Project Number 289706

COLLABORATIVE PROJECT

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

D10.3: Secondary impacts: Economic estimates of secondary impacts in relation to parameters such as impacts on non-target organisms, greenhouse gases, and water quality and health

Start date of the project: 01/12/2011
Duration: 48 months
Organisation name of lead contractor for this deliverable: University of Reading
Revision: 1.1
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Project funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Objectives

- To evaluate the impact of the use of GM varieties on non-target organisms and the emergence of secondary pests
- To estimate the impact of the use of GM varieties carbon dynamics, greenhouse gases and climate change
- To discuss the wider environmental impacts related to pesticide loading, resistance, gene flows and water quality

Introduction

In this section the wider secondary impacts of growing genetically modified crops are considered. The primary benefit of the current generation of transgenic crops is likely to be to farmers in terms potential agronomic and economic benefits and these have been outlined in the review undertaken in Deliverable 10.1. In this deliverable we consider the broader environmental consequences if the adoption of GM crops was to become more widespread in the EU.

1. Impacts on non-target organisms and the emergence of secondary pests

1.1. Review of literature

The development of synthetic insecticides in the mid-twentieth century allowed agriculture productivity to increase significantly. Both farmers and scientists considered such technological advance as a solution to the world’s agriculture limitations to feed the world (Oerke 2006). Notwithstanding the positive results, the heavy dependence and overuse of insecticides had many unintended consequences. This overuse of insecticides led to several issues hampering agriculture production such as insects developing resistance, negative effects on non-target species populations – e.g. natural predators – and the development of secondary pests (Matson et al. 1997, Vitousek et al. 1997). Along with several environmental problems – e.g. increase in greenhouse gas emissions – as well as negative human health impacts (Metcalf 1987, Pimentel 2005). Genetic Engineered Insect Resistance (GEIR) technology offers an alternative that may reduce the negative side effects and limitations of conventional farming. However, regardless of global increasing adoption of GEIR crops and their potential advantages, the technology still faces several uncertainties (Andow et al. 2006). As with insecticides, GEIR crops when introduced, alter the ecosystem having a large and complex landscape-level effect on pest dynamics, leading to a rearrangement of niches occupied by crop-associated insects (Garcia and Altieri 2005, Lövei et al. 2009). Some of these effects are likely to be of advantage to crop growers, while others bring undesirable effects, limiting the cost-effectiveness of the technology. Although a great majority of laboratory and field studies indicate that Bt-crops do not have any clear unforeseen toxic effects on natural enemy species of agricultural pests (Marvier et al. 2007, Wolfenbarger et al. 2008, Naranjo 2009), some other studies do illustrate concerns (Lövei et al. 2009, Stephens et al. 2012).

A further concern is that secondary pests species that are not susceptible to the expressed toxin will evolve and cause significant damage to the crop (Wang et al. 2008, Eizaguirre et al. 2010, Gross and Rosenheim 2011, Hilbeck et al. 2011, Zhao et al. 2011). Nonetheless, Gatehouse (2008) argued that this issue could be solved by introduction of additional *Bt* cry gene to the crop, enlarging its protection against a wider range of pests. Indeed this is already occurring with a range of stacked traits already at market. Nevertheless, there is still a need for on-going research in order to comprehend and avoid the risks concerning the long-term ecological impacts of GEIR crops. Such research should look beyond the immediate impacts in a given cropping year, but also to investigate impacts over several years of production, taking into consideration the carry-over effects which potentially affect crop yields (Snow et al. 2005).

The research presented here focusses on an issue which to date has received only limited attention, the outbreak of secondary pests within GEIR crops. Only a few studies have addressed the impacts of controlling one pest on the population of a second pest, and the consequent economic and ecological implications which may ensue, specifically for the case of GEIR crops (Wang et al. 2006a). Citing Harper (1991, p.22), "ignoring secondary pests can lead to devastating crop damage that may continue over a considerable period of time".

In most current GEIR cropping systems, although insecticides applications have been substantially reduced, they are still a recurrent, cheap and highly efficient means of controlling pests once the economic threshold has been reached, (Wang et al. 2009). The majority of research on secondary pest emergence comes from the largest Bt Cotton producers, such as China (Lu et al. 2010), India (Stone 2011), in Australia (Wilson et al. 2006) and in South Africa (Kunert 2011, Schnurr 2012). These cases appear to be directly linked with reductions of broad-spectrum insecticide applications (Men et al. 2005, Lu et al. 2010, Li et al. 2011). However two other factors are also preponderant on the outbreak of secondary pests, the reduction in natural enemies' population and the reduced competition from pests targeted by the Bt toxin (Whitehouse et al. 2007, Zeilinger et al. 2011). Hence, three main causal mechanisms make a replacement of a primary pest by a secondary one possible in a GEIR crop:

- a significant reduction in a pests natural enemy community (Daly and Buntin 2005, Naranjo 2005, Lövei et al. 2009, Arpaia 2010) ;

- a reduction in broad-spectrum insecticide applications (Naranjo 2011) (Sharma and Ortiz 2000, Nagrare et al. 2009, Lu et al. 2010, Naranjo 2011);

- a decrease in competition with susceptible species that share the same ecological niche (Catangui and Berg 2006, Dutcher 2007, Dorhout and Rice 2010, Virla et al. 2010, Price et al. 2011)

If outbreaks of secondary pests become recurrent on GEIR crops, it could possibly lead the farmer towards a "novel insecticide treadmill". For instance the farmer starts to use GEIR crops to reduce insecticide use, but then has to start using pesticides against a secondary or tertiary pest which emerges as an economic vector due to the removal of the primary pest. Hence, there is a need to find an optimal balance between the conservation and perpetuation of healthy functional agroecosystems and the need for economically sustainable production from a given agricultural system.

