number of conventional and organic farm types that were representative of the average farm for a number of selected geographical areas in the EU;
- estimated on-farm levels of adventitious presence of GM crops in non GM crops and the effects of changing farming practices. This was based on using a combination of expert opinion and computer models of different farming practices (eg, in winter oilseed rape for seed production, the model used ranks cropping systems according to their probability for gene flow from herbicide tolerant oilseed rape to rape volunteers both in time (via seeds) and in space (via pollen and seeds)). In maize the in-field adventitious presence modelled focused on cross pollination. Expert opinion was used for estimations of post-harvest levels of adventitious presence of GM oilseed rape;
- assumed that any costs arising from taking action to reduce the adventitious presence of GM crops in non GM crops falls on non GM producers.

Winter oilseed rape for seed production

The key findings of the analysis (Table 48) were:

- applying current farming practices on the five model farms (three producing certified oilseed rape seed (two of which were organic) and two farms producing farm-saved seed (one organic)), the levels of adventitious presence of GM crops in non GM crops were estimated to be within the range of 0.42% and 1.05% if it was assumed that 50% of all EU oilseed rape crops were planted to GM varieties. Organic farm types were predicted to have higher levels of adventitious presence because of their lower efficiency in volunteer control compared to conventional controls;
- all farms could achieve a hypothetical 0.3% threshold for GMO content in seed production by changing farming practices;
- levels of adventitious presence could be reduced to very low levels (0.1%) by changing farming practices, although for conventional farms producing farm-saved seed this would require major changes to post-harvest practices;
- levels of adventitious presence of GM crops depend on field sizes, isolation distances, volunteer control, and the farm structure for dealing with post-harvest handling of the seed crop. Also seed purity and varietal selection can affect the level of adventitious presence (male sterile parent lines are more prone to cross pollination than non hybrid varieties);
- the modelling analysis predicted that effective measures to take to minimise adventitious presence included (i) not growing oilseed rape at any time within the rotation within a radius of 300 metres from the seed production plot (costs not estimated as difficult to estimate), (ii) changing set-aside management by sowing the field in spring in order to minimise survival of volunteers (estimated cost €94/hectare) and (iii) longer rotations

- with an additional (non rape) spring crop to control volunteers (no additional costs assumed);
- changing set-aside management and establishing oilseed rape-free zones of 300 metres around the seed plot were considered to be the most efficient practices to adopt, though costs would be incurred and there may be a requirement for co-operation between adjacent farmers. The study also suggested that this (latter) type of measure might already be applied on some farms as part of contractual obligations from seed companies⁷³;
 - The JRC work also included estimates of additional costs associated with monitoring costs (establishment of a HACCP based system of controls with testing and checking, including capital set up costs allocated over an average of five years). These costs were estimated to be about €1/hectare for both conventional and organic seed producers. In addition, insurance costs were included of €2.2/hectare for conventional crops and €6.5/hectare for organic producers. The insurance costs were assumed to cover short term losses from having products downgraded from non-GM conventional status or organic status. Overall, including these additional costs, the total cost of meeting a 0.3% threshold for the presence of GM material in non GM oilseed rape crops used for seed were estimated to be €126/hectare for conventional oilseed rape and €232/hectare for organic oilseed rape

Table 48: Levels of adventitious presence of GM oilseed rape in non GM oilseed rape seed production in conventional and organic agriculture with current and recommended farming practices to meet the stated thresholds (assuming 50% GM crop penetration)

	Certified seed production: conventional	Certified seed production: organic	Farm-saved seed: conventional	Farm-saved seed: organic
Average farm area (ha)	131	131	351	351
Average seed plot size (ha)	6	6	11	11
Number of seed plots	1-2	1-2	6-7	6-7
Adventitious presence expected under current practices	0.42%	0.61%	0.59%	1.09%
Best change to meet 0.3% threshold for GM presence	Introduce spring crop in rotation	Spring sown set-aside	Dedicated machinery and cleaning equipment	Spring sown set-aside
Total rate of adventitious presence expected: after farming practice change	0.19%	0.04%	0.23%	0.11%
Additional cost involved (€/ha)	Nil (127)	194.3 (345)	93.2 (126)	194.3 (345)
Best change to	Spring sown set-	Spring sown set-	Not achievable	Combination of

⁷³ The EU Scientific Committee on Plants recommends an isolation distance of at least 600 metres for hybrid seed in the year of seed production to avoid cross pollination (opinion of 13 March 2001)

meet 0.1% threshold for GM presence	aside	aside		practices
Total rate of adventitious presence expected: after farming practice change	0.03%	0.04%		0.075
Additional cost involved (€/ha)	194.3 (321)	194.3 (345)	-	198.6 (393)

Source: JRC 2002

Note: bracketed figures in the costs involved include monitoring costs and insurance. Non bracketed figures are costs of changing farm practices only

Grain maize

The analysis relating to the production of maize is summarized in Table 49:

- seven farm types were examined, covering conventional and organic in intensive and non intensive systems. The levels of adventitious presence of GM crops in non GM crops were estimated to be within the range of 0.16% and 2.25% if it was assumed that 50% of all EU maize crops were planted to GM varieties. Organic farm types were predicted to have lower levels of adventitious presence;
- all farms could achieve a hypothetical 1% threshold for GMO content. It would require some change to farming practices for conventional producers and no changes for organic producers;
- levels of adventitious presence could not be reduced to very low levels (0.1%) by changing farming practices;
- levels of adventitious presence of GM crops mainly derive from cross pollination. The level depends on plot sizes and isolation distances, with small farms or farms with smaller fields more affected. Volunteers in maize are not a significant source of adventitious presence. For conventional farms, post harvest handling represents an additional source of adventitious presence as maize is often dried, cleaned and stored in central (co-operative) facilities. Seed purity can also affect the levels of adventitious presence, the purer the purity level (eg, 0.1% adventitious presence) the lower the 'knock-on' level in the final product;
- the modelling analysis predicted that effective measures to take to minimise adventitious presence on conventional crop production systems would be increasing isolation distances to 100-200 metres, the introduction of varieties with different flowering times and improving post harvest management practices;
- the costs of increasing isolation distances and changing post harvest management practices were not estimated (due to the complex nature of the changes that would have to be examined). For the difference in flowering times, the GM variety has to flower earlier than the non GM variety, and as earlier varieties generally have lower yields, this would add costs of about €45/ha for the GM producer;
- organic producers using organic seed with high purity and not growing any GM maize (and separating their organic production from conventional production) could meet a 1% threshold without changing current farming practices;
- a threshold of 0.1% would be extremely difficult to achieve for any farm;
- The analysis on maize by the JRC also included estimates of additional costs associated with monitoring costs (see oilseed rape above). These costs were estimated to be about €52/hectare for conventional maize producers and €55/hectare for organic maize producers. In addition, insurance costs were included of €3.3/hectare for conventional crops and €6.7/hectare for organic producers. Overall, including these additional costs,

the total cost of meeting a 1% threshold for the presence of GM material in non GM maize crops are estimated to be €55.3/hectare for conventional maize and €92/hectare for organic maize.

Table 49: Levels of adventitious presence of GM maize in non GM maize production in conventional and organic agriculture with current and recommended farming practices to meet stated thresholds (assuming 50% GM crop penetration)

	Conventional: France	Conventional: Italy	Organic: large	Organic: small
Average farm area (ha)	60	50	60	10
Average maize plot (ha)	3-4	8	3-4	1
Number of maize plots	14	3	14	1
Adventitious presence expected under current practices	2.25% (+/-0.6%)	1.75% (+/-0.2%)	0.16% (+/-0.07%)	0.58% (+/-0.04%)
Best change to meet 1% threshold for GM presence	50 degree days difference in flowering time + improved post harvest management	Minimum 200 metre distance + improved post harvest management	No change required	No change required
Total rate of adventitious presence expected: after farming practice change	0.66% (+/- 0.3%)	0.69% (+/- 0.3%)	As above	As above
Additional cost involved (€/ha)	45.4 plus (95.6)	Not determined	Nil (127)	Nil (not available)
Threshold 0.1%	Not deliverable	Not deliverable	Not deliverable	Not deliverable

Source: JRC (2002)

Notes: Assumes intensive maize cultivation practices (this accounts for the majority of production). Non intensive maize production showed lower levels of adventitious presence than the intensive production systems because of the larger isolation distances. Bracketed figures in the costs involved include monitoring costs and insurance. Non bracketed figures are costs of changing farm practices only

UK context is there are about 100,000 hectares of forage maize and 2,000 hectares of grain maize. Within this there are about 500 hectares of organic forage maize (no organic grain maize or sweet corn)

Potatoes

The main findings of the research were (Table 50):

- the potato has very different characteristics compared to oilseed rape and maize, as the harvested potato is not the result of a fertilization event. This means that there are far less problems regarding pollen flow as a source of adventitious presence of GM crops;
- Four farm types were examined, covering conventional and organic in main crop and early potatoes. The main sources of possible adventitious presence come from ground keepers and post harvest handling. The levels of adventitious presence of GM crops in non GM crops was estimated to be within the range of 0.1% and 0.54% if it was assumed that 25%-50% of all EU potato crops were planted to GM varieties. Organic farm types were predicted to have lower levels of adventitious presence;
- all farms could achieve a hypothetical 1% threshold for GMO content without changing farming practices. Some minor changes to post harvest handling might be required on some conventional farms (many may, however already be applying strict segregation of varieties post harvest to meet market requirements);
- levels of adventitious presence could not be reduced to very low levels (0.1%) by changing farming practices;
- a threshold of 0.1% would be extremely difficult to achieve for any farm;
- The potato analysis by the JRC also included estimates of additional costs associated with monitoring costs. These costs were only estimated for early potato growers and were €2.5/hectare for conventional early potato producers and €7.2/hectare for organic early potato growers. In addition, insurance costs were included of €14.4/hectare for conventional early crops and €176.7/hectare for organic early producers. Overall, including these additional costs, the total cost of meeting a 1% threshold for the presence of GM material in non GM potato crops are estimated to be €107/hectare for conventional early potatoes and €174/hectare for organic early potatoes.

Table 50: Levels of adventitious presence of GM potatoes in non GM potatoes production in conventional and organic agriculture with current and recommended farming practices to meet the stated thresholds (assuming 25%-50% GM crop penetration)

	Main crop for table and processing consumption: conventional	Main crop for table & processing consumption: organic	Earlies: conventional	Earlies: organic
Average farm area (ha)	150	150	75	75
Average potato plot size (ha)	10	5	3	3
Number of plots	3	5	5	5
Adventitious presence expected under current practices	0.36% (+/- 0.15%)	0.1% (+/- 0.02%)	0.54% (+/- 0.21%)	0.16% (+/- 0.05%)
Best change to meet 1% threshold for GM presence	No change required	No change required	No change required	No change required
Additional cost involved (€/ha)	Nil (53.1)	Nil (201)	Nil (107)	Nil (Not available)
Threshold 0.1%	Not achievable	Not achievable	Not achievable	Not achievable

Note: bracketed figures in the costs involved include monitoring costs and insurance. Non bracketed figures are costs of changing farm practices only

Further research suggested

The JRC study recommended that further research be conducted to a) identify and evaluate the effectiveness of practices that farmers could specifically use to minimise probability of adventitious presence of GM crops in non GM crops, b) examine impact on maize seed production, levels of seed impurities generally marketed and c) undertake deeper economic analysis of consequences at the whole farm (rather than crop) level.

A 4.5 The Danish (2003) study (Tolstrup et al)

The crop-specific key points raised in this report were as follows.

Oilseed rape

a) Seed multiplication

At 0% adoption (ie, adventitious presence possible via imports only), there is a small possibility of adventitious presence from airborne pollen and volunteers. These could be easily controlled through good control of volunteers, increased field size and borders with non GM oilseed rape crops.

At either the 10% or 50% GM adoption levels:

- For fully fertile varieties, adventitious presence could be kept below the 0.3% level through strict regulation of separation. It would probably not be possible to keep adventitious presence in organic seed production below the 0.1% detection level;
- For hybrid varieties and varietal associations, it was not possible with present knowledge to recommend separation distances and lengths of rotation to ensure compliance with a 0.3% tolerance. With strict control of hybrid seed before certification, it may be possible to achieve the threshold value by discarding batches of seed that do not meet requirements.

b) General crop production

At 0% adoption, for fully fertile inclusive hybrid varieties, it should be possible to keep the adventitious presence in conventional productions below 0.9% and it should also be possible to keep the presence below the detection limit for organic production (0.1%).

At either the 10% or 50% GM adoption levels:

- For fully fertile varieties and hybrids, adventitious presence could be kept below the 0.9% level through strict regulations on separation after the first stage of distribution. The 0.1% threshold currently applicable in organics is not achievable unless exceptional measures are introduced (eg, large distances between crops, more rigorous control of seed and seed banks);
- For varietal associations, it is not possible with present knowledge to recommend separation distances and a cropping interval that ensures compliance with the 0.9% threshold.

Overall, the study called for further analyses of existing data at the field level relating to adventitious presence from volunteers and the dispersal of characteristics such as erucic acid content and other non GM genetic markers.

Maize

a) Seed multiplication

As there is no maize seed production in Denmark this was not examined.

b) General crop production

At all levels of adoption, an increased cultivation of GM maize will result in more airborne GM pollen. However, as very little maize is grown in Denmark no difference was perceived for the different levels of adoption (0%, 10%, 50%). To achieve the 0.9% threshold for conventional farming, a separation distance of 200 metres was proposed, which corresponds with the requirements for multiplying existing certified seed with a purity of 99.8%. For organic farming, the current 0.1% threshold was considered achievable, as long as organic seed has a high degree of purity and a separation distance of 200 metres is achieved with GM maize crops.

The study called for further analyses of actual adventitious presence levels under field conditions.

Sugar beet

a) Seed multiplication

This was not examined because almost all seed is imported and there is no organic sugar seed production in Denmark.

b) General crop production

At 0% adoption, in conventional production, the import of seed is expected to result in the adventitious presence of less than 0.3% being achieved. In organic farming, the threshold of 0.1% is achievable with special measures.

At either the 10% or 50% GM adoption levels:

- The recommendation for all management practices is that volunteers and bolters, both within and outside fields are controlled effectively in order to prevent secondary dispersal of GM material;
- In conventional crops an adventitious presence could be kept below 0.3% level through the use of certified seed and cleaning of machinery and transport equipment. Increased separation distances (50 metres) would also reduce the level. In organic crops it is expected that the 0.1% threshold currently applicable could be achieved by using non GM seed, controlling bolters, cleaning field machinery and transport equipment, increasing separation distances to 100 metres and cropping intervals to five years.

The study called for further study of annual weed beets, the decline of cross pollination with distance into the field of seed production and the effect of farm size on the risk of adventitious presence in seed production.

Potatoes

a) Seed multiplication

At 0% adoption (ie, adventitious presence possible via imports only), there is a small possibility of adventitious presence, which would have to be controlled if seed came from GM growing regions.

At either the 10% or 50% GM adoption levels:

- The production of potato seed in Denmark already has legal constraints on the maximum level of varietal impurity of up to 0.05% depending on class. There are also regulations on separation distances, cropping intervals and deployment of machines;
- It is expected that adventitious presence could be kept at a very low level through controlled use of seed, regulations on separation distances from GM crops, control of ground keepers, increased cropping interval for certified seed producers and a conversion period for farmers moving out of GM production. It would be possible to keep

adventitious presence in organic seed potatoes to a minimum with the same additional measures referred to for conventional production (plus a longer conversion period from GM potato production).

b) General crop production

At 0% adoption, the only source of adventitious presence would be from imports – measures required are the same as referred to above for seed.

At either the 10% or 50% GM adoption levels:

- There is already a requirement that seed is regularly replaced and that farm-saved seed is for own use only;
- In conventional production, the present regulations regarding the replacement with certified seed, separation distances to GM crops combined with varied crop rotation, the control of ground keepers and cleaning of machinery according to good agricultural practice should keep adventitious presence at a very low level (0.1%-0.7%). A conversion from GM potatoes to conventional would require a conversion period;
- In organic farming it is expected that with the use of slightly more rigorous measures, it would be possible to meet the 0.1% threshold, as long as organic seed potatoes with organic origins are used in all preceding classes.

The study recommended further research into pollen dispersal under local conditions and the extent of over wintering ground keepers.

Wheat

a) Seed multiplication

At 0% adoption, no problems were envisaged in meeting thresholds of 0.3% adventitious presence in conventional seed or 0.1% for organic seed.

At either the 10% or 50% GM adoption levels, it should still be possible to comply with the 0.3% threshold and the 0.1% for organics, provided an effective production system is established that will keep lots segregated.

b) General crop production

At 0% adoption, the only source of transmission is imported seed. No problems were envisaged with keeping adventitious presence in conventional production below 0.9%. It should also be possible to keep the presence below the detection limit for organic production (0.1%).

At either the 10% or 50% GM adoption levels there should be no problems in keeping adventitious presence in conventional production below 0.9%. The 0.1% threshold in organics is achievable if there is an effective segregation system throughout the production system.

A 4.6 Other work

In relation to issues such as pollen movement, oilseed rape volunteers and gene transfer in oilseed rape (Nelson 2003) cites the following relevant points:

- Pollen flow measured from non GM herbicide tolerant oilseed rape in Australia was reported to move up to 2.6 kms. Despite this presence, the highest frequency of cross pollination measured within this radius was a sample of 0.225%, with 69% of samples tested showed no out crossing at all and only five samples having herbicide tolerant seedlings of more than 0.1% presence (Rieger et al 2002). Based on these levels of

adventitious presence the authors concluded that pollination between commercial fields occurs only at very low levels;

- Even though Rieger's work suggested that pollination between commercial fields occurs only at very low levels, recommended management plans developed by Monsanto and Bayer CropScience for using herbicide tolerant oilseed rape propose that farmers should keep a five metre buffer zone from adjacent non GM crops to minimise the possibilities of cross pollination;
- Based on these buffer zones (separation distances), and a comprehensive review of international research into pollen flow, the Australian Gene Technology Grains Committee has proposed that GM and non GM oilseed rape production systems can co-exist (ie, provided there is a minimum 5 metre separation distance (GTGC 2002));
- Oilseed rape volunteers are not a significant problem (including volunteers with herbicide tolerance) and where they occur, farmers have a variety of herbicides available that can be used to control them (Nikman et al 2002);
- Whilst there is a possibility of transfer of genes between different cultivated brassica species, the potential for hybridisation in the field, introgression of a herbicide tolerant trait and then stable expression in the progeny of weeds is considered a very low and manageable risk (Green & Salisbury 1998);
- Where farmers in Australia are faced with instances of weed resistance to glyphosate, most have adopted resistance management plans which aim to reduce the level of weed pressure and to reduce the frequency of glyphosate use in rotations (eg, using trifluralin pre sowing instead of glyphosate).