1.2 Secondary pests' economic impact in the context of GEIR crops

Notwithstanding the causal mechanisms that lead new pests to emerge as an economic problem, the replacement of a primary pest by a secondary one is an important consequence that will necessitate a shift in insect control techniques in agricultural systems (Dutcher 2007). However, not many studies have addressed the impacts of controlling one pest on the population of a second pest, and the consequent economic and ecological implications which may ensue, specifically for the case of GEIR crops (Wang et al. 2006a). One exception is the ongoing research in China, where several studies have focused solely on understanding the impact of secondary pest infestation in Bt Cotton (e.g.Wang et al. 2009, Lu et al. 2010, Pemsl et al. 2011, Zhao et al. 2011, Wan et al. 2012). Several studies focusing on Chinese cotton production have shown that Bt cotton has effectively controlled *H. armigera*, a major lepidopteran pest (e.g. Wu et al. 2008, Pemsl et al. 2011, Pray et al. 2011).

However there is a growing concern regarding the future perpetuity of Bt cotton efficiency and profitability (Zhao et al. 2011). A number of research studies have shown that Chinese Bt adopters are not economically better off when compared with conventional cotton farmers due to an increase in secondary pest infestations. Lu et al. (2010) point out that these secondary pests could be a result of the reduction in insecticide spraying targeting *H. armigera*. As a result, the savings in insecticide expenditures for lepidopteran pests are being offset by the increase spraying intensity against mirid bugs. Mirids have already acquired major status in Chinese cotton production adoption (Zhao et al. 2011). Before Bt cotton commercialization, Chinese farmers used an average of 20 insecticide treatments in a season to control bollworm infestations (Huang et al. 2003). In 1999, at the early stages of Bt adoption, those applications were reduced to an average of 6.6 applications (Pray et al. 2002, Huang et al. 2003). But just a few years after, in 2004, some farmers where applying up to 20 treatments on average, (Wang et al. 2006b). Similar patterns can be observed in other major Bt cotton producing countries (Qaim and Zilberman 2003, Bennett et al. 2004, Traxler and Godoy-Avila 2004, Qaim et al. 2006). Wang et al (2009) suggests that caution needs to be taken when drawing conclusions and further studies need to be conducted, since mirids population densities are strongly correlated with on climatic events – temperature and rainfall.

In Europe, although several other events are under evaluation by the European Food Safety Authority (EFSA), the only Bt maize currently allowed for cultivation in Europe is that containing the transformation event expressing Cry1Ab Bt toxin (EFSA 2010). This event presents a highly efficient level of resistance to two major maize borers present in the Europe, the Mediterranean Corn Borer (MCB), *Sesamia nonagrioides* and the European Corn Borer (ECB) [*Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae) (Dicke and Guthrie 1988, Malvar et al.

2004). However, is not efficient against the Western Corn Rootworm nor to other lepidopteran secondary pests, for example the True Armyworm (TAW), *Mythimna (Pseudaletia) unipuncta* (Haworth) (Lepidoptera: Noctuidae) (Pérez-Hedo et al. 2012). Western Corn Rootworm was first noticed in Europe in the mid-1980s (Bača 1994, Kiss et al. 2005, Miller et al. 2005). Wesseler and Fall (2010) calculated the accumulated economic benefits of completely controlling Western corn rootworm in Europe to be about 472 million euro per year.

Presently, in European maize production, arthropods pests (see Meissle et al. 2010 for an exhaustive list) are usually controlled with additional pyrethroids and organophosphates – broad-spectrum – insecticide applications (Meissle et al. 2010). Bt maize is mostly grown in Spain where maize lepidopteran borers are serious pests (Pérez-Hedo et al. 2012). Nonetheless, despite the success of Bt cropping in Spain, it has been suggested that the increase of transgenic maize could affect the populations dynamics of lepidopteran pests on maize due to the high efficiency of Bt maize against some specific target pests (López et al. 2000, López et al. 2008, Eizaguirre et al. 2010). This would be especially the case if other lepidopteran pest, such as TAW, take advantage of both: i) the decrease in insecticides applications and, ii) absence of corn borers due to their high mortality on Bt maize. Additionally, Eizaguirre et al. (2009) suggested that MCB pheromones could possibly influence directly the behavior of TAW. Nonetheless the same authors noted that more research is needed to draw robust conclusions. These species are representative of the problem posed in this paper, as both species compete for the same food resource – maize – and present different susceptibility level to Bt Cry1Ab toxin.

In order to assess the impacts of Bt technology on pests populations and economic returns to farmers, a bioeconomic model was developed and analyzed through a series of numerical simulations under certain approximate realistic conditions, having in mind a major and a secondary pest of this crop in Spain. In particular it assessed the farmers' net returns due to the changes on insecticide use and the development of secondary pests on Bt maize. Spain was chosen as basis for the calibration of the bio-economic model since it is the EU Member state with highest Bt maize adoption rate and the only country cropping Bt maize in noteworthy quantities (Gomez-Barbero et al. 2008).

1.3 Materials and methods

Study area

In the Catalonia region, Bt maize represents almost 80% of the maize cropping area as it provides very effective control of the primary pests previously mentioned, Mediterranean and ECB (Eizaguirre et al. 2010). Additionally, the two other Lepidoptera, TAW and *Helicoverpa armigera* (Hübner), are considered important secondary pests causing occasional but severe damage to maize (Eizaguirre et al. 2010, Pérez-Hedo et al. 2012). From the total of

441,4 thousand hectares of maize cropped in Spain in 2013 (MAGRAMA 2013), about 1/3 (136,962 hectares) where devoted to Bt maize, making Spain the largest European adopter with a representative 94% share of the total Bt maize hectarage in the EU (James 2014). This would suggest that lessons from Spain may help to shape EU legislation in the future and therefore this makes a sensible region for this case study on secondary pests.

Surrogates species

The MCB, is here used as an example of primary pest due to its historical importance and present susceptibility (99%) to the Cry1Ab toxin (Hellmich et al. 2008). This species is a cosmopolitan multivoltine species with a wide range of host plants, including corn (Kfir et al. 2002, Eizaguirre and Fantinou 2012). It is considered to be the most important pest in maize production in Spain and other Mediterranean countries (Cordero et al. 1998, Malvar et al. 2002). The damage caused by this pest on maize yield could reach up to 30% depending on the date of sowing and the development stage of the plant when attacked (Larue 1984, Meissle et al. 2010). In conventional maize cropping, MCB control through insecticides is only moderately effective since larval development occurs mainly inside the stalk (Albajes et al. 2002).

The TAW, is an important cosmopolitan secondary pest of the Noctuidae family, in Europe and North America (Bues et al. 1986, McNeil 1987, Cordero et al. 1998) is an invasive species that has been first noticed in Europe in the 19th century (Sheppard and Weinzierl 2002). Sporadic outbreaks, with huge larvae numbers “marching” across the landscape, can have devastating economic impacts (McNeil 1987). In Europe, it is more prevalent and important in the Mediterranean basin due to larvae inability to survive prolonged temperatures below freezing (Bues et al. 1987). This species in laboratory studies presented similar growth rate regardless of whether it is fed on a Bt Cry1Ab or a non-Bt diet (Eizaguirre et al. 2010, Pérez-Hedo et al. 2012). In field trials, there was no significant difference in the number of TAW larvae per plant between Bt and isogenic varieties (Eizaguirre et al. 2010, Pérez-Hedo et al. 2012). Hence the Cry1Ab toxin toxicity for this pest is far from a “high dose”, more than 3/4 of larvae are able to survive and complete their development (González-Cabrera et al. 2013, Pérez-Hedo et al. 2013).

Consequently decreasing conventional insecticide applications could favour the occurrence of these species as secondary pests, which could in time become major pest (Pérez-Hedo et al. 2012). Additionally, TAW’s extra advantage in Bt maize may be related to the absence of other Lepidopteran, such as the ECB or the MCB, due to their high mortality on Bt maize (Malvar et al. 2004, Eizaguirre et al. 2010). The niche replacement or guild rearrangement mechanism due to a decrease in competition with susceptible species that share the same ecological host it is perhaps the most controversial and least studied mechanism. The interaction between pests is very difficult to assess, either in laboratory or in field conditions. In a recent study, Eizaguirre et al. (2009)

suggests that MCB could indeed suppress TAW populations, however more research is needed to draw solid conclusions.

The bioeconomic model

The model takes into consideration the dynamics of the two surrogate species described above competing for the same resource and its effects on the production function to predict pest control decisions. The issue of pest interactions is explored using a production function approach as first proposed by Lichtenberg and Zilberman (1986). Harper and Zilberman (1989) examine secondary pest outbreaks caused by chemical treatments killing not only the primary pest but also predators of the secondary pest (for examples of criticisms on this approach please see Sexton et al. (2007)). The production function incorporates pest damage as a proportional loss of potential output, therefore accounting for the effect of pest population dynamics. The initial model assumptions are as follows: the agricultural product is attacked by two rather different species of pest; the first is a highly competitive pest that is also very susceptible to Bt toxin; the second pest is negatively affected by the first species, but has a higher tolerance to the Bt toxin. Both have the same negative impact upon the yield. It is assumed that farmers have only two means to suppress pests: adopting Bt varieties with the proposed rate, and spraying insecticides when pests densities exceed an economic threshold (ET1).

An agricultural landscape (whose area is normalized to 1 ha) populated by profit maximizing farmers is considered. As the scope is to evaluate the effect of Bt crops adoption (and the associated pest control practices) on the development of secondary pests, strategic behavior by individual farmers is ignored and the overall problem is formulated in terms of maximization of the Net Present Value (NPV) after 25 years of aggregate landscape profits, subject to the pest management problem. This is accomplished by choosing the appropriate amount of insecticide applications over time throughout the cropping season according to both ETs and given the above biological scenario. To make the problem more treatable, it is also assumed that all other inputs (Z) are applied in fixed proportions.

1.4 Main results

In the first scenario, in conventional maize cropping system in order to control and maintain the primary pest (MCB) below the economic threshold (ET), the farmers will apply insecticides. In this case, over 25 years, farmers will use an average of 1.05 insecticides application per ha (s.d.= 0.12), obtaining a total NPV of 8975

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[1] Economic threshold was defined by (Stern et al. 1959) as the "density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level." The economic injury level was defined by these authors as the "lowest population that will cause economic damage".

€/ha (table 1). The variability in the amount of insecticides used occurs because farmers are not able (and not economically willing) to completely eradicate the pest, but seeks to keep it under the ET. It is worth noting that having the latter goal in mind, farmers only react when the pest reach the ET. Hence in reality, due to the high MCB capacity to proliferate, its density will occasionally rebound above the ET obliging farmers to keep constant attention to their fields. Therefore, assuming that resistance factors are constant, pest populations will oscillate according to population numbers in previous years. In this scenario farmers may have no “knowledge” of the economic impact of TAW since it is always kept under the ET by both the effect of insecticide and MCB competition pressure.