Appendix 5: Literature review of international evidence relating to impact of growing GM crops on farmers profits

This appendix reviews literature on the impact of GM crops on farming profitability. It focuses on:

- Crops that can be grown in the UK;
- Some of the main GM crops grown commercially and on which there is a reasonable literature.

It is not intended to be exhaustive or cover all GM crops grown. Nevertheless, the review summarises the research findings of studies for the leading adopted GM crop traits globally: herbicide tolerant soybeans, herbicide tolerant oilseed rape⁷⁴, insect resistant (Bt) maize⁷⁵ and development results for potatoes, sugar beet and wheat.

A 5.1 Herbicide tolerant soybeans

Herbicide tolerant soybeans were one of the first GM crops to be commercialised (in 1996, in the USA). Since then there has been rapid adoption of herbicide tolerant soybeans by farmers wherever the technology has been made commercially available. By 2002, GM soybeans accounted for over 50% of total global soybean plantings, and dominate plantings in some of the leading soybean producing countries of the world. Ninety eight per cent of total soybean plantings in Argentina and almost three-quarters of US soybean plantings are transgenic (herbicide tolerant)⁷⁶. Also, in Brazil, the other leading global producer, a significant proportion of plantings are now illegally planted GM varieties. This rate of adoption has been much faster than adoption rates experienced for most new technologies in the agricultural sector over the last fifty years and is much higher than was achieved, for example in the first seven years after the commercial development of hybrid maize varieties.

In relation to literature examining the impact of herbicide tolerant soybeans, the majority of this relates to the USA although some, more recent work has also been undertaken in Canada and Argentina. An overview of the main findings of this research is presented in the sub-sections below.

A 5.1.1 Weed problems and conventional control

Weeds have traditionally been a significant problem for soybean farmers. For example between 1951 and 1960 annual soybean yield loss to weeds in the USA were estimated at 17%, and although this had fallen to an estimated 7% by 1994, this still constituted a problem area for soybean growers.

Before the advent of GM soybeans, and for growers of conventional varieties, weed management has mostly concentrated on the use of a mix of herbicides. For example, in 1995, 23% of the USA soybean area was treated with a combination of four or more active ingredients, with a further 28% receiving treatment from three active ingredients and 35% receiving treatment from two active ingredients (Gianessi & Carpenter 2000). In other words, 86% of the total US crop received treatment with at least two active ingredients. Of the herbicides used, the most commonly applied active ingredients in the USA were Imazethapyr, Pendimethalin, Trifluralin, Glyphosate, Imazaquin and Chlorimuron.

⁷⁴ In North America GM oilseed rape is mainly found in spring varieties and is known as canola

⁷⁵ The fourth leading GM crop; GM cotton is not included because cotton is not cultivated in the UK. The other three crops are grown in the UK, although in respect of soybeans the area planted is very low (under 1,000 hectares) and in respect of maize, the main form planted is forage maize

⁷⁶ Source: James 2002

Common conventional practice is to tank mix broad-leaved and grass weed herbicides and to spray both pre-emergence and post emergence. Broad-leaved herbicides such as Chlorimuron, Imazaquin and Imazethapyr were often used in a programme with pre-emergent grass herbicides like Trifluralin and Pendimethalin.

Another feature of conventional soybean weed control was an increasing trend towards conservation/no tillage or reduced tillage production systems (eg, by 1994, 57% of the US soybean crop was operating a no tillage regime). This has been attributed mostly to the increasing availability and use of post emergent herbicides in the early 1990s and by 1995 nearly three-quarters of the US soybean crop was being sprayed only with post emergent herbicides.

Overall, most weeds in soybean crops could be reasonably adequately controlled with herbicides in a well planned management system that combined the use of pre and post emergence spraying. The average number of active ingredients applied was, however increasing over time (eg, rising from 1.4 in 1986 to 2.7 in 1995 in the USA).

The relative importance of weed control to soybean producers can also be illustrated by reference to the importance of expenditure on herbicides relative to other forms of crop protection. For example, in Argentina expenditure on herbicides accounted for about 70% of total crop protection expenditure on soybeans (1998-2000: Qaim & Traxler 2002). Within the European context, herbicides account for about 85% of total crop protection expenditure on soybean crops in France, Austria and Spain and 95% plus of total crop protection expenditure on soybeans grown in Italy.

A 5.1.2 Impact on yield

Ever since herbicide tolerant (Roundup Ready) soybeans have been available for commercial planting there has been conflicting evidence presented as to the impact of the new technology on soybean yields. The majority of this work has been in the USA. Most of the disputes over the impact on yield have arisen from work that examined impact in the early years of GM crop adoption (1996-1999). Some work argues that the performance of Roundup Ready varieties are superior to conventional varieties, some that the performance is inferior and others that there is little difference. This is well illustrated in Table 51, which summarises the findings of the USDA study into the yield effect on the 1996-98 US soybean crops. This work has been considered by many observers to be the first significant study of the impact of commercially grown GM crops and, in relation to GM soybeans found what, the USDA called a statistically significant differences in yield in three regions in 1997 and one region in 1998. All these differences found higher yields for growers planting herbicide tolerant varieties. Instances of herbicide tolerant soybean crops delivering lower yields were recorded in some regions in the USDA study (eg, Heartland 1996, Mississippi Portal 1997) but these differences were considered to not be statistically significant by the USDA. However, the analysis recognized it did not take into account other factors, which may have influenced the recorded differences in yields. Thus these comparisons did not take into account differences in other characteristics between adopters and non adopters of the technology and the observed differences may have been due to adoption of the technology by better managers who tend to obtain higher than average yields normally or because the adopters were using production methods such as narrow row spacing (which contributes to higher yields).

Other US analysis included⁷⁷:

- Monsanto (1999) found that the yields derived from its grower survey for 1998 found that Roundup Ready varieties out-yielded the national average yield by 11% (4.5

⁷⁷ The number of studies cited respectively for lower yields, no change and higher yields should not be interpreted as representative of actual findings in the USA – we are citing all references identified

- bushels/acre). However, as with the USDA work, this comparison did not take into account (the same) differences in other characteristics between adopters and non adopters of the technology;
- Variety (yield) trials data from over 3,000 comparisons, from 40 university performance tests, in eight US (Northern) states in 1998 were bought together in a University of Wisconsin study (Oplinger 1999). This found that the average performance of Roundup Ready varieties were 4% lower in yield than conventional varieties (the performance for the top five performing Roundup Ready varieties with the top five performing conventional varieties was reported to be 5% lower). This yield lag was attributed to the Roundup Ready gene having, initially been put into varieties that were not the highest yielding varieties on the market, or plant breeders having failed to make enough backcrosses to capture all of the yield potential in the parental lines. Regardless of which of these explanations is taken on board, if correct, this suggests that the yield lag would decrease and ultimately be eliminated with time. A follow on study of university field trials in 1999 which was structured to be comparable with the 1998 study referred to above, to some extent provided corroborating evidence to this hypothesis by showing that Roundup Ready varieties, on average performed 3% lower than conventional varieties (a narrowing of the gap of 1%);
 - Duffy (2001) examined yield differences between GM and non GM soybeans on 172 fields in Iowa in 1998 and 2000. In both cases the herbicide tolerant crops yielded less than the conventional varieties (-4% in 1998 and -3.7% in 2000);
 - Benbrook (1999), drawing on the Wisconsin work and looking at field trial data from Central and Southern Minnesota reported that the average performance of Roundup Ready varieties was 5% lower than the average performance of conventional varieties (the five highest yielding herbicide tolerant soybean varieties performed 6% lower than five highest yielding conventional varieties). In Central Minnesota this differential was reported as high as 13%. This work also then went on to attribute this differential to yield drag⁷⁸. However, this view is dismissed by others such as Carpenter (2001) who pointed out that the varieties compared in the study by Benbrook (and Wisconsin) have differences other than just the Roundup Ready gene (ie, they were not necessarily the same varieties) and hence the main differences in yield performance were associated with yield lag rather than yield drag (see above);
 - Researchers in Nebraska⁷⁹ attempted to isolate the yield drag from the yield lag by comparing Roundup Ready yields from trials with 'sister varietal lines' (ie, those with similar (but not identical) genetic backgrounds). The work found that Roundup Ready varieties yielded 5% lower than their counterpart, nearest conventional varieties. This yield difference was also attributed to yield drag. Carpenter (2001) however, again pointed out that no other factors for the yield differences were taken into consideration (they were not identical lines) and no other published research into the question of yield drag is available to support or otherwise these assertions⁸⁰;
 - Benbrook (2001) has also suggested that yield drag exists in Roundup Ready soybeans because the insertion of the Roundup gene impairs root development, nodulation and nitrogen fixation in some Roundup ready varieties. This is thought to be temporary (immediately after spraying) and is exasperated by conditions of drought. Thus yields are thought to be impaired because, although plants ultimately recover their defence mechanisms impaired by the Roundup spraying, the initial phase of weakening can sometimes facilitate disease attack which contributes to some yield reduction;

⁷⁸ Which implies that the insertion of the genetic material that makes the Roundup Ready variety able to survive applications of Roundup was the cause of the yield variation

⁷⁹ Elmore et al at the University of Nebraska (2000)

⁸⁰ Monsanto are reported to have findings (unpublished by Delaney et al) that show no yield difference in the comparison of virtually identical Roundup Ready and conventional varieties

- Carpenter (2001) suggested that the selection of Minnesota and Wisconsin only as the basis for the work by Benbrook (see above) could be misleading, in that different conclusions would have been reached if two other states, eg, Illinois and Michigan had been examined. In these states comparisons of Roundup Ready variety trial plot yields with the yields derived from conventional varieties showed that the Roundup Ready varieties produced the highest yield;
- Weed control studies (that compare weed control programmes in terms of efficacy against particular weed species and resulting yields) have tended to find yield differences in favour of the Roundup Ready varieties mainly because of more effective weed control and the avoidance of crop damage (Carpenter (2001) and Fawcett (1997). However, since such trials usually compare different weed control programmes for a single variety, the yield potential of the variety is not usually considered. This, therefore, makes drawing general conclusions about the results of weed control trials, difficult to make. Breitenbach et al⁸¹ concluded that the yields for Roundup Ready varieties and conventional varieties are about the same;
- Horak et al (1998) and Wait et al (1998) suggest that in the early years of adoption, some farmers may have experienced yield losses from using herbicide tolerant soybeans because they applied the glyphosate too early and the crop suffered from weeds emerging after spraying.

Table 51: US soybean yields: herbicide tolerant soybeans vs conventional varieties (1996-98: % difference)

Region	1996	1997	1998
Heartland	-2.4	+13.6**	+4.4
Mississippi Portal	+2.8	-6.2	-3.6
Northern Crescent	I/D	-4.6	+4.8
Prairie Gateway	I/D	+21.0**	+24.2
Southern Seaboard	I/D	+13.3*	+21.4
Eastern uplands	I/D	I/D	-8.0

Source: USDA (1999)

Notes

Herbicide tolerant varieties include Roundup Ready and STS varieties

I/D = insufficient data to estimate

Difference in yield cannot necessarily be attributed solely to the seed technology used.

** significantly different from all others at the 5% level

* significantly different from all others at the 10% level.

What the conflicting evidence cited above highlights is that determining the impact of herbicide tolerant soybeans on yields is complicated and not always straightforward. When GM soybeans were first commercialised, yield data relating to impact was fairly limited and hence, most of the early published studies were based on field trial data, which have either been on yield trials or weed trials. Alternatively much early analysis examined only a single or two years of data.

More recently published analysis from other countries (Canada and Argentina) that covers commercially grown crops and relates to a number of years found:

- in Canada farmer survey-based research by the Council for Biotechnology Information (2002) identified a 0.3% higher yield for Roundup Ready soybeans relative to conventional soybeans grown in Ontario in 2001 (0.1% higher yield in 2000). Overall, these yield differences were considered by the researchers to be statistically insignificant;

⁸¹ University of Minnesota (1998).

- Qaim & Traxler (2002) also undertaking farmer survey work, found no difference between the average yield of GM soybeans and conventionally grown beans in Argentina for the period 1998-2000 (Table 53)⁸².

Lastly, Benbrook (2002), in reviewing a number of studies that have looked at yield drag issues concluded that yield drag exists, but that this was counterbalanced in Roundup Ready crops by improved weed control and reduced levels of plant injury from herbicides. Benbrook's overall conclusion was, therefore that Roundup Ready soybeans tend to yield at about the same level as equivalent conventional varieties.

A 5.1.3 Impact on production costs

The potential for achieving lower production costs from use of the technology stems primarily from more efficient weed control. As indicated above, conventional soybean production systems, control weeds mainly through the use of a combination of pre-emergent and post-emergent herbicides. However, although the use of sophisticated weed management system, based on using a mix of herbicides delivered reasonably good control levels, such a regime is perceived by some farmers to have a number of downsides (source: Gianessi & Carpenter 2000). These included the following:

- *Potential for crop injury*: this included stunted growth, leaf yellowing, reddening of leaf veins, speckling and burning. This could result in yield loss and contribute to delayed canopy closure, which in turn facilitated increased weed competition. The way around this problem was to apply herbicides in low dosage rates, which necessitated application when weeds were relatively small. However, this practice could result in incomplete weed control;
- *Development of herbicide resistant weeds*: as Imidazolinone, Sulfonylureas and Sulfonamide herbicides all have the same mode of action⁸³, several resistant (to ALS acting) weed populations have developed in parts of the Mid West part of the US (eg, waterhemp, shattercane, cocklebur). This has reduced the effectiveness of these herbicides;
- *Adverse effect for follow-on crops*. For example, maize (commonly planted after soybeans in a rotation) is susceptible to damage from some of the Imidazolinone herbicides commonly applied. Guidelines for use of these herbicides also suggest waiting up to 40 months before planting crops like sugarbeet or oilseed rape.

Herbicide tolerance (to glyphosate) is perceived to offer farmers the potential to simplify their weed control activities and to provide added flexibility to weed management practices. More specifically, it provides a wider herbicide application window, both in terms of control of larger weeds and the stage of growth, making management of weeds easier. It is also perceived to minimise any knock-on effects (residual nature of some herbicides in the soil) for rotation/subsequent crops that may arise with some other herbicides (eg, Imidazolinone). There may also be less incidence of crop damage for some farmers. Manufacturer's recommendations for use or application of Roundup therefore offered scope for savings in herbicide costs mainly because less herbicide is required to be used, in fewer spray runs⁸⁴.

⁸² In the first 2 years of adoption, RR soybeans yielded slightly lower yields. Qaim & Traxler suggest this was because the GM trait had only been put into a limited range of varieties and did not include some of the leading varieties

⁸³ Inhibiting the acetolactate synthase (ALS) enzyme.

⁸⁴ The number of spray runs recommended may vary by farm location and weed incidence. However, it may provide for one run instead of two/ three or two runs instead of three plus. A 1998 survey by Monsanto reported that in 1996 and 1997 about three quarters of Roundup Ready soybean farmers only applied one spray run of glyphosate and about a quarter applied two runs (only 1% applied three or more runs).

Empirical evidence examining the effect of adoption of herbicide tolerant soybeans on production costs and whether these perceived benefits have arisen are summarized below. As with the research into impact on yields, there have been differences in the conclusions drawn in some of the studies:

- 1997 survey-based data from the USDA (1999) identified that in the majority of US soybean growing areas the number of herbicide treatments was lower with Roundup Ready varieties (Table 52);
- The cost of using glyphosate (Roundup) on herbicide tolerant US soybeans (including technology fee⁸⁵) in 1998 was about \$16/acre (\$39.54/hectare) compared to a range \$14/acre (€34.6/hectare) to \$25/acre (\$61.77/hectare) for conventionally grown soybeans – the lower end of the conventional range was with a pre-planting treatment only and the higher end for a weed control programme using other combinations of herbicides and spray frequencies (source: USDA) 1999);
- Duffy (2001), examining impact on a random sample of 162 soybean fields in Iowa (2000) found that GM soybeans used 17% less herbicide than the non GM counterpart (- \$15.25/hectare), but when the cost of the seed premium and technology fee was taken into consideration the net impact on costs was negligible (ie, GM and non GM soybeans had the same variable costs of production). This did not however, take into account convenience/flexibility benefits and reduced harvesting crops (cleaner crops) that Duffy attributed to be the main reasons for adoption;
- A \$36-\$38/hectare saving on herbicide costs was reported by Furman and Selz (1998). Marra & Hubbell (1997) estimated the cost reduction at \$36-\$49/hectare, Lin et al (2001) estimated the weed control cost savings to be \$8.65/hectare, Moshini (2000) estimated the saving to be \$14.8-\$27.1/hectare and Moshenek (1997) put the benefit at \$22/hectare if only one glyphosate application was used;
- Farmer survey research undertaken for the Council for Biotechnology Information in Canada (2002) found that for growers in Ontario, GM soybean variable costs were Can \$48/hectare lower than the variable costs for conventional soybeans. This was due to savings of about Can \$80/hectare on herbicide costs, offset against additional seed costs of Can \$32/hectare.