Scenario	NPV (€/ha)	Insecticide applications	
		Mean	s.d.
No pest control	-2400.6	0	0
Only insecticide	8975.5	1.05	0.12
Only Bt	2470.6	0	0
Bt + insecticides	9383	0.81	0.16

Table. 1 NPV and Insecticides applications on the 4 different scenarios

In the second scenario, farmers have at their disposal Bt maize expressing Cry1Ab toxin. However, as with any new technology, the adoption rate is not linear. Within the context of technology adoption, farmers may lack a full understanding of the limitations of the Bt technology, therefore relying on it completely and ceasing all insecticide applications. In this case, after an initial period of rise in both pest densities, the MCB density starts to decline due to the increasing presence of Bt toxin. This leads to a decrease in the MCB competition capacity, hence a growth in TAW numbers. The model suggests that at about 4 years after adoption and with 62% of maize area planted with Bt varieties the MCB population falls below the ET. At this point the TAW populations would always be above the ET, being established as the main pest, causing serious damage to the crop. In this case, farmers obtain a NPV of just 2471 €/ha after 25 years (table 1), which is about one third of what they would get when relying solely on insecticides. This scenario and post analysis are slightly unrealistic as it fails to take into consideration the insecticide applications by non-adopting farmers; nonetheless it clearly demonstrates the problem of relying on a single pest control technique and what happens when farmers have no full knowledge of the secondary pest problem.

More realistically, farmers can be expected to utilize both of the pest control means at their disposal, Bt seeds adopted at the projected rate and insecticide applications used whenever pest number exceed the ET. In this case, farmers continue to apply insecticides but now in order to control TAW. The application frequency suffers a decline, farmers will use an average of 0.81 insecticides application per ha (s.d.= 0.16). This figure represents a reduction of approximately 23% in the number of insecticides applications (compared to the case in which no Bt seeds were available). This is sufficient to compensate farmers for the extra cost of Bt seeds (here assumed to be 10% more expensive than conventional seeds). After the 25 years farmers would realize a NPV of 9383 €/ha (table 1), which is 4.56% higher than what they realize without Bt seeds, and 3 times more compared with the case of only Bt maize would be used (table 2). This values are in line with previous economic studies concerning Bt adoption in Spain (Demont and Tollens 2004, Gomez-Barbero et al. 2008)

	Only *Bt*	Only insecticide
Bt + insecticides	6912.4 (+279.8%)	407.5 (+4.56%)

Table. 2 NPV difference between different control options

For comparison, in a case of perfect control by Bt toxin where both pests are equally and highly susceptible, farmers would stop applying insecticides slight after the 2nd of adoption, when 41% of maize cropping land was being planted with Bt maize. Farmers would have achieved the goal of entirely eradicating both pests and realized a higher NPV of 10681 €/ha after 25 years. Realistically however, this situation is unlikely due to two reasons: firstly agriculture is not a closed system, migration into crop fields from either known or unknown pests must be taken into consideration; secondly there is the potential for a tertiary concealed species either (or both) by the present insecticide use or by the effect of a strong competitor could sudden unexpectedly appear.

1.5 Main points for consideration

The assessment of secondary pests is made complex by the difficulty of performing randomized experiments at suitable spatial and time scales (Hardin et al. 1995, Dutcher 2007). Therefore, in order to fully take advantage of this technology, which could indeed promote a healthier agriculture is necessary a full understanding of how GEIR crops affect the complex interactions within herbivore communities. The benefits and risks of any GEIR crop adoption are entirely correlated with the tritrophic ecological interactions within the agro and adjacent ecosystems within which it has been placed (Dowd-Uribe 2013). However, the detailed nature of the tritrophic ecological interactions is still not well understood given pests strong selective and short life cycle, pests are indeed incredible in surviving and adapting (Price et al. 2011). Hence, the importance of on-going monitoring and data collection over longer timeframes, since previously published studies performed in the early years of adoption may not be able to forecast the possible development of secondary pests. Our results demonstrate the need to be conscious of the possibility of an outbreak from a secondary pest and the consequences of such an event upon yields and farm profits. The research to date has enabled us to conclude the following:

- Few studies have specifically been designed to assess the impact of GEIR on secondary pests, although there is a well-established body of evidence (irrespective of the pest control method) that suggests that when a primary pest is removed there is the potential for ingression or expansion of a range of secondary pests;

- There are several examples emerging where GEIR crops are used across wide areas in which secondary pests are not killed by the expressed toxin – such as sap-feeding herbivores (e.g. aphids and mirids) – are becoming of high economic importance, implying additional precautions need to be considered;

- Although having been substantially reduced, pesticide applications are still used recurrently in most current GEIR cropping systems due to the fact that they represent a relatively cheap and highly efficient means of controlling pests once the economic threshold has been reached;

- It may take several years for secondary pests to proliferate to higher levels of importance, thus the relevance of understanding pest dynamics;

- Secondary pest density is significantly higher in Bt maize compared with sprayed fields, due to two factors: i) the absence of insecticides and ii) low competition from the primary pest;

- Despite the fact that farmers may clearly understand the benefit of using Bt to reduce the use of chemical insecticides targeting the primary pests, they may not realize that secondary pests exist until they have grown to become a significant economic vector on the farm;

One claimed solution to the advent of secondary and tertiary pests are the so called ‘‘stacked’’ or “pyramid” events, in which two or more single events are combined by conventional crossing. Such plants expressing different *Bt* toxins could effectively provide a method of dealing with the emergence of *Bt*-resistant pests (Snow et al., 2003). Nonetheless, it is important to note that resistance to pyramid *Bt* varieties is driven by the same evolutionary processes as single *Bt*-toxin varieties, not being this a infallible solution (Ives et al., 2010). When such control fails it is likely the farmer will once again use pesticides. As previously mentioned, the benefits exists, and they could be quite substantial, economically, environmentally and even socially (Wesseler et al. 2007, Skevas et al. 2010), if an effective control and compliance with certain procedures (e.g. refuge strategy) were employed (Meissle et al. 2011). The theoretical and numerical results reported in this study are not merely important to the economic assessment of the transgenic crops, but may be as well relevant to a wide variety of other agricultural pest issues, either insects or weeds, involving competition. An example could be the complete evaluation the impact of invasive pests, insecticide restrictions, new transgenic traits, other means of pest control – natural enemies, pheromone traps or biological insecticides – and possible eradication programs – setting the pest economic threshold to zero.

1.6 Implications in EU context

The research presented here is part of the Reading team's on-going investigations into secondary pest dynamics. The modelling work utilizes the limited empirical evidence available that suggests that in some environments there is a real danger of secondary pest emergence and a gradual erosion of incomes to those who have adopted BT varieties. It is clear that stacked varieties may help to overcome this issue in some systems, but where a wide range of insect pests are in evidence there will always be the potential for the emergence of new pest species.

Liu and Huang (2013) found that, among several other hypotheses (e.g. low quality Bt Cotton seeds, secondary pests, etc), risk aversion was the main factor for spraying insecticides in excessive amounts. Hence in order to ensure that GEIR adopters will be able to attain their high expectations of enhanced pest management, and even increase yields and consequent profit, there is a need for technology-specific continuous training and education (Storer et al. 2012, Liu and Huang 2013). It is therefore reasonable to question how GEIR cropping will behave in the context of these conceivably highly interdisciplinary and complex recognized risks (Nap et al. 2003). No less important is the critical evaluation of the magnitude and persistence of negative effects with other pest management techniques – especially the effects of broad-spectrum insecticides (Hails 2002, Dutton et al. 2003). In this context, there is a necessity and even an obligation to find a stable and trustworthy balance between the conservation and perpetuation of functional ecosystems teeming with biodiversity and the sustainability of world's agricultural systems (Arpaia 2010).

Although this research is on-going is does highlight the possibility that more attention should be given to the potential emergence of secondary pests in a given region prior to the release of given events and that clear guidelines are needed in relation to monitoring of secondary pest emergence following first plantings of GM varieties in a given region. That said it is clear that the emergence of more complex stacked events, the use of which may lead to the control of a range of key pest species is also an exciting agronomic possibility. The research to date shows that although farmers may feel that adoption of the GEIR technology may allow some "simplification" of their management practices, the reality is that they need to continue to monitor crop performance and where necessary "supplement" the BT technology with targeted insecticides applications if they are to achieve optimum margins.

2. Issues related to carbon dynamics, greenhouse gases and climate change

2.1 Review of literature

The direct and indirect contributions of agriculture to GHG emissions and thus potential climate change are well documented. Given that the use of GM crops can lead to changes in cultivation and various other agronomic practices (for instance pesticide applications) there is the potential for their use to either directly or indirectly influence the emission of GHGs. Against the backcloth of the United Nations Framework convention on Climate Change (UNFCCC, 2005) this suggests that transgenic crops may have a role to play in climate change mitigation. For the developed countries of the EU the Kyoto Protocol required a reduction (on average) of GHG emissions to 5.2% below their 1990 levels. There are basically three mechanisms through which the use of transgenics could contribute to GHG reductions:

a. If less pesticide is used overall then less fossil fuel will be used in the manufacture of pesticide thus reducing overall loading

b. If less pesticide needs to be applied to fields then there is a direct saving in fuel related to those applications

c. In some cases the use of transgenic has been associated with a reduction in cultivation. This has the potential to save fossil fuel, thus potentially reducing emissions.

A range of industry supported reports (ISAAA) have suggested significant savings in relation to carbon. The 2009 report suggested a saving of 1.1BN kg of carbon through the use of less sprays. However this is dwarfed by the potential savings related to reduced cultivations that take place as a result of the use of GM crops, estimated to be 13.1Bn kg in 2007 (ISAAA 2009). This illustrates the importance of reduced tillage in any agricultural system in relation to direct carbon release from the burning of diesel to undertake that tillage, but also because over time no-till is likely to lead to a build-up of carbon within the soil (i.e. sequestration), thus helping to off-set carbon released during other aspects of agricultural production. This was recognised by Glover et al (2008) who noted that 16-18% of Australia's net greenhouse emissions were associated with agricultural sector and thus the sector needs to either reduce emissions or increase sequestration.

Agronomic practices that lead to increased min or no till can lead to less oxidation of soil organic matter and a potential reduction in soil erosion and thus greater retention and sequestration of soil carbon over time. For instance some studies have found correlations between the growth of HT Canola and minimum or zero tillage practices (Smythe *et al*., 2011; Young, 2006). Clearly the use of transgenics with selective herbicides can reduce the need for cultivation and thus saving energy. It should be noted that it is accepted that no-till at least in the initial years of adoption can lead to an increase in pesticide use whist the system settles into a new equilibrium. However it should also be noted that reduced tillage practices in Canada and the USA cannot be attributed purely to HT varieties, although the high degree of weed control facilitated by the adoption of GM HT Canola has aided no-tillage production methods.