Table 52: Soybean herbicide treatments biotech vs conventional (1997)

	Biotech – Roundup Ready	All other
Heartland	1.80**	2.34
Mississippi Portal	2.09**	2.62
Northern Crescent	2.22	2.15
Prairie Gateway	2.02	2.01
Southern Seaboard	1.04**	2.14

Source: USDA 1998

Note:

⁸⁵ Roundup Ready soybeans were sold in the USA via a technology fee based system. Farmers signed a licence agreement on a per bag of seed fee basis. In 1996 the fee was \$5/lb bag and at that time the licence also required farmers to use only Roundup brand herbicides (ie, sold by Monsanto). This was widened in 1999 to allow the use of other (non Monsanto) glyphosate-based products and from 2002 the technology fee system was changed in favour of a royalty system. The key point to note is that under the technology fee system the technology provider was effectively receiving a fixed fee per bag of seed sold whilst now under a royalty system, the technology provider receives a % based share of seed sales and the ‘technology fee’ is now currently operating like a seed premium. US soybean farmers also have not been restricted to using only Roundup brand herbicides since 1999 and can use alternatives (Monsanto lists approved alternatives where it has reached agreements with other suppliers and the product has been tested on the Roundup Ready soybeans – farmers could technically use ‘non authorised’ glyphosate products but if there was crop damage, Monsanto will not accept any liability for such crop failure)

Herbicide treatments are the number of different active ingredients applied per acre times the number of repeat applicants.

** significantly different from all others at the 5% level.

In Argentina the adoption of Roundup Ready soybeans is estimated to have resulted in a 15% reduction in production costs (Pengue, 2000). Groves (1999) put this cost saving (net of seed costs) to be \$25-\$30/hectare. In both cases, we have not been able to identify the bases for these estimates. The most comprehensive work on the impact of herbicide tolerant soybeans in Argentina has, however, been conducted by Qaim & Traxler (2002). This work is one of the most detailed pieces of research into the farm level impact of herbicide tolerant soybeans conducted in any country. The research involved interviews with 59 farmers in three provinces and covered regions where GM soybeans are concentrated (Buenos Aires and Sante Fe) and the region of Chaca where soybean production has been a fairly recent development. It examined impact over a three year period (1998-2000) and included a roughly 50:50 observation split between GM and conventional soybean production. Key findings from the research included (Table 53):

- The cost of the technology (ie, higher seed cost) was \$3.61/hectare (+21%);
- Herbicide costs decreased by \$14.54 hectare (-43%);
- Mainly as a result of increasing use of no/low tillage practices (the average number of tillage passes for herbicide tolerant soybeans was 0.69 compared with 1.66 for conventional soybeans, and the proportion of GM soybean farmers using no tillage practices was 80% compared to 42% for conventional soybean growers) and reduced harvesting costs, savings in machinery repairs/fuel and on hired labour have also arisen. These amounted to \$6.82/hectare on machinery repairs/fuel (-28%) and \$3.6/hectare (-8%) on hired labour;
- The total variable cost savings were estimated to be \$20.71/hectare (-9.7%).

It is difficult to gauge how representative this analysis is of GM soybeans grown in Argentina. However, the results are consistent with all other findings to date.

Table 53: Impact of herbicide tolerant soybeans at the farm level in Argentina 1998-2000 (\$/hectare)

	Conventional soybeans	Herbicide tolerant soybeans
Price of output	160	160
Yield	3.01	3.02
Revenue	482	483
<i>Variable costs of production</i>		
Seed	17.19	20.80
Herbicides	33.64	19.10
Other crop protection	13.55	13.82
Machinery fuel & repairs	24.25	17.43
Hired labour	46.82	43.22
Commercialisation	77.54	77.91
Total variable costs	212.99	192.28
Gross margin	269.01	290.72

Source: Qaim & Traxler (2002)

The examples above illustrate a range of savings. This reflects the fact that the potential for making savings depends on which weed control programme a farmer chooses. As growers tailor their control programmes to fit local weed pressures (at a field level), choosing herbicides and combinations of herbicides is very much a local issue. Consequently, the attraction of the

herbicide tolerant crop tends to be greatest where the weed pressure is greatest and has, in the past, necessitated a complex weed management programme that probably involved use of several active ingredients in a number of passes. As such, many of the early adopters of the new technology may well have been from those who fell within the category of growers with above average herbicide costs per hectare.

A second factor that has to be taken into consideration when examining the impact of the adoption of herbicide tolerant soybeans on production costs is the price of herbicides. The price of Round Up fell by 22% between 1996 and 1998 in the US (and a third over the period 1996-2001), whilst the price of conventional herbicides such as Chlorimuron and Imazethapyr fell by between 40% and 50% over the same period. As a result of these real price decreases, the aggregate expenditures on soybean herbicides in the 13 States covered by the USDA surveys of 1995 and 1998, fell significantly (by \$0.3 million from \$1.5 million in 1995). Extrapolated to the national level this suggested that the US soybean farmers paid out \$380 million less on soybean herbicides in 1998 than they had spent in 1995. Balancing this against the requirement to pay an additional technology fee for using herbicide tolerant soybeans (of an average of \$6/acre which equated to a total fee of \$160 million in 1998), this puts the net saving to US soybean farmers on weed control in 1998 at \$220 million.

Similarly in Argentina, the price of herbicides also fell. Glyphosate prices fell 53% between 1995/96 and 2000/01 and other herbicide prices fell by an average of 32% over the same period. This equates to a saving of about \$184 million on herbicide costs to Argentine soybean farmers in 2002 relative to pre-GM soybean herbicide costs.

A 5.1.4 Impact on farm profitability

The impact on farm profitability is ultimately determined by whether the perceived benefits of the technology (as advertised by the technology providers) are greater than the associated additional costs. Inevitably analysis of research findings into the impact of GM soybeans on farm profitability has produced a divergence of findings because of differences in findings on the impact on yield and costs of production. As indicated above, in the first two to three years of commercialisation of GM soy varieties in the USA, the main varieties available that offered herbicide tolerant were not necessarily the highest yielding varieties. Therefore adoption of the new technology sometimes resulted in some farmers switching away from the highest yielding varieties to lower yielding varieties containing herbicide tolerance. Not surprisingly where this resulted in negative impacts on yields post adoption of GM soybeans, the net impact on farm profitability is less positive (or possibly neutral or even negative) than in examples where the yield effect has been neutral or positive.

Secondly, one aspect of the impact on costs of production that can critically affect farm profitability is the amount of additional money farmers are required to pay to access the GM technology. Where studies identify little or no change (or even negative) to farm profitability after using GM soybeans, such studies are usually those that assume the highest average costs for using the technology or the lowest average costs for conventional production systems. All such analysis has validity although transparency in showing assumptions made helps the reader understand what the outcome might be in a number of 'what if' alternative assumptions.

In the USA, adopters have been required to pay a technology fee for using GM soybeans, which makes the cost of seed more expensive than conventional, non GM soybeans. Whilst this technology fee has varied since introduction, it has been equal to \$12 to \$17/hectare according to various studies⁸⁶ and therefore has effectively increased the seed cost by about 30%-35% relative to non GM soybeans. In contrast in Argentina, the scope for extracting a technology fee from

⁸⁶ For example, Duffy and Ernst (1998), University of Illinois (1999) and Furman & Selz (1999).

farmers has been much reduced relative to the US. Weak plant variety protection legislation, which allows the legal re-use of harvested (farm-saved) seed means that it is difficult to enforce rules that prohibit the farm multiplication of seed for re-sale. Partly due to this, about 50% of all soybeans sown in Argentina are thought to be of on-farm origin (compared to 5% in the USA). Due largely to this competition from farm-saved seed, the price of herbicide tolerant soybean seeds in Argentina fell from \$907/tonne in 1997 to \$397/tonne in 1999. Thus although the first transgenic soybean seeds were sold for a technology premium equal to about 100%, by 2001 they were selling at a premium of only 21% (+\$3.6/hectare: Table 53) to conventional seed (ie, in Argentina the technology is sold via seed premia only and farmers do not sign any licence agreements). The comparatively weaker intellectual property rights also facilitated the dissemination of the new technology through development of adequate germplasm. Whilst, all transgenic soybeans currently sold in Argentina are based on Monsanto technology, Monsanto has not been able to patent protect the technology. As a result other plant breeders (notably Nidera which supplies about two-thirds of all soybean seed in Argentina) have released transgenic soybeans with the Monsanto technology that are suited to Argentine growing conditions. The lack of patent protection (these plant breeders do, however mostly pay voluntary licence fees for the germplasm) has also stimulated the development of some herbicide tolerant varieties for regions that are less favourable for soybean production (if reasonable patent protection had existed these would probably have not been developed).

Taking into consideration both the possible savings associated with adopting herbicide tolerant soybeans and the counterbalancing factors associated with using the technology, the majority of the (limited) early empirical evidence available to date provided somewhat divergent evidence about GM soybeans resulting in profitability benefits to US farmers:

- Duffy & Vontalage (1999) suggested that differences in returns on land and labour were not significantly different between GM and non GM soybeans. However, if herbicide tolerant soybeans allow for savings in labour associated with the convenience effect then the same return is derived from less labour input, which in turn points to an increase in returns on labour⁸⁷. Duffy's later work (2001) drew similar conclusions that essentially there was little difference between returns of GM and non GM soybeans except lower harvesting costs of GM soybeans and an intangible benefit associated with additional management convenience and flexibility;
- Roberts et al (1999) compared returns to Roundup Ready and conventional soybean varieties from field trials in Tennessee for the years 1995-1997 and found that returns to the Roundup Ready varieties were 13% higher than the next best alternative (attributed to a combination of higher yields and lower costs);
- Arnold (1998) compared the three highest yielding Roundup and conventional varieties trialed in Mississippi and found that the net returns to the Roundup Ready varieties were \$60/acre (\$148/hectare) higher than returns to conventional varieties at two of the three trial sites;
- Webster et al (1999), however, found from trial data in Arkansas for 1997 and 1998, that two conventional trial programmes had the highest returns - \$92/hectare and \$122/hectare while only two of the Roundup Ready trial programmes had positive returns (\$35/hectare and \$39.5/hectare);
- A USDA study (1999) of plantings in 1997 also found no evidence of any significant change in variable profits⁸⁸. In contrast, Furman and Selz (1998) estimated the increase in profitability of using herbicide tolerant soybeans to be between \$14.83/ha and \$24.71/ha and Marra et al (1998) put the benefit at \$14.82/ha⁸⁹

⁸⁷ This work looked at 1998 crop data in Iowa from 365 soybean fields. It found that GM soybean yields were slightly lower than the conventional varieties but so were the costs of production

⁸⁸ Based on a survey of 800 farmers in Iowa in 1997

⁸⁹ Both these latter studies were based on field trial results rather than commercial plantings

More recent work undertaken includes:

- the Council for Biotechnology Information in Canada (2002), farmer survey work found that, for growers in Ontario, GM soybeans produced higher returns in the two years 2000 and 2001. This mainly reflected the lower variable costs of production (yields were roughly the same), which more than offset the small price premia available for non GM soybeans⁹⁰;
- Qaim & Traxler (2002) found a clear gross margin profitability benefit of \$21.71/hectare (+8%) in Argentina (Table 53);
- Gianessi et al (2002) revised (upwards) their estimated weed control cost savings associated with using herbicide tolerant soybeans that had been identified in earlier work to \$49.2/hectare relative to the alternatives that would have been used in 2001, if Roundup Ready soybeans had not been available⁹¹.

As indicated above, some of the US-based empirical evidence suggests conflicting evidence for the impact on profitability. This is not surprising given the wide range of climatic and weed pressure differences faced by farmers and the different baseline information used in different studies (eg, base yields and costs). Overall, examining impact on profitability the following points should be taken into consideration:

- Making comparisons between yields, performance, costs of production and returns to herbicide tolerant versus conventional varieties is not straight forward. As the studies to date illustrate the results may be due to the technology but equally may be due to other factors such the yield potential of a variety, the skill of the adopter/non adopter, region and underlying (local) weed incidence;
- None of the US studies have examined commercial impact over a number of crop years. This is important if factors such as weather, which can significantly affect annual yields and performance are to be adequately taken into consideration. Additionally, annual fluctuations in prices can significantly affect returns, hence the need for longer term studies. More recent work in Canada and Argentina (see above) that looked at more than one year found that GM soybeans were delivering improvements in profitability relative to conventional soybeans;
- Much of the early US analysis was based on yield trial performance data rather than observed differences in commercial production systems;
- In the first two to three years of adoption that early US studies looked at (and some more recent ones that cite some of the earlier US-based work⁹²), herbicide tolerance did not tend to be available in the highest yielding varieties. It is likely that plant breeders have, to a large extent, caught up with this, and herbicide tolerance is now available in more of the highest yielding varieties (this will reduce and/or eliminate the counterbalancing effect of lower yields, referred to above). This has been confirmed to the authors of this research, as the leading five varieties in the USA (in terms of sales) are reported to be herbicide tolerant and these varieties all have the same yield potential as the leading five non GM varieties⁹³;
- As the convenience factor can be difficult to quantify, its impact has not tended to be included in the assessments of the impact on profitability in the USA. This has included impact on labour, machinery and harvesting costs. These issues are discussed further below, although some quantification of the beneficial impact of

⁹⁰ In 2001 non GM soybeans had a 1.1% price premia relative to GM soybeans, whilst in 2000, the premia was 3.8%

⁹¹ In other words taking into account reduced effectiveness of previously used alternative herbicides, due to increasing problems of weed resistance. The Gianessi et al (2002) was based on desk research/analysis and a survey of agronomists

⁹² For example Soil Association 2002

⁹³ American Soybean Association (2003) personal communication

using GM soybeans on labour and machinery use is cited in the Qaim & Traxler (2002) for Argentina;

- It should be noted that in all soybean studies to date, both GM and non GM soy have been assumed to sell for the same price. Only the Council for Biotechnology Information, farmer-based study in Canada identified a price differential (in favour of non GM supplies), although there is also anecdotal evidence⁹⁴ that some US farmers growing GM soybeans have received premia for supplying cleaner seed to crushers (ie, with lower levels of weed impurities). This highlights the lack of price differential at the farm level in North America. Where a price differential in favour of non GM soybeans has developed it has tended to be small (1%-4%).

Given these factors, it is likely that herbicide tolerant soybeans did (and continue to) provide profitability improvements (and convenience benefits: see below) for the majority of adopters in the early years (in both the US and Argentina). If this were not so, then the rates of adoption would probably have fallen after the first year or two, as expectation of higher returns did not materialise. Certainly, it is unlikely that the adoption rate would have continued to increase and be maintained at the high levels reported (nearly three-quarters of US and 98% of Argentine soy plantings in 2002) unless some profitability benefit was evident. Claims made by some, for example, the Soil Association 2002, that one reason for farmer adoption of GM soybeans in the US can be attributed to ignorance is not supported by the evidence of take up. Whilst it is reasonable to assume that ignorance may have contributed to adoption in the first year or two of adoption, farmers would have quickly realized if the technology was delivering a positive return or not and if it had failed to do so, would have stopped growing the GM version. Other suggested reasons for continued (reluctant) use of herbicide tolerant soybeans in the US cited in the Soil Association's report of 2002 such as there being limited competition and availability of non GM seed (and non GM seed being inferior varieties) is also not supported by evidence from the US. There are some 112 seed supplier companies in the US of which, 12 are owned by biotechnology companies. There are about 2,000 varieties of soybean available to growers, of which 1,200 have the GM herbicide tolerance trait (ie, 800 are non GM). The leading five non GM varieties also offer the same yield performance as the leading GM varieties.

Lastly it is also important to recognize the importance of the more intangible convenience benefits as a major positive factor for adoption. This alone has probably been an important driver behind the widespread and rapid levels of adoption in both the USA and the Argentine. In the US this has probably been the main reason behind the rapid take-up of the technology. In Argentina, where the costs of using the technology are lower than in the USA, the likely more apparent profit benefit coupled with the convenience have been the main drivers of take up.

A 5.1.5 Convenience and other farm economic effects

Although these types of impact are sometimes more difficult to quantify, studies of the impact of herbicide tolerant soybeans have frequently cited GM adopting farmers as having identified the following reasons for adopting GM soybeans (eg, USDA 1999, Gianessi & Carpenter 2000, Qaim & Traxler 2002, Duffy 2001, Benbrook 2001):

- Increased management flexibility that comes from a combination of the ease of use associated with glyphosate and the increased/larger time window for spraying;
- Treatment can be made when the crop is well established and less vulnerable to the herbicide (less risk of crop damage);
- Facilitates the adoption of conservation or no tillage systems. This provides for additional cost savings such as reduced labour and fuel costs associated with ploughing;

⁹⁴ Source: US Soybean Association (2003), personal communication

- Has contributed to reduced harvesting costs – cleaner crops have resulted in reduced times for harvesting.

As indicated above, quantifying these impacts is difficult, although, as indicated above (Table 53), research by Qaim & Traxler (2002) was able to quantify some of these in Argentina (a \$3.65/ha saving (-7.8%) in labour costs and a \$6.82/ha (-28%) saving in machinery/fuel costs. Also farm surveys (eg, Duffy (2001) in the US and Qaim & Traxler (2002) in Argentina) have identified this convenience impact being cited by a significant proportion of farmers as a reason for using GM, herbicide tolerant soybeans.

A 5.1.6 Other issues impacting on farm profitability

Possible development of glyphosate resistant weeds and weed shifts

The development of weeds resistant to herbicides is not a new development in agriculture. It occurs mostly when the same herbicide(s), with the same mode of action have been applied on a continuous basis over a number of years.

As glyphosate is the primary herbicide used in GM (herbicide tolerant) soybeans and the planting of GM soybeans may have encouraged increased use of no/low tillage practices (this was nevertheless a trend occurring before herbicide tolerant crops were launched), it is possible that these factors could lead to the emergence of weeds resistant to glyphosate and to weed shifts towards those weed species that not well controlled by glyphosate. In addition, it is possible that herbicide tolerant soybean plants could become volunteers in a subsequent crop which cannot be controlled by using glyphosate. Evidence to date on these issues⁹⁵ suggests:

- Limited instances of glyphosate resistance in weeds have been reported in Australia with ryegrass and in the USA with ryegrass, horseweed, marehail and water hemp (Van Gessel 2001, Heap 2000 and Harzler 1999). In all cases these examples of resistance build up were in conventional crops;
- Any possible development of weed resistance to glyphosate that is thought likely, by some analysts, to be at slower rates of development for many other herbicides because of its mode of action, chemical structure, limited metabolism in plants and lack of residual activity (Bradshaw 1997). This assertion is to a large extent backed up by the very low incidence of glyphosate resistance having been developed globally by weeds, given the 20 years plus of extensive use of glyphosate;
- The potential for weeds in herbicide tolerant soybean crops evolving resistance might currently be low but may occur in the future. For example, Benbrook (1999) refers to this possibility in respect of water hemp and cites an increase in the average rate of glyphosate applied (in kgs of ai) on herbicide tolerant crops between 1996 and 1998 as possible evidence of poor control by glyphosate on some weeds, necessitating higher dosage applications and/or additional spray runs on the crops;
- Shaner (2000) suggests that glyphosate resistance, whilst likely to develop in the long run, will not be the primary problem that farmers will face. Weed shifts are likely to be occur more rapidly than selection for resistance and therefore farmers will eventually have to supplement their glyphosate treatments with other herbicides to give adequate weed control. The weeds most likely to increase in frequency will be those with natural tolerance to glyphosate (eg, in soybeans *Abutilon theophrasti*, *Amaranthus rudis*, *Ipomoea* spp) or ones that can avoid being treated due to germination and emergence patterns. Benbrook (2002) is also of the view that 'as a result of weed shifts and slipping efficacy of Roundup in the control of some weeds, most US farmers growing Roundup Ready soybeans now apply 1 to 3 active ingredients in addition to glyphosate'. Benbrook goes on to suggest that the net cost of these treatments (including the technology fee) are

⁹⁵ See Hin et al (2001)

similar to the weed control programmes of conventional soybeans and therefore the net impact on farm returns of using this Roundup Ready-based system leads to no significant difference to growing conventional soybeans;

- There are no reports having been found of herbicide tolerant volunteer soybean plants being problems in subsequent crops, that could not be easily controlled in the period 1995 and 1999⁹⁶ (Hin et al 2001);
- weed resistance build up to other herbicides used on conventional soybeans (and other crops) may have contributed to the popularity of glyphosate tolerant soybeans. For example, an alternative to GM herbicide tolerant soybeans is the conventionally produced herbicide tolerant soybeans that are tolerant to sulfanylurea herbicides. Varieties containing this tolerance were developed in the late 1980s and early 1990s and accounted for about 10% of total US soybean plantings in 1998. This area planted has subsequently fallen (eg, to 7% in 1999) with the products limited market take-up (compared to Roundup Ready soybeans) because of its lower levels of average yields and reported weed resistance to this type of herbicides in 69 weed species (Hin et al 2001). This factor (in relation to problems of weed resistance to sulfonyleurea and imidazolinone herbicides) is also cited by Benbrook (2002) and Baldwin (2002) as a contributory factor in the popularity of Roundup Ready soybeans in the USA.

A 5.1.7 Summary of evidence on impact

Summarising the evidence to date on the impact of GM soybeans on farm profitability:

- Impact on yield has been largely neutral. Early studies in the US produced some conflicting evidence and found some examples of negative impact on yields and some examples of positive impact. This conflicting evidence partially reflected the limited nature of some studies (eg, trials data or for one year only). In addition, factors such as the early GM soybeans being in varieties that were not necessarily leading varieties may have contributed to negative yield impacts being reported. More recent and longer term studies, notably in Canada and Argentina suggest the yield effect is, on average, neutral (around this average there will be examples of some who experience positive and negative impact on yields);
- Impact on costs of production and profitability has, on balance probably been positive. As with yield impact, conflicting evidence, where found has often been related to the early years of adoption, where instances of negative impact on yields were sometime reported and when the cost of the GM technology was at its highest (the costs have fallen in subsequent years). More recent and detailed work, again notably in Canada and Argentina, suggests improvements to the average levels of profitability and to reductions in average costs of production. Around this average, there will be found instances of some farmers who have made greater levels of savings or profitability improvements and others who have experienced more limited benefits (and possibly net negative impacts). Where farmers have experienced low levels of positive returns these are often farms for which the level of weed problems have tended to be limited or, conversely where weeds may have become less susceptible to glyphosate;
- intangible benefits are cited as important reasons for adoption by many farmers. These include reductions in labour, machinery and harvesting costs, for which most US-based studies have not quantified. Quantification of some of these benefits has been provided in a limited number of studies (eg, in Argentina).

⁹⁶ The Soil Association (2002) suggests herbicide tolerant soybean volunteers are a problem, but cite only one farmer as an example indicating this is a problem in subsequent crops. No indication is given as to how representative this example is or of the additional costs incurred in dealing with the problem

A 5.2 Herbicide tolerant oilseed rape

Herbicide tolerant oilseed rape has been commercially available to North American farmers since 1996 in Canada and 2000 in the USA⁹⁷. In 2002, 65% of the Canadian crop (2.9 million hectares) was planted to GM varieties and an additional 20% to non GM (herbicide tolerant) varieties, leaving 15% planted to conventional varieties not tolerant to herbicides. In the USA, 0.41 million hectares were planted to GM varieties, equal to 67% of total US oilseed rape plantings in 2002. Ninety five per cent of the US GM crop was Roundup Ready oilseed rape in 2001 (Coleman 2001).

Empirical studies that have examined the farm level impact of using herbicide tolerant oilseed rape are much fewer in number than studies on herbicide tolerant soybeans. The evidence presented below summarises impact from all publications identified in the course of this review.

A 5.2.1 Conventional weed control

Weeds represent a significant problem for growers of oilseed rape. They can contribute to reduced yield and can impair quality by contamination (eg, wild mustard seeds cause processing problems, being high in erucic acid and glucosaminates). Uncontrolled, the negative impact on yield in North America has been estimated to be within the range of 19% to 77% (Kirkland 1995).

Conventional treatment for weeds in North America has focused on the use of a mix of herbicides including trifluralin, ethalfluratin, sethoxydim and quizalofop. These herbicides have provided reasonably good control, with spraying both pre and post emergence, although some resistant weeds have developed (eg, to trifluralin). Another problem reported as been sensitivity in the oilseed rape crop to herbicide carryover from treatments made on preceding crops like cereals and soybeans (sensitivity to herbicides such as chlorsulfuron, imazethapyr and methribizin).

The relative importance of weed control to oilseed rape producers can be illustrated by reference to the importance of expenditure on herbicides relative to other forms of crop protection. For example, in Canada expenditure on herbicides accounted for almost all (95% plus) of total crop protection expenditure on oilseed rape (2000: Canola Council 2002). Within the European context, herbicides account for about 60-65% of total crop protection expenditure on oilseed rape in most countries (eg, UK, France, Germany) and 95% of crop protection expenditure in Sweden.

A 5.2.2 Impact on yield

Of the studies carried out on GM oilseed rape in North America and Australia, the following yield impacts have been identified:

- Jenks (1999) reported that a move to a single application of glyphosate produced an increase in yield of 6% (0.15 tonnes/ha) in the USA⁹⁸;
- In Canada analysis undertaken by the Canola Council in 2001⁹⁹ (Table 54) and based on a survey of 650 oilseed rape farmers (each growing an average of over 198 hectares of oilseed rape) of which 50% respectively were growers of herbicide tolerant oilseed rape and 50% grew conventional varieties found an average 10.7% yield increase and improved quality of harvested seed (lower docking %) from using GM seed in 2000;

⁹⁷ There are 2 types of herbicide tolerant oilseed rape available; Roundup Ready oilseed rape which is tolerant to glyphosate and LibertyLink, tolerant to glufosinate. In addition, a mutagenic (non GM) herbicide tolerant oilseed rape is available. This is Clearfields, tolerant to imidazolinone herbicides

⁹⁸ Cited in Gianessi et al (2002) without further detail

⁹⁹ In addition, 13 detailed case studies of a cross section of farmers in the main oilseed rape growing were conducted. These more detailed analyses covered practices over the period 1997-2000 rather than the single year, which was the focus of the main survey

- Fulton & Keyowski (1999), using 1999 estimates by the Pioneer Grain Company identified, for Canada, the same yields for conventional open pollinated seed with GM Liberty Link seed, but a net yield loss of 7.7% for Roundup Ready oilseed rape relative to these two alternatives (ie, an estimated average yield of 31.5 bushels/acre compared to 35.7 bushels/acre for conventional open pollinated seed and Liberty Link (GM) seed);
- A comparison of conventional and GM variety yields in Alberta (1998: Alberta Province)¹⁰⁰ found a range of yield differences from +15% to -15%. Overall in black soil areas conventional 'Argentine' varieties delivered the highest yields, followed by herbicide tolerant varieties and Polish varieties had the lowest yields. In dark brown soil zones, yields of GM and conventional (Argentine) varieties were similar;
- Zand & Beckie (2002) estimate that Invigor hybrid oilseed rape has been providing an average 10%-15% yield benefit relative to open-pollinated varieties in Canada. This is consistent with forecasts being used by Bayer (2003a) which expect Invigor hybrids to deliver a 10%-20% yield improvement in Australia;
- Nelson (2003) estimates that the likely impact of adopting herbicide tolerant oilseed rape will lead to an average 8% yield increase across the whole Australian sector (this derived from a variety of effects including benefits from being able to plant early, improved weed control and significant yield gains (+20%) for farmers who had previously used triazone-tolerant (ie, herbicide tolerant from conventional technology) oilseed rape¹⁰¹

Early analysis, some of which was based on trials/estimates, identified some examples of net yield decreases from adoption of herbicide tolerant varieties and examples of net yield increases. Later more comprehensive (farmer survey based) work has tended to identify net yield gains from using herbicide tolerant oilseed rape, although there is a broad range of responses with some farmers experiencing a gain and others losses. Although no papers researched have examined the issue, it is possible that, as in soybeans, the early GM varieties available may not have been in leading varieties (this was also a time when new, conventionally bred hybrid varieties of oilseed rape became available).

Examination of the yield impact of herbicide tolerant oilseed rape in the EU is more limited. The only data identified to date includes:

- Forecasts based on trials data from France (Messean 1998) of glyphosate tolerant oilseed rape were reported to have shown a yield increase of 15%;
- trials of glufosinate tolerant oilseed rape (with early manifestation of the GM hybrid component) have shown improved (yield) performance relative to conventional open pollinated varieties and broadly similar performance relative to conventional hybrids (Booth et al 2002);
- recent UK farm level trials conducted in 2002 (containing improved GM hybrid vigour relative to earlier generations of seed) have shown yield gains of 14% for winter oilseed rape and 22% for spring oilseed rape (BayerCropScience 2003). In 2001, the yield gain was estimated to be about 9%.

¹⁰⁰ The Economics and Statistics Branch of Alberta Province, cited in Economic impacts of genetically modified crops on the agri-food sector, European Commission (2000)

¹⁰¹ This type of herbicide tolerant oilseed rape is planted on 55% of the Australian crop and suffers a significant yield penalty relative to other varieties. It is however popular because it permits farmers to spray a post emergent herbicide for control of troublesome weeds, which otherwise would have a significant negative effect on yield

A 5.2.3 Impact on costs of production and profitability

USA

- Jenks (1999) identified that where farmers moved to a single application of glyphosate, this increased returns by 12% (+\$44.48/hectare);
- Gianessi et al (2002), based on desk research/analysis and surveys of agronomists, estimated that growing of herbicide tolerant canola resulted in a \$31.26/hectare saving in North Dakota, based on a comparison of conventional herbicide costs of \$85.62/hectare relative to herbicide tolerant crop control costs of \$54.36/hectare (inclusive of seed premium and technology use fee).

Canada

The analysis undertaken by the Canola Council in 2001 (Table 54 overleaf) found:

- The main cost burden of using the new technology was the technology fee and seed premium which added \$Can 44.63/hectare (+17%) to variable costs in 2000;
- GM seed users had a slightly higher usage of fertilizer, although the differences were not statistically significant;
- Significant cost savings were made on herbicide costs (+\$20/hectare). There were also savings on tillage/harrowing, and crop scouting and weed control services. In total, these savings amounted to about \$39/hectare in 2000;
- The use of GM seed resulted in a net increase in total variable costs (seed premia and technology fee) of about \$12/hectare (+4.6%) in 2000. This was, however more than offset by the revenue increase associated with yield (and quality) enhancement;
- Overall, the use of GM seed resulted in an increase in gross margin of almost one third (+ \$26/hectare) in 2000. The margin of error around this mean was put at 5.5%;
- For a number of case study farms, the results of which were not fully representative of all farms and for which data was collected over the period 1997 to 2000, the average yield improvement of GM varieties was +15.6% (+Can \$ 0.3 tonnes/hectare) and the average improvement in gross margins was 45% (+ Can \$41.3/hectare).

In contrast, data presented in Fulton & Keyowski (1999), which related to estimates made for growers in Saskatchewan in 1999 (by the Pioneer Grain Company) identified conventional open pollinated canola as delivering the highest returns (Can \$242.13/acre) with Liberty Link (GM) and Roundup Ready (GM) canola delivering returns that were respectively 1.7% and 7% lower than conventional open pollinated varieties. It should however be recognised that this data related to canola grown in one year, in one region and were estimates, not reported survey results.

Lastly the work cited in the European Commission's report of 2000 (Alberta simulations for 1998) found:

- On black soil zones, conventional Argentine varieties produced the highest gross margins (€163/ha) compared to margins of €131/ha for herbicide tolerant varieties and €76/ha for conventional Polish varieties;
- In dark brown soil regions herbicide tolerant varieties produced the highest gross margins (€84/ha) compared to €48/ha for conventional Argentine varieties. The main reasons for this difference in returns were lower costs of crop protection products used (-€4/ha or - 11.4%) and lower use of fertiliser (-€12/ha or - 25%).

Table 54: Comparative returns, costs and gross margins: herbicide tolerant (GM) versus conventional oilseed rape (2000: \$Canadian/hectare)

	Conventional	GM	Difference	% difference
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Yield (tonnes/ha)	1.78	1.97	0.19	+10.7
Dockage %	5.14	3.87	-1.27	-24.7
Yield after dockage (tonne/ha)	1.70	1.892	+0.192	+11.3
Price/tonne	201	201		
Revenue/hectare	342	380	+38	+11.1
Variable costs				
Seed & application	54.7	72.77	+18.07	+33
Herbicide & application	74.0	54.26	-19.74	-26.7
Tillage/harrowing	40.5	22.83	-17.67	-0.44
Fertiliser	85.87	92.04	+6.17	+7.2
Weed control/scouting	4.74	3.29	-1.45	-0.31
Technology use fee	0.0	26.56	+26.56	
Total variable costs	259.81	271.76	-11.95	+4.6
Gross margin	82.19	108.24	+26.05	+31.7

Source: An Agronomic and Economic Assessment of Transgenic Canola (2001), Canola Council of Canada

In Australia, modelling work of the potential impact of using herbicide tolerant oilseed rape suggests that there will be a saving on total variable production costs of 3% (Nelson et al (2001). Later work by the same author (2003) suggests that the cost saving will be Aus \$10/ha, based on a reduction of Aus \$35/ha in herbicide costs less the technology fee of Aus \$25/ha.

A similar pattern to that identified for the impact of herbicide tolerant soybeans appears to have occurred for herbicide tolerant oilseed rape. Some analysis has found examples of net negative impacts of using herbicide tolerant varieties, whilst others have found examples of improved returns. On balance, it is likely that herbicide tolerant oilseed rape has provided profitability improvements for the majority of adopters in the early years (in both the US and Canada). If this were not so, then the rates of adoption would probably have fallen after the first year or two, as expectation of higher returns did not materialise. As in the case of GM soybeans, it is unlikely that the adoption rate would have continued to increase and be maintained at the high levels reported (about two-thirds of the total crop area in both the USA and Canada in 2002) unless some profitability benefit was evident.

A 5.2.4 Convenience and other farm economic effects

As in the case of herbicide tolerant soybeans, GM (herbicide tolerant) oilseed rape may have provided some additional 'convenience' benefits, for which few studies have attempted to make quantifications. These include:

- Increased management flexibility that comes from a combination of the ease of use associated with glyphosate or glufosinate and the increased/larger time window for spraying. Overall, this convenience from having easier and better weed control was cited by 50% of the farmers using herbicide tolerant oilseed rape surveyed by the Canola Council (2001) as the main reason for adoption. Post adoption, 81% of users indicated that weed control effectiveness had been improved;

- Where the herbicide tolerant crop is based on glufosinate, this provides growers with an additional herbicide for use in rotations that has not generally been used in other grain crops (Norton 2003). This has the potential to provide an additional product for dealing with herbicide resistant weeds;
- Increased rotational flexibility (Norton 2003). As herbicide residues affect crop rotations (eg, amazpr is highly persistent in the soil and therefore it has up to a 34 month interval before oilseed rape can be grown after use), the use of glufosinate and glyphosate tolerant crops (which are much less residual in the soil than for example imazapyr or atrazine) will enable growers to delay crop selection and provide additional flexibility in case of early season crop failure;
- Treatment of canola typically involves use of two herbicide applications, one pre and one post emergent, although in some cases only one application is required. The use of herbicide tolerant crops facilitates removal of competition for moisture and nutrients between the crop and weeds and reduces costs for additional machinery movements over fields (Fulton & Keyowski 1999);
- Facilitates the adoption of conservation or no tillage systems (ie, it may contribute to an accelerating the rate of adoption of these systems). This provides for additional cost savings such as reduced labour and fuel costs associated with ploughing;
- Has contributed to reduced harvesting costs – cleaner crops have resulted in reduced times for harvesting and less docking of payments (penalties) on poor quality grounds;
- Norton (2003) cites (based on trials findings) that Invigor oilseed rape produces an average increase in the oil content of oilseed rape of 2%. Evidence from farm level trials in the UK (Bayer CropScience 2003) supports this finding with an increase in oil content found of 1.5%.