Examples in which transgenics have led to changes in practice include the adoption of conservation tillage in soya bean production where the American Soya bean Association suggests that such practices have led to a 90% reduction in wind and water erosion as well as saving considerable amounts on fuel use. Similarly rotational benefits have been noted in Canada where the "cleaning" impacts of HT Canola have reduced the need for fallow and mechanical weeding thus increasing overall productivity. McConkey *et al.* (2007) and Smythe *et al.* (2011) estimated that the use of reduced tillage in Canada associated with GM HT Canola has led to 1M t of carbon being sequestered or not released annually compared to 1995. Similar findings related to the GHG advantages of GM were reported by Brookes and Barfoot (2012) who estimated that whilst no till / reduced till cultivation potentially sequesters carbon at the rate of 55 kg ha^{-1} yr^{-1}, the fuel intensity of conventional tillage can lead to a net release of 10 kg ha^{-1} yr^{-1}. Brookes and Barfoot (2012) also estimate that the cumulative, permanent reduction in tillage fuel use in GM HT Canola in Canada over the period 1996–2010 was 301.7M litres, equivalent to a reduction in carbon dioxide emissions of 806M kg. This reflects a 37% reduction in fuel usage from 49 l ha^{-1} in conventional tillage to 30.62 l ha^{-1} in no-till/reduced till cultivation.

There has also been debate about the use of transgenics for biofuels thus potentially off-setting the use of fossil fuels, although Ceddia et al (2009) suggests they probably do not have sufficient advantage over conventional varieties to provide the main stimulus for a grower to convert to biofuel production.

2.2 Impacts related to current growth of GM in the EU

The arguments related to the limited area of transgenics grown in the EU have been rehearsed elsewhere. Nonetheless in 2014 approx. 140000 hectares of BT Maize were grown mainly in Spain. It is possible to provide a broad estimate of the energy and GHG savings that are likely to have occurred from planting in 2014 on the basis of:

Energy cost per hectare to apply spray, 115 MJ per pass (estimated from Bailey and Basford 1998)

Energy density of diesel fuel, 37MJ per litre

Approx energy embodied in a single pesticide spray, 100 MJ ha^{-1}

Carbon dioxide released when 1 litre of diesel is burnt, 2.68 kgs

Number of insecticide sprays foregone, 1.5 (this may be more in heavily infected areas)

Overall saving per hectare 322 MJ of energy, 8.7 diesel equivalents and 23.4 kg of carbon dioxide.

Across the current transgenic hectarage in the EU this equates to 3276 tonnes of carbon dioxide not emitted or saved because of the current use of transgenics in the EU. This equates to the average annual carbon emission of about 200 US citizens (based on 17 tonnes per capita). This calculation does not account for any more substantive changes in cultivation practice that may take place as part of rotational benefits they may occur.

2.3 Potential impacts related to predicted areas of growth in the future

It is extremely difficult to predict the areas of transgenic crops that may be grown in the future in the EU even if regulatory approval were to be in place. Park et al (2011) estimated the areas of transgenic crops that may be grown in the EU based on an absence of regulatory constraint and making the assumption that farmers would grow transgenic crops where there was a perceived agronomic benefit. Estimated areas across the EU27:

Bt Maize, based on lower estimate of infected areas	2.033 Mha
Bt Cotton, based on benefit across whole area grown	0.26 Mha
HT Soya, based on weed benefit across the whole area	0.5 Mha
HT OSR, based on weed benefit across the whole area	6.5 Mha
HT Sugar Beet, based on weed benefit across the whole area	1.46 Mha

Audsley *et al* (2009) provide direct energy costs for herbicide inputs into arable crops which for Oilseed Rape 752 MJ ha^{-1}, Sugar Beet 2283 MJ ha^{-1} and "Beans" 645 MJ ha^{-1} and these have been used as the basis for the calculations in Table 2.2

Table 2.2: Estimates of potential carbon savings if GM crops were grown in the EU where there is a potential agronomic need.

Crop	**Area that could derive benefit from transgenic (Mha)**	**Energy saving per hectare (MJ)**	**Total energy saving (MJ x 10^6)**	**Total carbon saving (Tonnes)**
Bt Maize	2.033	322	654.6	47416

Bt Cotton	0.26	322	84	6000
HT Soya	0.5	645	322	23320
HT OSR	6.5	752	4888	354000
HT Sugar Beet	1.46	2283	3333	241410
TOTAL	10.75		8625	**624777**

Using the average US citizen again as an example this would save carbon dioxide equivalent to the emissions' of 37000 US citizens.

2.4 Implications for the EU

The EU emits about 10% of the global greenhouse gases and about 10% of these are derived from agricultural sources. Thus changes in agricultural practices do have the potential to drive down emissions. The fact that the adoption of transgenic crops can reduce the volume of pesticide used and can reduce the amount of cultivation undertaken by farmers means they could contribute to overall reductions in GHGs. The degree of reduction will clearly depend on the overall adoption and in particular the degree to which this leads to reduced cultivation. This suggests that the adoption of current HT technologies could potentially have the greatest impact in the short term, although at present there are no HT events approved for use in the EU. Evidence from other areas of the world, particularly North America (with Soya and Canola) suggests that the use of such events can lead to significant changes in rotational practice, reducing the degree of cultivation thus saving energy and reducing GHG emissions. The key to note here in terms of EU policy is that the use of transgenics crops are very likely to contribute to a small reduction in the release of GHGs and are very unlikely to lead to an increase in the release of GHGs from EU farming systems. In terms of pre-release evaluations it would not be difficult to provide estimates of likely impacts on GHG emissions' if assumptions are made about likely changes in farming practice and potential areas of adoption within the EU. However, general changes in the policy which help to facilitate IPM and the use of reduced tillage across the EU are likely to lead to more substantive benefits in terms of GHGs.