The Alberta simulations work from 1998 reported in the EU Commission's work of 2000 found that herbicide tolerant crops had the lowest level of capital costs (associated with labour and machinery use) with an average of €75/ha costs in Black soil regions compared to €92/ha and 102/ha respectively for conventional Argentine varieties and conventional Polish varieties. In the dark brown soils region, however capital costs between herbicide tolerant and conventional Argentine varieties were similar.

The Canola Council survey (2001) identified savings from reduced fuel use equal to between 12.6 and 15.56 litres/ha. This was equal to a saving of Can \$ 5.3/ha and Can \$ 6.53/ha.

A 5.2.5 Other issues impacting on farm profitability

Possible development of glyphosate resistant weeds and weed shifts

In the case of herbicide tolerant oilseed rape there are two main herbicide resistant crops, glyphosate and glufosinate resistant crops. (there is also a non transgenic herbicide resistant type (resistant to imidazolinone). It is therefore possible that focusing weed control strategies on 1-3 herbicides only could lead to the emergence of weeds resistant or less sensitive to these respective herbicides. In addition, it is possible that herbicide tolerant oilseed rape plants could become volunteers in a subsequent crop, which cannot be controlled by using the herbicide to which the volunteer is resistant. Evidence to date on these issues includes the following:

- The Canola Council survey based work in 2001 included questions of adopters about their management practices to avoid weed resistance and for volunteer management highlighting the point made earlier that farmers already adopt strategies to minimise the development of weed/pest resistance. About 60% of adopters in 2000 perceived that herbicide management to avoid weed resistance had been made easier, with only 7% perceiving it had been made more difficult (the balance perceived no change). In terms of volunteer canola management in subsequent crops 60% perceived that management was

about the same as before, 16% indicated it was easier and 23% thought it more difficult. These findings are not surprising because if resistance were to develop this would probably take a number of years to occur. However, problems with volunteers do not appear to be problem for most of the farmers surveyed;

- The Soil Association (2002) cite a press article in the Leader Post for 21 October 2001 which suggests that GM adopters may reduce their use of herbicides in the first year of adoption but then increase their use in subsequent years to deal with volunteers. The Soil Association report also gives examples of several Canadian farmers who have indicated problems with volunteer, herbicide resistant oilseed rape volunteers in subsequent crops. It is not stated how representative this is of all GM oilseed rape growers and data was provided as to how farmers have dealt with the problem;
- Work by English Nature (2002) cites examples of gene stacking and the development of some instances of the development of weeds resistant to more than one herbicide. The analysis suggested that out crossing is inevitable and that farmers (in the UK) would have to place greater emphasis on post harvest control of volunteers and that there might be increased use of herbicides other than glyphosate/glufosinate, as a pre-drilling treatment in oilseed rape crops. Green and Salisbury (1998) reviewed this possibility in respect of the crop in Australia and concluded that whilst there is a possibility of transfer of genes between different cultivated brassica species, the potential for hybridisation in the field, introgression of the herbicide tolerant trait and then stable expression in the progeny of weeds is considered to be a very low and manageable risk;
- Limited instances of glyphosate resistance in weeds have been reported (see A 5.2 soybeans) and in all cases these examples of resistance build up were in conventional crops, not GM crops;
- The issue of herbicide tolerant volunteers has been examined in Australia (Niknam et al 2002), in respect of non GM herbicide tolerant crops (triazine tolerant and imidiazolinone tolerant). This work concluded that volunteers of oilseed rape (conventional or herbicide tolerant) were not a significant weed in cereals or pulses (conclusion based a survey of farmers in Victoria) and where farmers did experience problems, they had many alternative herbicide options for dealing with the volunteers.

The potential for out crossing of herbicide resistant oilseed rape with non transgenic seeds is reported to be more likely in oilseed rape than soybeans (see examples cited above). The extent to which these problems, as well as that of volunteer (herbicide tolerant) oilseed rape in follow on crops, exist is not known in North America, as there are no current studies available on the subject.

A 5.3 Insect resistant maize

Insect resistant (Bt) maize is the second most grown GM crop globally, being planted in several countries including the USA, Canada, Argentina, South Africa, Spain, Germany and Honduras. In total, 7.7 million hectares were planted to Bt maize in 2002 with a further 2.2 million hectares planted as 'stacked' gene maize, containing both insect tolerance and herbicide tolerance genes. The vast majority of this maize is grown in the USA, where 24% of the total US maize crop in 2002 (about 7.7 million hectares) is planted to Bt maize. As indicated earlier, Bt maize is the only currently commercially available GM crop in the EU, where about 20-25,000 hectares of Bt maize were planted in Spain in 2002.

Research evidence examining the impact of using Bt maize are discussed below. As this form of GM crop is the only form commercially grown in the EU in 2002, we have focused on impact in the EU (ie, Spain) and made comparisons with evidence from the USA (the primary source for this is Brookes 2002). The Spanish work was based on data relating to over 500 farms growing Bt maize which accounted for about 10% of Bt maize grown in Spain.

A 5.3.1 Insect problems and conventional control measures

The European Corn Borer (ECB) is the main insect pest that attacks maize crops in Spain and an important pest in most other grain maize growing regions of the world. Nevertheless, its incidence and impact varies by region and year, being significantly influenced by local climatic conditions and planting times. For example, it is evident that of the regions where Bt maize plantings are concentrated in Spain these are regions with high to medium ECB pressure and 25% of maize planted in Spain is probably in regions classified as suffering high ECB pest pressure and a further 40% is in regions classified as suffering medium ECB pest pressure. A similar pattern of pest pressure and concentration of Bt maize use is exhibited in the USA, where ECB pressure is widely considered to increase westwards and the highest incidence of Bt maize usage is found in the more Western states of Kansas, Nebraska, and South Dakota and the more western parts of Iowa, Minnesota and Missouri¹⁰².

Maize farmers tend to use one of two main alternative approaches to dealing with ECB infestations. These are either treatment with insecticides or no active policy for treatment at all. In Spain 6%-20% of the total crop is treated with insecticides, hence a significant majority of crops are not treated for Corn Borer problems. Whilst a significant proportion of this can be attributed to low levels of ECB pest pressure (35% of the maize growing area in Spain has historically experienced low levels of ECB pest pressure), some of the crop that is not treated with insecticides is in regions which have traditionally suffered medium to high levels of ECB infestation levels. A similar pattern of limited use of insecticides to control ECB was found in the USA. For example, USDA (1985) estimated that 4% of the US Corn Belt only was treated with insecticides for ECB and other USDA surveys in Iowa and Illinois (1990) put the state level use of anti ECB insecticides at less than 5% of maize crops.

The main reasons why a significant proportion of the Spanish and US maize crops are not treated with insecticides that target Corn Borer are:

- A farm level perception of limited effectiveness of the insecticides: it may kill corn borers on the surface of the soil and plants at time of spraying but is less effective against corn borers that have bored into stalks. Also, egg laying can occur over a three week period and most insecticides are only effective for 7-10 days. In other words the insecticides are effective at time of spraying/soon after and would be effective if farmers initiated frequent spray programmes, however, practicalities, time requirements and cost considerations mean that actual practices are rarely optimal or economic;
- The insecticides may kill certain beneficial insects/organisms that are natural predators of other maize pests (eg, spider mites) and this then requires additional insecticide use to deal with spider mite attack;
- Timing of spraying is important to maximize effectiveness because sprays are effective only during a short period after eggs hatch and before larvae bore into stalks. Spray too early and the insecticides degrade before all larvae have hatched and spray too late and early hatches will have already bored into stalks. This requires management time for crop walking and being able to secure the services of aero plane sprayers when required. As such, it is not always possible to undertake frequent crop walking and/or to get spraying undertaken when required;
- The cost per treatment is widely considered to be high relative to perceived effectiveness;
- some farmers perceive some of the insecticides used to be difficult and hazardous products to use;
- ECB pest pressure varies and hence in some years damage may be limited;

¹⁰² Source: Fernandez-Cornejo J & McBride W (2002) Adoption of bio-engineered crops, USDA Agricultural Economics Report No 810

- Some farmers probably do not appreciate the level of damage to yields inflicted by the ECB (eg, some Bt maize users indicated that it was only after using Bt maize that they realized fully what adverse impact the ECB caused);
- some farmers appear to accept some degree of loss rather than incur the cost of (only partially effective) insecticide treatments. For example, many US farmers are perceived to be prepared to accept losses of 3%-6% before considering using formal methods of control like insecticides or Bt technology (Source: Fernandez-Cornejo J & McBride W (2002)).

A 5.3.2 Impact of yields

As indicated in the sub-section above, the damage that Corn Borer can cause to yield varies by location, year, climatic factors, timing of planting, whether insecticides are used or not and the timing of application. Not surprisingly, this means that the positive impact on yields of planting Bt maize varies. In Spain, Brookes (2002) identified the following yield benefits obtained from using Bt maize:

- an average 10% yield improvement (ie, 1 tonne/hectare on a base yield of 10 tonnes/ha) where insecticide treatments were previously used (Sarinena region of Huesca and an area of high average ECB infestation levels). The range of yield improvements being within a range of 5%-20% for the period 1998-2001;
- an average 15% yield improvement where insecticide treatments were not previously used (Sarinena region of Huesca and an area of high average ECB infestation levels). The range of yield improvements being within a range of 10%-40%;
- an average of 6.3% yield improvement on trial plots across a number of regions in 1997 – within a range of 2.9% to 12.9% yield improvement;
- 1%-1.1% average yield improvement (about 0.15 tonnes/hectare) average over the four year 1998-2001 – source: one farmer in the Barbastro area of Huesca – an area of low to medium average corn borer infestation¹⁰³.

These results show a number of similarities with findings from the USA. Without providing an exhaustive list of US-based studies undertaken since 1997, Table 55 below taken from Marra et al (2002) provides a summary of such works in recent years. The US evidence illustrates significant variation in impact by year and region, with a US average yield benefit of just over 5%¹⁰⁴, although in some of the main corn growing states of the Mid West the range was between 5.34% in Iowa and 13.69% in Minnesota (Table 55).

Table 55: Summary of farm level impact on yield of Bt maize in the US 1997-2000

State	Number of studies examined	Average yield benefit of Bt maize: tonnes/ha (1)	Average benefit %	Range
Corn Belt	6	+0.68	+8.12	+4 to +12.8
Illinois	4	+1.02	+12.26	+1.1 to +22.6
Iowa	5	+0.45	+5.34	+2.2 to +9.2

¹⁰³ This farmer indicated that, in his location 1998 had been an average level of attack for the area, 1999 and 2001 had seen little/no infestation and 2000 had been a higher than average year for corn borer attack

¹⁰⁴ Some others, notably Benbrook (2001) estimate the net yield benefit to US maize yields over the 1997-2001 period to be 3% but with states such as Colorado and Texas respectively experiencing the greatest gains. These two states have high annual ECB pest pressure (13% and 17% annual yield loss attributed to ECB attack) and accounted for 37% of the total US gains from using Bt maize yet planted only 6.3% of the area planted to Bt varieties

Kansas	3	+0.49	+5.87	+2.8 to +9.0
Minnesota	1	+1.14	+13.69	+13.69 to +13.69
Nebraska	2	+0.46	+5.57	+3.2 to +7.9
South Dakota	2	+0.65	+7.75	+5.8 to +9.7
USA as a whole	5	+0.42	+5.04	+2.5 to +9.0

Source: Taken from Table 7 of Marra et al (2002) The pay-offs of agricultural biotechnology: an assessment of the evidence, International Food Policy Research Institute

Note: In the original work, yield benefits are presented in bushels per acre. These values have been converted to tonnes/hectare and compared in % terms against an annual average US maize yield for the period 1997-2000 (the period in which most studies applied) of 8.345 tonnes/ha

% figures in column 4 have been rounded

A 5.3.3 Impact on costs

The main cost elements of maize production affected by any decision to use Bt maize are the additional cost of the Bt seed relative to conventional seed and costs expended on crop protection measures (ie, on insecticides). In addition, there may be some changes to labour and management costs.

The key relevant baseline costs for growing maize in (the Huesca region) Spain in 2002 were:

- €150/hectare seed costs;
- €14-€22/hectare agro-chemical costs comprising €0-€120/hectare herbicide costs and €24-€102/hectare insecticides (€24-€84/hectare for corn borer control and possibly €18/hectare for control of spider mites).

Where no insecticide control is used as the baseline (in regions of low to medium average ECB infestation levels like around Barbastro), insecticide use is usually zero, hence total crop protection costs are €0-€120/hectare for use of herbicides.

The impact of using Bt maize on these costs is:

- +€18.5/hectare for the Bt seed;
- for farmers who previously sprayed crops with insecticides to treat corn borer, - €24 to - €102/hectare savings occurred because they no longer needed to spray for corn borer infestation and, in some cases no longer had to also spray for spider mites (beneficial insects having been destroyed by use of insecticides for ECB control). Where the conventional crop was not subject to insecticide use, the impact on this element of cost is zero. It should also be noted that the prices of the main insecticides used to treat the ECB (chlorpyrifos and synthetic pyrethroids) have not changed significantly since Bt maize became available commercially in Spain (ie, there is no need to adjust downwards the value attributed to savings on insecticide use that might otherwise have occurred if the manufacturers of these insecticides had reduced prices as a competitive reaction to the launch of Bt maize).¹⁰⁵

In addition, there are marginal cost savings relating to labour/management time in crop walking and/or applying insecticides via irrigation systems. Also there may be savings in energy/fuel use where aerial spraying is no longer required. This latter saving is, however (in Spain) not usually a benefit attributable to the farm level because, aerial spraying is mostly undertaken by external contractors.

¹⁰⁵ As occurred in respect of some (competitor) herbicide prices when Roundup Ready soybeans were commercially launched

No comparisons with the USA are presented on costs as almost all analysis from the USA focuses on impact on profitability (see below). Also US analysis mostly refers only to the additional cost of using the Bt technology and does not consider impact on farms that have previously used insecticide treatments for corn borer¹⁰⁶.

One area where some US-based work has focused has been on insecticide use and work such as Benbrook (2001) have suggested that insecticide use increased rather than decreased as a result of using Bt maize. This work did, however only examine total insecticide use and not specifically whether insecticides used were targeted at corn borer or other pests. As the main insecticides used on maize in the USA (chlorpyrifos, carbofuran, fonofos, permethrin, lambdacyhalothrin and methyl parathion) are often used to control the ECB and other pests such as rootworm, it is probable that this reported increase in usage was due to additional treatments for other pests which proved to be more of a problem in 1997 and 1998. Evidence from Brookes (2002) in Spain and from Gianessi & Carpenter (1999) suggest that the introduction of Bt maize has resulted in reductions in the use of insecticides targeted at the ECB.

A 5.3.4 Impact on profitability

The impact of using Bt maize on profitability for farms in the Huesca region of Spain are summarized in Table 56 overleaf. Key points to note are:

- in the Sarinena region (an area of high annual average ECB infestation), the positive balance on margins derived from using Bt maize has been +67€/ha to +€29.5/ha (average €46.5/ha). In terms of the base gross margin for maize grown in the region, this is equivalent to an improvement of +5.5% to +32.4% (average +12.9%);
- in the Barbastro area (an area of low to medium annual average ECB infestation), the net result of using Bt maize has been 'break even' in term of cost and revenue changes (ie, not net change over four years)¹⁰⁷;
- in break even terms, the cost of using the Bt technology is more than recouped via the savings on insecticide costs for farmers in the Sarinena area and therefore for farmers in high ECB infestation areas that traditional use insecticides (to control the ECB), the benefits of the technology are self evident. Yield benefits are in effect a bonus to these farmers. In contrast, for farmers that do not usually spray for ECB, the break even point for adoption (based on the 2001 harvest price of €123/tonne) is a yield benefit of 0.15 tonnes/ha (1.5% yield improvement relative to the 2001 average yield across Spain). Clearly if a higher price and differential for using Bt maize was used (eg, the recommended prices of Syngenta at €9/hectare differential), the break even point would require higher levels of yield benefit. In Barbastro the break even point would be an additional 0.235 tonnes/ha and in Sarinena, farmers who have traditional used only one insecticide treatment (via irrigation) would require a small yield improvement of 0.04 tonnes/ha to break even.

Comparisons with research findings in the US show a number of similarities with this Spanish research. Much of the initial research into the impact of Bt maize in the US (examining impact in 1997 and 1998) provided conflicting evidence as to the benefit of the technology for adopters. For example, Gianessi and Carpenter (1999) estimated the benefit to be 45-54 \$/ha in 1997 and a loss of 4.47\$/ha in 1998, Ostlie et al (1997) estimated the benefit in 1997 at 17.8\$/ha, the USDA (1999) identified positive returns on average across the country's maize regions in 1997 but

¹⁰⁶ Gianessi et al (2002) do take this into account in estimating the impact on yield/revenue but do not appear to consider spray costs or to disaggregate the cost change data from overall farm income impact

¹⁰⁷ This farmer indicated that year one was one of average ECB attack and the impact of Bt use was positive, year two was one of low infestation and hence the impact of Bt use was negative, year three was one of high ECB attack and the impact of Bt use was positive and year 4 was one of no ECB attack for which Bt impact was negative

negative returns for 1998. Similarly, Benbrook (2001) estimated that benefit accrued to the average maize farmer in 1996, 1997 and 2001 but losses were incurred in 1998, 1999 and 2000 and that overall, a net average loss occurred across all Bt maize grown between 1996 and 2001 of about €3.5/hectare. Lastly, Gianessi (2002) estimated the average impact (in a year of average corn borer attack) to be about +€2.5/hectare, derived from an average yield benefit of 3.5%.

The key points about this conflicting evidence was that the respective reports were estimating average impact data from across a number of regions and were not necessarily relating them to corn borer pest pressure/incidence. As subsequent work in the US (eg, Gianessi 2002, Benbrook 2001) and in Spain (Brookes 2002) highlight, the level of impact on yield, costs of production and, in turn, returns are determined by actual pest pressure, historic pest pressure experience (which influences whether insecticide treatments might be used or not) and the prices used for both maize and the cost of the Bt technology. Pest pressure, impact on yield and prevailing husbandry practices towards the corn borer vary not only on an annual basis but regionally, including within a small locality. These factors should be taken into consideration when assessing the impact of a technology like Bt maize, which targets a sporadic and uneven pest like the corn borer.

Table 56: Impact on base gross margins of using Bt maize in the Huesca region (Sarinena) of Spain (1998-2001: €/ha)

	Barbastro: conventional	Sarinena (average) conventional	Bt: Barbastro area	Bt: Sarinena range	Bt: Sarinena average
Revenue					
Price (€/tonne)	123	123	123	123	123
Yield (tonnes/ha)	13-14.85	10	13.15-15	10.5-12.0	11
Sales revenue	1,599-1,827	1,230	1,617-1,845	1,292-1,476	1,353
Area payment	460	460	460	460	460
Total revenue	2,059-2,287	1,690	2,077-2,305	1,752-1,936	1,813
<i>Base costs of production</i>					
Seed	150	150	168.5	168.5	168.5
Fertiliser	211-301	211-301	211-301	211-301	256
Crop protection	90-120	114-222	90-120	90-120	105
Irrigation	211	211	211	211	211
<i>Total of these variable costs</i>	<i>662-782</i>	<i>686-884</i>	<i>680.5-800.5</i>	<i>680.5-800.5</i>	<i>740.5</i>
<i>Total base variable costs</i>	<i>451-571</i>	<i>475-673</i>	<i>469.5-589.5</i>	<i>469.5-589.5</i>	<i>529.5</i>
Gross margin	1,277-1,625	806-1,004	1,276.5-1,624.5	1,071-1,135.5	1,072.5
Base gross margin	1,488-1,836	1,017-1,215	1,487.5-1,835.5	1,282-1,346.5	1,283.5

Source: Fieldwork in Spain, July 2002: Barbastro example farm and Sarinena = members (500) of a local co-operative of maize producers

Notes:

1. Price = average farm level price for maize in September/October 2001
2. Area payments based on €63/tonne multiplied by the national irrigated maize reference yield of 7.3 tonnes/ha
3. Base variable costs = seed, fertilizer and crop protection only

A 5.3.5 Other issues impacting on profitability

Brookes (2002) also identified the following other impacts in Spain:

- Some farmers indicated that one additional reason for using Bt maize is for insurance purposes – it takes away the worry of significant ECB damage occurring and therefore represents an important tool for managing and reducing production risk. This point was particularly relevant for the farmers who indicated that over the four years of use they estimated that the net financial impact of using Bt maize was neutral. Use for these farmers was largely a function of its contribution to production risk reduction;
- There is ‘convenience’ benefit derived from having to devote less time to crop walking and/or applying insecticides (where farmers previously applied insecticides);
- A small net saving in energy use – mainly associated with less use of aerial spraying (where relevant), although these cost changes, mostly accrue to aerial spray contractors;
- There is a farm level perception that the quality of Bt maize is superior to non Bt maize from the perspectives of having lower levels of mycotoxins. Evidence from, for example, Bakan et al (2002) who examined *Fusarium* infection levels in Bt versus non Bt corn trial plots in five locations (three in France and two in Spain) found that Bt maize had up to ten times less fumonisin content than the non Bt varieties. In terms of revenue from sales of corn, however, no reported premia for delivering product with lower levels of mycotoxin levels have, to date been reported.

In addition, the literature review has not found any papers that have identified any problems of insect resistance build up to Bt maize. As with weed resistance, it is reasonable to assume that some degree of resistance development or reduced effectiveness of Bt maize may develop in the long run. However, farmers are required to operate non Bt maize refuges in their crops in all Bt maize adopting countries in order to minimise the possibility of resistance development. Also any potential development of resistance to Bt maize (which would make it less effective) is no different to the development of resistance of pests to conventional forms of control such as insecticides. Any consideration of possible future development of resistance to Bt maize by pests and its impact on farmer profitability should therefore, for comparison purposes, also take into consideration the likely parallel development of resistance to insecticides in conventional maize crops.

A 5.3.6 Summary of impacts of using Bt maize

The evidence to date on the impact of GM (Bt) insect resistant maize on farm profitability shows the following:

- Impact on yield varies according to local conditions, pest pressure and planting times. This also varies on an annual basis. Therefore the net impact therefore varies from negligible impact to significant positive yield gains. Examination of the literature suggests that on average, yields gains have occurred in the USA and in Spain and this is the primary gain associated with the technology;
- Impact on costs of production and profitability has shown positive and negative effects, although on balance the net impact on profitability has been positive. For some farmers costs of production have increased post adoption, mainly because of the cost of the technology and the fact that they had previously not used insecticides to control corn borer problems. Cost savings tend to greatest where insecticides were previously used to control corn borer;
- Other benefits are cited, as important reasons for adoption (some of these are intangible). These include increased management flexibility and convenience,

reductions in contractor costs (for spraying) and a contribution to reducing production risk (peace of mind).

A 5.4 Herbicide tolerant maize

In 2002 about 2.5 million hectares were globally planted to herbicide tolerant maize plus a further 2.2 million hectares of seed containing both Bt insect resistance and herbicide tolerance (source: James 2002). This is mostly in the USA where it accounts for about 9% of the total maize planted area (2.5 million hectares: 7% as herbicide tolerant maize and 2% in a stacked form with insect resistance). A small area (about 5,000 hectares) was also planted in Bulgaria. The technology is also awaiting regulatory approval in other countries such as Argentina and Romania (and the EU). Within the USA, about 60% of the herbicide tolerant crop is estimated to be Roundup Ready (glyphosate tolerant) and 40% Liberty Link (glufosinate tolerant). Uptake of the technology in the USA is perceived (see Gianessi et al 2002) to have been significantly below technical possibilities because of:

- Lack of incorporation of the Roundup Ready trait in several leading varieties – this may however be less applicable in future years as Monsanto and Pioneer have now agreed licencing arrangements;
- Lack of approval of varieties containing herbicide tolerance for import and use in the EU – this is perceived to have discouraged some farmers from planting over concern about the saleability of their crop in export markets;
- The Roundup Ready trait having not been put into some regional varieties when first launched (eg, suitable for growing in the South East part of the country).

In the sections below, papers reviewing the impact of herbicide tolerant maize are summarized. Relative to studies on the GM traits reviewed above, there has been very little coverage of herbicide tolerant maize.

A 5.4.1 Conventional weed control

Weeds represent a major ‘problem’ for most maize producers, with 28 weed species being widely considered to be troublesome in the USA (Gianessi et al 2002). These include 12 annual broadleaved species, 9 annual grass species and 7 perennial species.

The primary method used for controlling weeds in US maize crops is the application of herbicides, with the main herbicides used being atrazine, which was sprayed on about two-thirds of the total maize area treated with herbicides. Other important herbicides used include dicamba, metolachlor/S-metolachlor and acetochlor which were sprayed on 29%, 28% and 25% respectively of the total US corn area in 2000. Overall (prior to the introduction of GM traits), about 98% of the total crop received some form of herbicide treatment with about 40% receiving a pre-emergent treatment only, 21% receiving a post emergent treatment only and 38% receiving both a pre and post emergent treatment (USDA 1994).

Gianessi et al (2002) indicate that, in combinations herbicides used on conventional maize have provided fair to excellent control of most troublesome weed species, although some weeds have continued to be troublesome and have developed resistance to some herbicides (eg, shattercane with resistance to ALS herbicides like primisulfuron).

It should also be noted that because some herbicides like atrazine persist in the soil for an extended period, there are label restrictions on the number of months that must pass before certain follow on crops can be planted. For example, crops like sugar beet and potatoes should not be planted on land treated with atrazine for 18 months.

In the EU, herbicides also account for the most important part of farmer expenditure on crop protection measures. For example, in France and Italy, herbicides account for over 70% of maize crop protection expenditure. In Spain the herbicide share of total crop protection expenditure is nearer 80%.

A 5.4.2 Impact on yield

There is very little published work on the impact of herbicide tolerant maize on yield. The USDA (2001) estimated that the net impact of herbicide tolerant maize in the US had been yield neutral. Fernandez-Cornejo et al (1998) based on USDA field survey data from 1996, found a similar impact (a small positive impact). Lastly, analysis by Gianessi et al (2002) also assumes a yield neutral impact.

A 5.4.3 Impact on costs of production and profitability

The only analysis we have identified includes:

- Fernandez-Cornejo et al (1998): based on 1996 USDA field survey data, estimated that there had been no statistically significant impact on profitability (parameters/confidence intervals not stated);
- Gianessi et al (2002) estimated that the net positive impact on profitability to adopters was \$24.86/hectare (based on savings from lower herbicide costs balanced against the technology fee and seed premium of \$15.07/hectare). The Gianessi work found that farmers derived improved control of troublesome weed species for which there are weaknesses in conventional programmes (eg, wild pros millet, sandbur, hemp dogbane), growers had reduced applications of soil-applied pre-emergence herbicides and were substituting glyphosate or glufosinate for previously used post emergent herbicides. The reduced cost with the herbicide tolerant programme was based on a 25% reduction in the rate of use of pre-emergent herbicides followed by one application of glyphosate or glufosinate which substitutes for the post emergent applications. The savings were considered to reasonable when compared with the conventional costs of controlling the troublesome weeds;
- Phipps & Park (2001) cite pesticide usage data collected in the US by the agricultural market research company, Doane that the use of herbicide tolerant maize has reduced herbicide use by 30% (in active ingredient terms). There was no indication as to how representative this data was, although the authors' know that Doane conducts detailed, annual surveys of crop protection product usage in the USA and therefore the findings may well be reasonably representative of average trends in the USA.

The only dispute about impact identified in the literature relates to impact on herbicide use where Benbrook (2001) suggests that herbicide use has increased as a result of using herbicide tolerant maize rather than the decreases identified in the research cited above. Gianessi et al (2002) has responded to the Benbrook work by indicating that the reason for the difference relates to assumptions made by Benbrook about the rate of use of herbicides on conventional crops. Benbrook assumes the rates of use of conventional herbicides to be the average rate of use across all US maize whereas Gianessi suggests that this understates the level of use that farmers who have switched to using herbicide tolerant varieties would otherwise utilize. Gianessi et al highlight that most adopters of herbicide tolerant maize have tended to be farmers with bad weed problems (ie, were using above average levels of herbicides to control weeds in their conventional crops). Therefore a more reasonable cost to compare herbicide tolerant maize with is the conventional

programme of herbicide treatment¹⁰⁸ that delivers an equivalent level of control on tough/persistent weeds (equivalent to the control delivered by the herbicide tolerant crop).

A 5.4.4 Convenience and other economic impacts

Gianessi et al (2002) indicates the following factors have been important for adoption (based on factors cited by university specialists and press report, including the Soybean Digest 1999 and McClusky 1999):

- Increased flexibility in timings of herbicide treatments (the crop and weeds can be higher when treatments occur);
- There is reduced concern about injury to the corn crop from herbicide treatment;
- Reduced concern about carry over damage from residual herbicides in the soil on follow on crops like sugar beet.

None of these perceived or reported benefits were quantified.

A 5.4.5 Other impacts

Issues relating to the possible development of weed resistance to the herbicides used (glyphosate and glufosinate) and about possible out crossing of GM varieties with conventional varieties have not been examined in any studies to date. The issues and possibilities of these occurring in relation to herbicide tolerant maize are similar to those discussed above in relation to herbicide tolerant soybeans and oilseed rape.

A 5.5 Herbicide tolerant sugar beet

Herbicide tolerant sugar beet is currently not approved for commercial use in the EU. It is also not grown commercially in any other country¹⁰⁹. Not surprisingly, the literature examining the potential impact of this GM trait is therefore limited and largely based on either trial results or desk-based simulations of possible impact.

A 5.5.1 Conventional weed control

Sugar beet is a crop that exhibits sensitivity to climatic conditions, weed infestations and to pest incidence and, uncontrolled early emerging weeds can result in yield losses of between 26% and 100% (Schweizer & May 1993, Schweizer & Dexter 1987). This means that an efficient weed management system is crucial if a crop with reasonable yields is to be delivered.

The main weeds found in sugar beet across Europe include perennial species (eg, *Elymus repens* and *Cirsium arvense*) and annual weeds like *Chenopodium album*, *Polygonum aviculare*, *Matricaria chamomilla* and *Fallopia convolvulus*. Crop volunteers of potatoes, oilseed rape and sugar beet are also problems, and weed beet in particular is present in about 60% of UK sugar beet fields (May 2001).

Across the EU, the primary form of weed control is through the use of herbicides. In the main sugar beet producing countries (Germany, France, UK, Netherlands, Spain and Belgium), there are between 8 and 11 active ingredients that account for the majority of herbicides used on sugar beet

¹⁰⁸ As derived from a survey of agronomists in the US undertaken by Gianessi et al

¹⁰⁹ We understand that Roundup Ready sugar beet was approved for commercial use in the USA in 1999, however it has not been grown by farmers because of a refusal by US sugar processors to accept GM sugar (the commercialisation occurred at about the same time as the EU moratorium was introduced and the Starlink problems arose in the USA)

crops¹¹⁰ (Coyette et al 2002). The main active ingredients used are metamitron, which accounts for about 46% of total market share, followed by (in descending order of importance) chloridazon, ethofumesate, phenmedipham, glyphosate, lenacil, quinmerac, desmedipham and clopyralid. In the UK, metamitron is the most widely used herbicide accounting for 28% of total active ingredient used in 2000 (Coyette et al 2002)¹¹¹.

Control programmes typically use both pre and post emergent herbicide treatments, with the most important products (in terms of volume) used pre emergence. For a combination of cost and efficacy reasons only one active ingredient tends to be used on pre emergent applications (therefore higher rates are used to ensure sufficient weed control). In the UK, the most commonly used pre-emergent treatment is chloridazon. For post emergent treatments, tank mixes are commonplace, usually in several split applications at lower dose rates than in pre emergence. Recent practices trends have been to use very low dose rates of different active ingredients in post emergence, hence the number of applications has increased and usually follows a strict timetable in line with weed stage development. As a result delays of only a few days (eg, due to poor weather), can result in a need to increase dose rates to deliver efficient weed control. In the UK, sugar beet crops are typically sprayed 4-5 times (including preceding stubble treatments), with the number rising typically to seven applications on organic (peaty) soils where repeated weed flushes occur (May 2003).

Within the herbicides currently used glyphosate is usually sprayed pre-planting (a second application is sometimes used with special equipment in the crop to control specific weeds like weed beet and volunteer potatoes). Pre-planting treatment is estimated to occur on about 37% of the UK crop (Coyette et al 2002). Hand weeding is also still an important part of weed management systems for many farmers and is probably undertaken on about 30%-40% of the UK crop. Hand weeding is typically used to deal with volunteer beet (May 2003).

The relative importance of weeds and weed treatment in sugar beet can be seen from expenditure levels on herbicides relative to other forms of crop protection on sugar beet. In the UK, herbicides account for 75%-85% of total expenditure on crop protection for the average hectare of sugar beet grown.

A similar pattern of weed control is practiced in the USA (Gianessi et al 2002). Between 95% and 99% of weeds are considered to be adequately controlled, through a combination of herbicide use and hand weeding (hand weeding is an important part of weed control programmes, although with increasing use of post emergent applications, hand weeding is estimated to be less prevalent than in the early 1990s).

Sugar beet is also usually grown as a break crop for many combinable crops, particularly winter wheat. As such, it is often considered to be 'cleaning crop' within a crop rotation.

In general, many herbicides registered for use on sugar beet have a narrow range of selectivity for target weeds and changes in environmental conditions can result in phytotoxic effects. For example, high temperatures and high intensity light can increase injury following treatment of phenmedipham and desmedipham (Bethlenfalvay & Morris 1977). Also, herbicide damage to sugar beet can occur if there is frost, too much rain or wind within 2 days of spraying or if there is inadequate soil moisture. Most of the currently used selective herbicides will also only control weeds that are small (hence the need for pre emergent and early post emergent treatments). This means that sugar beet growers usually operate to a tight and short time window for implementing spraying regimes to deliver good weed control.

¹¹⁰ There are additional active ingredients used but the numbers cited are the most commonly used ones

¹¹¹ A total of 22 active ingredients are registered for use on sugar beet in the UK

A 5.5.2 Impact on yield

USA

The main evidence available is cited in Gianessi et al (2002). This cites trials work by Guzo et al (1998) in Oregon where Roundup Ready sugar beet using two applications of glyphosate delivered equal yield and weed control relative to conventional sugar beet crops using three applications of phenmedipham, desmedipham and ethofumesate. Otherwise the Gianessi paper mainly focuses on impact on costs of production (see below).