3. Wider environmental impacts related to pesticide loading, resistance, gene flows and water quality

3.1 Overview

There is still considerable debate surrounding the environmental impacts of GM crops and indeed issues surrounding environmental risk analysis form part of the underlying ethos of the AMIGA project. A range of previous studies have been undertaken into environmental impact. More focussed studies have considered a range of crops for instance maize (Brookes and Barfoot, 2012; Henry et al., 2003; Kendall et al., 1997; Morse et al., 2006; Park et al., 2011; Wesseler et al., 2011). There is a danger that sometimes ERA focuses on the potential negatives without noting that in some cases the adoption of BT can have potential benefits, for instance see (National Research Council, 2010). Here we focus on:

- Herbicide and insecticide impacts
- Resistance and gene flow issues
- Issues associated with water quality

As with GHG emissions it is worth drawing a distinction between direct and indirect impacts, for instance potential direct impacts on local fauna and indirect impacts that for instance could occur if the wider adoption of GM crops leads to a wider change in landscape patterns and thus the biodiversity within a given region. Smythe *et al.*, (2011) also note differences related to immediate, delayed and cumulative changes. In terms of changes in pesticide use, which is perhaps the most likely impact of the adoption of GM, a comparison of the amounts of active ingredient (AI) applied between different systems is a commonly used measure. Despite the apparent simplicity of this measure, i.e. a comparison between conventional and GM systems, it is complicated by the strength, dose rates efficacy and nature of different pesticides. This is particularly true when changes lead to the use of more targeted rather than broad spectrum pesticides. Similar issues around comparability were common in the integrated systems experiments in the 1990s (HGCA Report 173). Indeed Kovach et al (1992) developed the Environmental Impact Quotient (EIQ) as a more robust and comprehensive indicator of environmental impacts. The measure has been used in a variety applications, for instance in terms of assessing the impact of Integrated Pest Management (IPM) and other pest management strategies in both developed and developing countries (see, for example, FAO, 2008), their use as an evaluative tool in transgenic comparisons appears to have been limited.

The EIQ takes into account the toxicity and other environmental characteristics of individual products and the effects on farmers, consumers and the ecology to provide a single field value per ha. For any herbicide regime, the EIQ value can be multiplied by the active ingredient used per ha to provide a measure of the environmental impact at the field level. EIQ has been extensively used in empirical studies measuring the environmental impact of pesticide and herbicide use including in GM OSR (Brimner *et al*., 2004).

Other techniques for assessing environmental impacts of growing GM crops have been used such as life cycle analysis (LCA) (Bennett *et al*., 2004; Strange *et al*., 2008), descriptive statistics after compiling information on insecticide and herbicide use, and GHG emissions (Brookes and Barfoot, 2012), and statistical tests using data from monitoring fields (Morse *et al.*, 2006), and wider trials such as the UK Farm Scale Evaluation (Henry *et al*., 2003). Research has used a range of indicators such as weight of active ingredient, weight or volume of pesticide per hectare through to more specific monitoring of species or numbers of individuals. Examples include the impact of Bt maize on soil microbes has been analysed finding no evidence of a negative effect on them (Al-Deeb *et al*., 2003; Motavalli *et al*., 2004; Saxena and Stotzky, 2001). Indeed impacts of GM on the soil fauna are subject to detailed evaluation within the AMIGA project.

3.2 Herbicide and insecticide use

Here we will focus on the events grown internationally that could potentially have agronomic benefit in the EU if they were approved for growth. It should be noted that new events are continually being approved and released in other parts of the world and that increasing there is a trend toward the use of stacked traits with events being tailored to combat specific agronomic issues that arise in a given region or country. Thus new stacks may lead to changes in both insecticide and herbicide regimes. Here for simplicity we focus mainly on single traits but the potential to combat multiple agronomic problems by utilising GM in a given location is now a reality.

The adoption of HT GM often leads to the substitution of more selective and toxic herbicides with less toxic broad spectrum herbicides (Giesy *et al*., 2000; Williams *et al*., 2000). However Qaim (2009) suggests that the use of GM HT does not always lead to a reduction in the actual amount of herbicides used, just a lowering of overall toxicity. If effective weed control is achieved by using GM, then this can have an impact in following years, thus providing a rotational benefit. For instance Gusta *et al.* (2011) considered the spill-over benefits into subsequent years of adopting GM HT Canola in Canada. Their research found that 54% of those who completed their survey (n=600) reported a spill-over benefit in the second year with a potential average benefit of Can \$15.05acre^{-1}.There are no OSR varieties approved for cultivation in the EU at present, and most of the Canola varieties grown in Canada are short season therefore it is difficult to predict the potential benefits in terms of herbicide savings in the EU countries. Rotations are also different within and across the EU. Nevertheless the possibility for the replacement of a range of herbicides with low toxicity products such as glyphosate may be environmentally attractive.

In terms of herbicide loading, Brookes and Barfoot (2012) report that herbicide active ingredient use on GM glyphosate-resistant (0.65 kg ha^{-1}) and GM glufosinate-resistant Canola (0.39 kg ha^{-1}) is lower than in conventional Canola (1.13 kg ha^{-1}). The average EIQ load for GM HT Canola is generally lower than that for conventional Canola (10 ha^{-1} for GM glyphosate-resistant Canola, 7.9 ha^{-1} for GM glufosinate-tolerant Canola versus 26.2 ha^{-1} for conventional Canola).