UK

- May (2003) examined the possible economic impact of GM herbicide tolerant sugar beet in the UK in some detail. This largely desk-based 'simulation' analysis drew on a variety of references and cited the possible yield benefit from using herbicide tolerant sugar beet to be between +5% and +10% (see below) when compared to conventional weed control measures (in the analysis on costs of production and profitability May assumes the lower end of this range, 5%). This yield benefit was mostly attributed to gains associated with crops suffering reduced levels of phytotoxicity to the crop when herbicide applications are applied when the crop is under stress. May (2003) also indicates that the herbicide tolerant sugar beet varieties currently being used in the UK Farm Scale Evaluations (FSEs) may deliver reduced yields relative to conventional sugar beet. If so, this would most likely be attributed to the seed varieties in the FSEs being varieties that are not leading varieties in 2003¹¹². If the evidence from the FSEs identifies reduced yields of GM sugar beet relative to conventional varieties and this is attributable to the (GM) trait being in non leading varieties of 2003, this will be similar to some of the findings for the early yield findings associated with GM crop commercialisation of soybeans in the USA;
- Dewar et al (2003) conducted five field trial plots in 1999 and 2000, using glyphosate tolerant sugar beet. This trial work explored various timings of glyphosate applications and identified that there was a yield benefit in each trial from using herbicide tolerant sugar beet of an average of +9.7%. The yield benefit was, however considered to be statistically significant by Dewar et al, on only two of the trial plots. The paper compared this GM sugar beet yield results with previous trial results that identified yield benefits for GM sugar beet of between 5% and 15% (Brant & Harms 1998, Moll 1997, Wilson 1999 and Wilson et al 2002). These yield benefits were attributed to a combination of reduced phytotoxic effects of not using the conventional programme of a number of herbicides and to improved overall weed control;
- Dewar et al (2000) conducted field trials in 1998 which examined the impact of delaying control of weeds in glyphosate tolerant sugar beet. The research compared a conventional herbicide regime that was representative of commercial practice in the region with three different glyphosate regimes (for the glyphosate tolerant crops). The different glyphosate regimes, each used two applications of glyphosate, but varied the timing of application (eg, option one sprayed at the 2/4 leave and 12-14 leave stage of crop development and four leaf stage of development for weeds, option three sprayed at the 12-14 leave and 16-20 leave stage of crop development and mature stage of development for weeds). The research identified that the option one glyphosate regime produced a higher yield of about 4.5% relative to the conventional crop but if spraying was delayed, yield losses relative to the conventional crop occurred (eg, at the option 3 spray regime, when weeds were fully mature, the yield loss was about 31/32% relative to the conventional crop). Given that the

¹¹² The trait would have been introduced into varieties probably in the period 1997-1999 and as such, these varieties will have now been superseded by newer, higher yielding varieties. This is a feature of almost all crop markets where new seed varieties usually have a relatively short 'shelf life' (up to 5 years is commonplace) before they are outperformed by newer varieties entering the marketplace

- option one glyphosate regime was probably the closest to likely commercial practice (if the crop was grown commercially), this suggests that the GM crop yield benefit was 4-5%
- John (2003) cites evidence of a yield loss of 24% to 31% from trials using glyphosate tolerant sugar beet. This citation is essentially referring to the Dewar et al work (2000) and refers to the delayed spraying options for glyphosate referred to above. As these yield losses refer to the boundaries of the research (late applications of herbicides when weeds have been allowed to become well established) they are not considered to represent likely commercial practice. The yield loss claims by John are therefore not representative of the typical or average husbandry practice that would be adopted by commercial growers.

A 5.5.3 Impact on costs of production and profitability

USA

The main US-based work that has examined and reviewed literature on the possible impact of herbicide tolerant sugar beet in the USA is Gianessi et al (2002). This work draws on some field trial work and makes estimates of impact if adopted commercially in the USA.

Key points to note in the work are:

- Based on Rice (2001), the technology fee for using Roundup Ready sugar beet was estimated at between \$101/hectare and \$141/hectare, depending on the seed rate used – the cost assumed in Gianessi's analysis (see below) was \$121.1/hectare;
- Conventional weed control costs for sugar beet were estimated to be an average of \$336/hectare;
- The glyphosate-based weed control programme was based on two applications of glyphosate, which was considered to be equivalent to conventional programmes (ie, would deliver the same level of weed control). The cost of this programme was put at \$187.85/hectare, producing a net weed control cost saving of \$148.2/hectare;
- Overall, the effect on costs of production and profitability of using glyphosate tolerant sugar beet was estimated to be net gain of \$148.15/hectare (cost of the technology and glyphosate weed control programme = \$121/hectare technology fee plus \$37.1/hectare herbicide cost and \$29.65/hectare application costs (total \$187.85/hectare) compared to conventional weed control costs of \$336/hectare.

UK

The only identified work on the possible impact of herbicide tolerant sugar beet on the costs and profitability of sugar beet production in the UK is May (2003). This is a detailed piece of desk-based analysis that draws on evidence from herbicide tolerant sugar beet trials and the author's detailed knowledge of conventional sugar beet husbandry and economics.

The paper by May (2003) identifies a number of points of relevance to costs and profitability (Table 57):

- The assumed technology fee (ie, additional cost relative to conventional seed) was between £20 and £30/hectare (based on information supplied by Monsanto UK);
- The cost of herbicide used is assumed to be £29/hectare for the conventional production system and £13/hectare under the herbicide tolerant regime of two treatments per crop (relative to an average of 4.5 for conventional crops). Two treatments with glyphosate is considered to deliver as good or better than conventional weed control programmes (Dewar et al (2003));
- Reduced number of spray runs, hence less concern about adhering to a strict timetable within a spray programme. This reduces the requirements for crop (agronomic)

consultants. The average cost of independent advice on weed control in sugar beet is about £10/hectare and is used on about 30% of the UK sugar crop. In May's analysis he assumes a cost saving of £3/hectare based on the average across the UK crop;

- As spraying can be delayed to await suitable soil conditions, a saving derives from less risk of damage to soil structure from spraying operations and this leads to savings from no longer having to subsoil after the beet crop to correct soil structure. Sparkes et al (1996) estimated this cost to be about £20/hectare, May assumes the average saving in his analysis to be £10/hectare;
- Savings in weed beet and bolter control of about £10/hectare and yield benefits from improvement in weed beet control (of conventional beet varieties);
- There would be a net additional cost of needing to use other herbicides on set-aside land that followed sugar beet to control any herbicide tolerant sugar beet volunteers - £8/hectare;
- Savings in stubble spraying were estimated to be about £5/hectare. This stems from the current practice of using glyphosate between cereal and sugar beet crops (pre-crop treatments for rotational weed control and to deal with cereal volunteers) on about 44% of the UK sugar beet area, which would no longer be required at this time (it would be replaced by one of the two glyphosate sprays applied in the GM sugar beet spray regime);
- Rotational crop benefits were estimated to be an average of £2/hectare. This arises from the follow on benefits in subsequent crops like wheat. May estimates that there would be a reduction in the cost of control of weeds like creeping thistle, which could be as high as £8/hectare. Glyphosate use in sugar beet would also facilitate improved control of weeds like black grass that have become increasingly resistant to a number of other herbicides;
- Savings of an average of £4/hectare would probably arise from being able to switch from ploughing to minimum tillage techniques in the sugar beet crop. May suggests this would be relevant for up to a quarter of the UK sugar beet area;
- Overall, the estimated cost savings were £103/hectare (£153/hectare including savings from needing to plant a reduced area to achieve quota contracts).

The analysis by May (2003), whilst not reflecting commercial practice (which could only be measured when and if the technology is given regulatory approval and is taken up commercially by UK farmers), represents a detailed analysis of the possible farm profitability benefits that may arise from the adoption of GM sugar beet in the UK. May's assumptions are clearly stated and transparent and therefore others that may disagree with his assumptions can re-work the analysis to alternative assumptions (see below: FARM critique). Despite critique of May's paper (see below) the detailed presentation of May's work in this report reflects the limited number of published studies on the topic and the detailed nature of the analysis presented by May.

Table 57: Cost comparisons between herbicide tolerant and conventional sugar beet in the UK (£/hectare: 2003)

	Conventional	Herbicide tolerant	Average differences +/- positives from using GM technology	Assumed area in the UK crop where impact possibly applicable %
Cost of herbicide	100-120	13-27	80	100
Cost of herbicide applications	29	13	16	100
Technology fee	0	20-30	-25	100
Crop consultancy fees	3	0	3	100

Weed beet & bolter control	15-500	5	10	70
Yield loss from weed beet	6	0	2	7
Set-aside ground keeper control	11	37	-8	25
Rotational weed control	13	8	2	30
Stubble spraying	15	0	5	30
Subsoiling	30	0	10	30
Minimum tillage	34	17	4	25
Other impacts (eg, wind erosion, insecticide use, nozzle changes)	34	0	4	5-50
Total saving with GM technology			103	

Source: May (2003)

Notes: May also reports a saving of £50/hectare associated with being able to produce the same volume of production from a smaller area. The analysis also excludes the opportunity cost for alternative uses of this area

A critique of the work by May has been made by the UK farm organisation FARM (2003). This critique essentially states that May's work overstates the financial benefits that UK sugar beet farmers would derive from using herbicide tolerant sugar beet in the following ways (relative to the cost changes highlighted in this study):

- Average conventional crop herbicide costs are £55-£75/ha instead of the £100-£120/ha stated in May;
- FARM disputes the potential for the savings identified by May for crop consultants, stubble spraying, weed beet/bolter control, minimum tillage and wind erosion;
- FARM suggests that May should have added a cost for segregation of the crop;
- Infers that farmers using the technology will be 'locked into' using Roundup Biactive (average cost assumed to be £4.43/litre) compared to alternative and available generic glyphosate which can be obtained for £1.75/litre;
- FARM estimate that the impact of using the technology, based on the same assumed price for the technology that May uses to be a net increase in costs of £45/ha and not the savings estimated by May.

May's response to the critique included the following:

- The average herbicide cost data used was based on the average identified from a random sample of 500 growers (using British Sugar audit data) and is therefore representative of the average costs across the UK sector. The FARM data is based on a limited number of 'above average' performers (ie, they spend below the average amount on herbicides);
- Segregation costs are not included because May assumes that British Sugar will only contract with GM growing farmers if they have a market for the product.

What the two pieces of work do illustrate well is the variability around the average for costs of production across the UK sugar beet producing sector. In essence both sets of data have validity, although May's data on costs appears to be more representative of the current average performance as it is based on a sample of 500 farms whereas the FARM data is derived from a combination of a very small number of farmers and recommendations for crop protection practices from the Morley Research Station. In addition, May's reason for not including any segregation costs is reasonable,

as the authors of this study agree that it is extremely unlikely that British Sugar would contract with GM growing farmers until such time as there is significantly improved levels of market acceptance (see appendix 3 for further discussion of this issue). Also, if British Sugar were to consider buying GM sugar for non food use markets, practicalities of processing and production would probably result in British Sugar concentrating GM sugar processing in a single processing plant (as it current does in respect of organic beet), and growers planting GM sugar would probably also be growing only GM varieties rather than both GM and non GM beet. This specialisation of production and processing to minimise the scope for adventitious presence tends to be more cost effective and less risky than growing both GM and non GM crops on the same farm or processing in the same plant. It is also the most widely observed approach taken in markets where GM and non GM crops exist (eg, soybeans, oilseed rape and maize) and crops need to be 'streamed' to meet different markets. Clearly if this scenario of use were not to occur in sugar then additional provision for segregation/IP costs would need to be taken into account in any calculation of the possible benefits.

Lastly, based on information provided by Monsanto (personal communication 2003), UK sugar beet farmers choosing to plant herbicide tolerant sugar beet would probably not be required to use Roundup Biactive as a condition of use of the technology. Whilst this may have been part of user licence agreements in the early days of Roundup Ready soybeans, this is no longer the case. Farmers are allowed to use any form of glyphosate they wish, although not all products may be on Monsanto's list of approved brands for use on herbicide tolerant crops – this list includes several brands/products that have been tested on crops, including non Monsanto products. If this point is taken into consideration, then the cost savings cited by May could be under estimating the potential savings available to farmers.

Germany

Dietsch and Marlander (2002) undertook some simulations of possible impact of herbicide tolerant sugar beet for a variety of farm types growing sugar beet in the period 1998-2000. These included ten types of farm (eg, farms experiencing problems with volunteer oilseed rape, volunteer potatoes and volunteer sugar beet, no tillage rotation, a sugar beet-maize-maize rotation, sugar beet-winter wheat-winter barley rotation). Analysis used costs of production (including fixed costs) for these farms and then examined the possible impact of herbicide tolerant crops on these 'model' farm margins¹¹³. Within the conventional crops grown across the ten model farms, total costs for growing sugar beet were estimated to be between €257/hectare and €492/hectare (the higher cost per hectare levels tended to be found where farmers had problems with volunteer oilseed rape, potatoes and sugar beet although no direct relationship was identified between total weed control costs and the unit cost of sugar production). On average the analysis found that herbicide tolerant crops increased the gross margin on all of the model farms, with Roundup Ready (glyphosate tolerant) sugar beet outperforming Liberty Link (glufosinate tolerant) sugar beet. Under some of the scenarios run, however gross margins were lower than conventional systems (five of the model farms). Conventional sugar beet production was reported to deliver higher gross margins when the yield assumptions for herbicide tolerant sugar beet were negative, the costs of the technology were highest and where existing weed control costs were lowest. In contrast, herbicide tolerant sugar beet delivered the largest margin improvements when farms had above average weed control costs.

A 5.5.4 Convenience and other economic impacts

Given that no herbicide tolerant sugar beet is currently grown commercially, there is no current evidence to draw on about commercial farmer experience of growing the crop. Based purely on crop trial observations, simulations of the likely husbandry practices to be adopted in a GM crop

¹¹³ The analysis ran a number of scenarios like the technology fee being equal to conventional seed, +25% and +50, the yield impact being -5%, neutral and +5%

and commercial experience reported in other herbicide tolerant crops, the following possible impacts have been cited (by May 2001 & 2003):

- Increased flexibility for growers in timing applications of herbicides. This is a benefit also cited as a major reason for the uptake of other herbicide tolerant crops like oilseed rape and soybeans;
- Reduced weed control costs and easier control in rotations and follow on crops (eg, thistles in cereals and potato volunteers that might contribute to potato cyst nematode problems in potato crops);
- Scope for switching to reduced/minimum tillage.

A 5.5.5 Other impacts

Issues relating to the possible development of weed resistance to the herbicides used (glyphosate and glufosinate) and about possible out crossing of GM varieties with conventional varieties have not been examined in any studies to date. The issues and possibilities of these occurring in relation to herbicide tolerant sugar beet are similar to those discussed above in relation to herbicide tolerant soybeans and oilseed rape. May (2003) does, however include in his cost analysis, consideration of additional (herbicide) costs being required to deal with volunteer herbicide tolerant sugar beet in subsequent crops (no longer being able to use a general volunteer clear up herbicide like glyphosate and having to use a more expensive alternative).

A 5.6 Herbicide tolerant wheat

Herbicide tolerant wheat is currently not approved for commercial use in the EU or any other country. The trait has been put into some hard red spring wheats grown in North America and could be available to growers in North America in 1-2 years time, if granted regulatory approval and the technology providers (Monsanto) decide to commercially launch the product¹¹⁴. We understand that no technology provider is currently undertaking field trial work on herbicide tolerant wheat in the EU. Any potential availability of herbicide tolerance in EU wheat is therefore at least 5-7 years away from possible commercialisation.

Against this background, the amount of literature examining the possible impact of herbicide tolerant wheat on farm profitability is extremely limited. The only work identified is Gianessi et al (2002) and this work is examined further in the sections below.

A 5.6.1 Conventional weed control

Weed problems in the US and conventional control

As in the UK/EU weeds can have a significant negative impact on wheat production in the USA. Problems with broad-leaved weeds (kochia, wild mustard), annual grass weeds (foxtails, wild oat) and perennial broadleaved weeds (Canada thistle, field bindweed) are widely recognized and if left untreated can lead to significant yield loss. Of these weeds Canada thistle has become a particular problem, due to the lack of effective controls (USDA 1994). Herbicide resistance has also become a problem in some regions (eg, Kochia to ALS herbicides like sulfonylureas, Trifluralin resistant green foxtail).

Current conventional control practices in the US typically involve one to two herbicide active ingredients for control of broad-leaved weeds (2-4-D, bromoxynil, Dicamba, MCPA and Tribenuron) and about half of the US spring wheat crop is also treated for grass weeds. The main

¹¹⁴ It is likely that even if the US authorities granted regulatory approval for use, the technology would not be launched commercially until approval for importation and use had also been granted in the EU and Japan

grass weed herbicides used are fenoxaprop, triallate, tralkoxydim, trifluralin and (for Canada thistle) clopyralid. Overall, these herbicides (used in combination) provide good to excellent control of the major weed species infesting spring wheat in the northern plains states where hard red spring wheats are mostly grown.

Average costs of broad-leaved herbicide treatment combinations are about \$9.9/hectare and the average cost for grass weed treatments is \$32.1/hectare. Added to this the cost of treatment for Canada thistle is about \$39.5/hectare. Due to this high cost of treatment for Canadian thistle, about a third of the crop is thought to receive no treatment at all for Canadian thistle (Donald et al (1990) mainly because the yield loss associated with Canadian thistle infestation is equal to be about \$30/hectare, whilst the cost of treatment is nearly \$40/hectare.

A 5.6.2 Impact on yield

We have not identified any published research trial papers that have covered yield impacts of using herbicide tolerant wheat.

The Gianessi et al work (2002) assumes that a yield benefit is derived for farmers who currently experience problems with Canadian thistle and hence the net financial gain from using herbicide tolerant wheat is estimated to be equal to about \$30/hectare. No yield benefit is assumed to occur for other hard red spring wheat farmers (ie, those who do not experience problems with Canadian thistle) because the glyphosate tolerant crop is assumed to deliver the same level of weed control as conventional systems.

A 5.6.3 Impact on costs of production and profitability

Gianessi et al (2002) estimate the following impact on costs and profitability would be delivered from using herbicide tolerant spring red wheat in the USA:

- The herbicide cost of treatment with Roundup would be \$18.5/hectare (two applications) plus a technology fee of £23.47/hectare (total \$41.97/hectare);
- The cost of treating conventional spring wheat is about \$42/hectare (excluding any treatment for Canadian thistle);
- Farmers with limited Canadian thistle problems would therefore probably be less likely to use the technology (the costs of the technology broadly equal the costs of current control measures), unless other benefits (eg, possible additional convenience) were considered to be sufficiently attractive. This highlights the sensitivity of potential take up to the level of technology fee charged;
- Take up of the technology would probably be concentrated amongst farmers experiencing significant Canadian thistle problems, and especially amongst farmers who do not currently spray for Canadian thistle. For these farmers the net gain from using the technology is estimated to be equal to the yield gains referred to above (\$30/hectare).

A 5.6.4 Convenience and other economic impacts

No studies identified examined other economic impact issues. However, given that herbicide tolerant wheat is similar to the applicability of herbicide tolerant technology in other arable crops, it is possible that similar impacts to those presented above for soybeans, oilseed rape, maize and sugar beet may occur. Thus impacts are associated with greater convenience and management flexibility, reduced use of crop consultants and machinery and greater scope for moving to a low/no tillage production system.

A 5.6.5 Other impacts

Issues relating to the possible development of weed resistance to the herbicides used (eg, glyphosate and glufosinate) and about possible out crossing of GM varieties with conventional varieties have also not been examined in any studies to date. The issues and possibilities of these occurring in relation to herbicide tolerant wheat are similar to those discussed above in relation to herbicide tolerant soybeans and oilseed rape.

A 5.7 Potatoes

A 5.7.1 The commercial application of GM technology to potatoes

GM potatoes were one of the first commercial applications of GM technology. Monsanto launched in the USA/Canada its New Leaf Plus potatoes, which contained a Bt gene (conferring resistance to Colorado Beetle (CPB)¹¹⁵) in 1996 and added resistance to the potato leafroll virus (PLVR) in 1999. By 1999 this GM potato was planted on about 4% of the US potato area (Gianessi et al 2002). This then fell to 2% in 2000 and in 2001 Monsanto withdrew from selling GM potatoes, to concentrate on GM crops in wheat, maize, soybeans and cotton. This commercial decision was probably heavily influenced by the decision by some leading potato processors and fast food outlets to stop using GM potatoes because of perceived concerns about this issue from their customers. Since the processing market is the main outlet for potatoes in the USA, the GM potato effectively become non viable, following this 'industry block' decision during 2000.

Currently, this type of GM potato is planted on a small area (under 1,000 hectares) in the Ukraine and Romania (Davies 2003).

A 5.7.2 Insect and virus resistant potatoes

There is limited data and studies available on the impact of this GM technology in the USA. The main source, which also reviews earlier studies is Gianessi et al (2002). As a point of reference to the UK context, it should be noted that Colorado Beetle has not been a problem in the UK potato crop, where effective quarantine measures have been in place for many years to minimise possibilities of the pests entering the country. However in parts of central Europe Colorado Beetle is becoming an increasing problem and growers incur considerable costs controlling the insect pest.

Key findings in relation to the impact of this pest and virus resistant potato used in the USA include the following:

- Potato leaf roll virus can significantly affect yields and the primary method of control is the use of insecticides to control aphids that carry the virus. PLVR can cause yield losses of up to 50% and nearly all commercial varieties are susceptible to its infection. The transgenic PLVR crop is capable of reducing insecticide usage by up to 100%;
- Potato virus Y (PVY) resistant lines were also developed in combination with CPB resistance. PVY is considered to one of the most damaging viruses because it causes economically significant yield depression. Severe infestation can reduce yield by as much as 80% (Bemster and de Boks, 1987). The transgenic control is more effective at PVY control than any insecticide programme. Protection to PVY reduced seed decertification risks for seed growers and helped to maximize yields for commercial growers with improved processing quality and storage;

¹¹⁵ A primary pest of potatoes in North America

- Colorado Potato Beetle (CPB) can also devastate crops. For several decades the primary control strategy for CPB has been the use of chemical insecticides and about 22 active ingredients are registered, in Canada for example, for this purpose. However, restrictions in the modes of actions of insecticides coupled with repeated applications have led to resistance development in most commercial production regions in Canada (Stewart, 2000). Crop rotation is an important control strategy for growers too, as might be biological control using insect-destroying fungi such as *Beauveria bassiana* and beneficial nematodes such as *Steinemema carpocapsae*. The use of these latter forms of control are, however only effective for a few days after application, and hence this type of treatment requires frequent and timely application;
- Yield data from 101 fields of commercially grown crops in 1996 and 1997 found that New Leaf cultivars produced the same yields as non Bt/Virus resistant potatoes (variety Russet Burbank) that had been treated with insecticides (cited in Gianessi et al 2002). However, Gianessi estimates that potato leaf virus still affects about 10% of the US crop, even when insecticides are used, causing an average yield loss of 5%. Gianessi assumed an average 1% yield gain in his analysis of impact of New Leaf cultivars (ie used a conservative assumption);
- Assuming a technology fee of \$114/ha, the average net reduction in costs of production (inclusive of application costs) was estimated by Gianessi to be \$142/ha (ie, total reduction in insecticide costs was \$256/ha). This was based on an average of findings for 1998 and 1999, with the insecticide savings estimated to be \$210/ha and \$331/ha respectively for 1998 and 1999;
- Riebe & Zalewski (2001) examined grower commercial experiences in the NorthWest of the US and compared these with paired field comparisons of the same potato variety grown conventionally (140 hectares monitored). The study found that average cost savings (net of the technology fee) were \$227/ha in 1998 and \$146/ha in 1999. Growers also reported an average benefit from reduced downgrades of crops from processors due to net necrosis in the potato equal to \$99/ha in 1998 and \$299/ha in 1999 (ie, these figures were the average downgrade losses experienced by the parallel conventional growers relative to the GM growers who suffered no downgrades).

The development of transgenic virus resistance has raised concerns over potential interactions between viral transgenes or their products with viruses that infect the transgenic plant itself. Scientific studies cited in Davies (2003) do not preclude any of the virus-virus interactions searched for by researchers occurring, but do indicate that such interactions are rare events and that the risks of their occurrence may not be expanded by the fact that one of the genes is a transgene (rather than several when some experiments have been conducted).

Overall, from the UK perspective it is important to recognize that currently the main developer of the technology, Monsanto has withdrawn from attempts to commercially develop the technology. Consequently there are no applications for regulatory approval for marketing, pending (or likely) in the EU for these agronomic traits. To minimize the impact of potato viruses the UK multiplies virus-free potato seed in Scotland where virus transmission by aphids is limited. UK potato seed trades at a premium to cover the extra costs of producing seed in Scotland. The UK is also a market with limited potential for any CPB-resistant trait because of the limited incidence of the pest.

A 5.7.3 Nematode resistant potatoes

Transgenic resistance to potato cyst nematodes has been achieved but has yet to be commercially deployed. Several distinct approaches are under development. The strategy based on the expression of inhibitors (cystatins) targeted against nematode digestive cysteine proteinases is most advanced (eg, research at Leeds University). A series of small-scale UK field trials funded

by SEERAD has demonstrated that expression of a cystatin in potato confers partial resistance to PCN on cv Desiree. These field trials together with containment glasshouse trials have established effective resistance against many nematode species (eg. PCN on potatoes $79 \pm 9\%$, *M. incognita* on rice $83 \pm 5\%$). Cystatins are highly biosafe; they are neither allergens nor toxins to mammals. Cystatins are present in common foods (maize and rice seeds; chicken egg white) and part of the normal diet of people in the UK. Cystatins are environmentally biosafe and they do not harm non-target insects such as aphids or leafhoppers when expressed constitutively in potato. In addition there is no evidence of adverse effects on aphid parasitoids. Promoters are available which restrict expression of the protein to the feeding sites of PCN, further supporting the biosafe use of cystatins. This approach results in minimal expression elsewhere in the plant including the tubers. Current work has established that expression of cystatins either constitutively or mainly at PCN feeding sites does not harm the soil microbial community or earthworms.

This demonstrates that it may be possible to develop a GM nematode resistant potato, however this research is still at a fairly fundamental level and is at least ten years away from possible commercialisation.

A 5.7.4 Fungal resistant potatoes

Verticillium Wilt can be significant problem in potato crops causing yield loss and rejection of crops for uses in the processing sector (eg, can lead to dark frying colour). It is a disease caused by soil borne fungi and therefore if potatoes are grown on the same land for several years there can be a build up of the fungi in the soil. Management practices to control the problem include cultural controls (crop rotation, water and fertility management), use of resistant or tolerant varieties and soil fumigation (ie, a water soluble fungicide often applied through sprinkler irrigation).

A gene derived from lucerne has been identified as having relevant anti-fungal properties and laboratory tests have been conducted into inserting such genes into potatoes in the USA. Some field trials with the Russet Burbank variety potatoes have been conducted in the USA to examine if the transgenic potatoes expressed the gene. To date the research remains at an early stage and possible commercialisation remains many years away.

A 5.7.5 Herbicide tolerant potatoes

As with the other arable crops examined in this section, weeds are a significant problem for potato growers. Conventional control measures are largely founded on the use of herbicides and, as in other crops, some weeds are more problematic than others and some weeds have developed degrees of resistance to herbicides.

A number of potato cultivars have been transformed to confer herbicide (glyphosate) tolerance in the USA and trials have been conducted in the USA. These include:

- work by Hutchinson et al (2000) which trialed plots in 1999 used two sequential applications of glyphosate and found 95% to 100% control of the main weeds, no crop injury and a 29% yield improvement relative to trial plots treated with rimsulfuron and metribuzan;
- Hutchinson (2001) also conducted trials in 2000 and 2001 in glyphosate tolerant Ranger Russet variety potatoes and found no difference in yields relative to conventionally grown potatoes (that had used herbicides pre and post emergent);
- None of the work reported examined impact on variable costs, although Gianessi et al (2002) provides some estimates of possible impact according to three scenarios when growers might use herbicide tolerant potatoes in the USA. This analysis does, however

assume that herbicide usage would not decline, with the main assumed benefit being from increased yields.

Although, herbicide tolerant potatoes could be made available to farmers, we are not aware of any of the technology providers bringing forward herbicide tolerant potatoes for commercialisation. This is not surprising given the experience with insect tolerant potatoes in the USA. It is therefore unlikely that herbicide tolerant potatoes would be commercialized until such time as anti GM sentiment amongst consumers fell substantially and potato processors might be willing to review their purchasing policies relative to GM potatoes. From a UK perspective, we are not aware of any pending or likely applications for approval of herbicide tolerant potatoes and if the technology is to be brought to the UK market it remains several years away.

Appendix 6: Other general issues

This appendix considers some of the broader issues raised by some of the literature (in relation to possible impact on farm profitability).

A 6.1 Are farmers faced with limited choice and hence 'have limited alternatives to using GM technology'

This is an argument cited in some literature (eg, Soil Association 2002) as a reason why some farmers continue to plant GM crops in North America, even though they may perceive them to be of little or no benefit. The argument is based on the view that the main biotechnology companies dominate plant breeding and seed multiplication and therefore have a vested interest in only making new varieties available that contain GM traits and accordingly neglect the provision of non GM seed (and/or non GM seed is only available in older, inferior performing germplasm). In examining this argument, the following points should be noted:

- Whilst some literature such as Soil Association (2002) has identified some farmers in North America who perceive this to be the case, there is no indication of how representative these views are. Based on information provided (personal communication, Soil Association 2003), these views appear to be drawn from a maximum of 25 farmers interviewed, two third of which were organic producers. This compares with, for example, a total number of farmers growing soybeans in the USA of about 600,000;
- A trend towards greater concentration into fewer, larger players in agriculture and allied industries is not unique to the plant breeding and seed production sectors. It is a trend that has occurred in most parts of the agricultural and allied sectors. A major driver of this trend has been the increasing costs and financial resources required to develop new products that only ever larger players can afford to stay in the marketplace. This concentration does, however not necessarily mean that farmers are faced with reduced choice of products like seed. For example, we understand that in the USA there are currently about 2,000 different soybean varieties available to US growers of which about 1,200 contain GM traits. This means that, even though 75% of the US crop is herbicide tolerant (GM), about 40% of all varieties available are non GM. We understand that there are 122 seed suppliers in the US of which 12 are owned by companies with interests in biotechnology. Also the leading five non GM varieties available have the same yield potential as the leading five GM varieties¹¹⁶. Whilst it is beyond the terms of reference for this study to examine the nature of competition in the seed markets of North America, the data presented above suggests that there is little evidence to suggest that there is a lack of seed choice for US farmers;
- The leading biotechnology companies do not own all plant breeding and seed production (see above). In most countries, including the UK, France, Germany and other parts of the EU, there are a number of plant breeders and seed producers, which are not owned by the biotechnology companies. These companies decide whether to include GM traits in their germplasm according to whether they perceive there may be a reasonable demand for them and hence sufficient scope for earning a return on investments, relative to the level of licence fees or royalties they would have to pay the biotechnology companies. It is likely that some of these companies may choose not to insert GM traits in some varieties, to offer both conventional and GM alternatives or to offer only GM alternatives. The choice will be made on commercial criteria and often without influence from biotechnology companies. In addition, it should not be assumed that the different plant breeders, even if owned by biotechnology companies will necessarily only offer GM traits, especially if a trait available is offered by a rival biotechnology provider. An example of this can be seen

¹¹⁶ If the leading performing varieties were only GM, this would suggest that impact studies should be showing consistent signs of GM varieties out yielding their non GM counterparts. The evidence to date does not show this – there respective yields are broadly the same

in respect of the US maize market, where herbicide tolerant maize did not develop a market share beyond 9% in the first few years after commercialisation because it was not made available in a significant number of the leading varieties. This was because Pioneer, one of the leading maize breeders and seed suppliers was unable to agree a commercial licencing deal for the trait with the technology provider (Monsanto) for 3-4 years;

- In any market economy, where there is reasonable demand for a product (eg, non GM seed), the market usually provides the requirement. The fact that there may be a reasonable demand for non GM seed (eg, in 2002 about 25% of the US soybean crop), this is likely to remain an attractive market for some plant breeders and seed suppliers. If a situation were to arrive where limited new seed became available to serve a particular market, this might suggest some form of market failure that governments might wish to address. Also if governments perceive that farmers were being provided with limited choice because of the structure of the supply industry and high barriers to entry, this problem is not related to the technology, but to a lack of effective competition policy – here any failure of farmers to benefit from new technology (including non GM) should be laid at the door of policy makers, not the suppliers of the new technology.

A 6.2 Are some farmers using GM crops because of fear of being prosecuted for breach of their GM crop users licence?

This is also an inference made in the Soil Association's 2002 report and a small number of farmers who have had problems are cited. There is no indication as to how representative this is of North American farmer experience for growing GM crops. The counter-argument to this, cited in for example, Nill (2002) is that only a handful of farmers have breached their licence agreements (out of the nearly 0.5 million farmers who have planted GM soybeans) and it is very easy for the seed suppliers and farmers alike to differentiate between accidental contamination and deliberately grown seed. Nill goes on to point out that the most prominent farmers who have claimed to be innocent victims of traditional non GM varieties having become contaminated through cross pollination, have been found, in Court, to have seed bearing the patented biotech trait at nearly 100% levels, and not surprisingly have lost their legal actions.

Providing any examination or investigation of these (legal) claims is beyond the terms of reference for this economic study and no additional comment is made.

A 6.3 Will widespread use of GM crops like Bt maize hasten the build up of resistance of pests (and weeds)?

In relation to whether the use of GM crops may hasten the build up of resistance problems, the following points should be taken into consideration:

- Where Bt crops are planted, farmers are required to plant non GM refuges so as to contribute to reducing the possibility of pest populations developing resistance. We are not aware of any studies to date that have specifically examined the impact of such refuges, however it is reasonable to assume that such actions will probably contribute to delaying the development of any pest resistance that might occur;
- Any discussion of the potential for pests and weeds to develop resistance to commonly used insect control products or herbicides must take into account the fact that products like Bt bacteria have been used to control insect pests for many years and instances of pests developing resistance to Bt toxins have not been reported. Similarly products like glyphosate have been used for about 25 years with very few documented examples of resistance having been found. Whilst this does not mean that some form of resistant pest or weed may develop in the future to these products, it is, as quoted in Nill (2002), '*overly simplistic to assume that pest-insect populations will fast become resistant, simply because*

'Bt toxins' are produced in crop plants on a wide area'. It is equally important to recognize that should future resistance develop to, for example, Bt or to a herbicide that is used on a herbicide tolerant crop, this could arise in pest/weed populations that have been treated during conventional or organic agriculture as well as GM agriculture;

- Some analysts have suggested (eg, Nill 2002) that it is possible that the onset of resistance developing in pests/weeds could be reduced/slowed down by the use of GM crops. For example, in organic agriculture, organic Bt spore powders are commonly sprayed on crops to control corn borer. However, such spraying is unlikely to deliver 100% control (see also the impact of using insecticides to control corn borer in section 2.3) and will be less than the level of control delivered by Bt maize. Such a low dosage organic Bt spore powder application may allow naturally Bt-resistant pest insects to become an increasingly larger fraction of that pest population. Nill does, however acknowledge that, to date, there have been no instances of reported resistance to Bt recorded in the US, even though organic farmers have been using the product for over 30 years. Nill goes on to say that this as another example of why it is too simplistic to assume that use of Bt maize (GM) might hasten the onset of pest resistance to Bt. No studies to date have been found that examined such a possibility, but this nevertheless remains an outside possibility;
- Nill (2002) also suggests that it is possible that herbicide tolerant crop use may contribute to slower development of weed resistance because it allows the use of herbicides like glyphosate and glufosinate on crops where it had not previously been used. As such this would represent an increase in the number of dissimilar herbicides available to farmers for weed control and therefore could contribute to reduced probability of herbicide resistant weeds developing.

Overall, there is no current evidence to support the hypothesis that GM crops, resistant or tolerance to pests/herbicides will hasten the build up of resistance of pests and weeds.

A 6.4 Is there any relationship between GM adoption and size of farm ?

This issue has been examined in two pieces of research:

- Fernandez-Cornejo & McBride (2000) examined the effect of size on adoption of GM crops in the US, using 1998 data. The a priori hypothesis used for the analysis was that the nature of the technology embodied in a variable input like seed (which is completely divisible and not a 'lumpy' input like machinery) should show that adoption of GM crops is not related to size. The analysis found that mean adoption rates appeared to increase with size of operation for herbicide tolerant crops (soybeans and maize) up to 50 hectares in size and then were fairly stable, whilst for Bt maize adoption appeared to increase with size. This analysis did, however not take into other factors affecting adoption such as education, awareness of new technology and willingness to adopt, income, access to credit and whether a farm was full or part time – all these are considered to affect adoption yet are also often correlated to size of farm. Overall, the study suggests that size has not been an important factor influencing adoption of GM crops;
- Brookes (2002) identified in Spain that the average size of farmer adopting Bt maize was 50 hectares and that many were much smaller than this (under 20 hectares). Size was not therefore considered to be an important factor affecting adoption, with many small farmers using the technology.

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