Some studies have reported higher levels of reduction in herbicide active ingredient use in Canada. For instance Smythe *et al.* (2011) estimated an annual reduction in herbicide use of nearly 1.3M kg for Western Canada alone. Empirical evidence from the USA suggests similar reductions in herbicide use (Brookes and Barfoot, 2012; Sankula and Blumenthal, 2003; Sankula and Blumenthal, 2006; Johnson and Strom, 2008). Overall the amount of AI used on GM HT Canola varieties has been estimated at between 0.5–0.75 kg/ha less than on conventional varieties (Sankula and Blumenthal, 2003; Sankula and Blumenthal, 2006; Johnson and Strom, 2008), although the introduction of ‘Clearfield’ varieties provides a new and different option for herbicide use reductions.

Clearfield Canola which has been developed using “conventional” breeding methods has altered the GM v Conventional Canola comparison so although GM glyphosate-resistant Canola actually uses marginally more active ingredient (+0.13 kg ha^{-1}) it still usually has a lower environmental footprint (EIQ load factor) than Clearfield Canola. Brookes and Barfoot (2012) estimated that in 2010, based on comparisons with Clearfield Canola, the reduction in herbicide use in Canada was still 0.22M kg with a reduction in EIQ load factor of 21.2%. Cumulatively, between 1996 and 2010, they estimated that herbicide active ingredient use for Canola fell by 18% (11.9M kg) while the EIQ load factor fell by 28%.

Using data from a number of empirical studies, Brookes and Barfoot (2012) estimated that in the three countries where GM Canola has been adopted – Canada, USA and Australia – there has been a decrease in the volume of herbicide applied and this the associated environmental impact. They estimate that in 2010, herbicide active ingredient use was 6.2% lower (a reduction of 0.4M kg) compared to the level of use if the entire crop had been planted to conventional varieties, with the EIQ load factor being lower by 18.7%.

HT soya was grown on 75.4 Mha in 11 countries in 2011, with about 47% of the global crop being GM (James 2012), its widespread adoption is in part due to rotational and minimum till benefits it imparts (Fernandez-Cornero et al, 2012) For instance a decade ago, Fernandez-Cornejo and McBride (2002) reviewed the rates of adoption in USA of HT soya bean and found that it did not have a significant impact on net farm returns in either 1997 or 1998. They suggested that other factors may have driven adoption for some farms, such as the simplification of farm management and the opportunity to use one product instead of several herbicides to control a wide range of weed pressures. Brookes and Barfoot (2013) reported that where yield gains have occurred from improvements in the level of weed control, the average farm income gain has tended to be higher. A second generation of GM HT soybeans became available to commercial soybean growers in the US and Canada in 2009. This technology offered the same tolerance to glyphosate as the first generation but with higher yielding potential. It also facilitated the adoption of no tillage production systems, shortening the production cycle and enabling many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season.

The farm-level impacts of growing soya in Europe were examined by Brookes (2005) who showed that the adoption of the technology delivered major improvements in farm income, mostly from yield enhancements associated with improved weed control in Romania. Otiman, Badea and Buzdugan (2008) reported that HT soybeans accounted for 68% of all soybeans planted in Romania in 2006. A major benefit was a reduction in the use of herbicide (on average, 1.9 treatments applied to HT and 4.3 treatments to the conventional soybeans) as well as the higher yields (3-3.5t/ha for HT versus 2 t/ha for the conventional product). Accession to the EU, and the lack of approval for the growth of HT soya meant the Romanians had to withdraw from the growth of GM soya.

It is also worth noting that the introduction of HT soyabeans, in particular, has changed patterns of use of chemical herbicides with glyphosate now being the most dominant herbicide, accounting for 92% of herbicide use on soya bean. It is classified internationally as a toxicity class IV pesticide, less toxic than most of the previously utilized herbicides. Workers can be exposed to pesticides through direct skin contact or inhalation during application. Such exposure also may occur when safety periods between application and harvest are ignored or when pesticides are overused or used improperly. Pesticides from aerial spraying may also drift into neighbouring areas and expose residents. Research has indicated reduced incidence of pesticide poisonings in South Africa since the introduction of transgenic crops (Bennett et al., 2006) and that 22 reduced pesticide use has had health benefits among Chinese farmers (Huang et al., 2002).

Transgenic herbicide tolerant sugar beet has had a very rapid adoption in the US; reaching 95% adoption within two years of its commercialisation in 2007, mainly due to herbicide savings and ease of management. Model simulations show that the annual benefits for GMHT sugar beet farmers in the USA average around $257/ha (Dillen *et al*, 2013). The impact of a hypothetical introduction of herbicide tolerant sugar beet to the EU has been modelled and the outputs indicated there would be significant gains to farmers and consumers, arising primarily from savings in expenditure on herbicide required for conventional sugar beet, which exceed the technology fee of €90-106/ha paid by growers in the USA (Dillen *et al* 2009a). The economic advantage of adopting HT sugar beet throughout the EU was estimated to be in the region of €300 million per annum to the EU as a whole, based on data from USA (Dillen *et al*, 2009b). No varieties are approved from growth in the EU.

In relation to insecticide use on GM crops, Brookes and Barfoot (2012) provide estimates for both average volume of insecticide and average field EIQ value since 1996, the year in which Bt maize was commercialised in the USA. Table 8.1 shows the comparison of the average US maize insecticide use and its environmental load between conventional and Bt maize for 1996–2010. Reductions in average insecticide use and environmental load have also been found also in other countries where insecticides have been used traditionally on maize (Brookes and Barfoot, 2012).

The widespread adoption of GM IR maize technology has resulted in ‘area-wide’ suppression of target pests such as the European corn borer in maize crops leading in some cases to a consequent reduction of pesticide use in conventional maize fields (Hutchinson *et al*., 2010).

Table 8.1. Average insecticide use (active ingredient) and its environmental load for conventional and Bt maize in the USA.

Year	Average ai/ha (kg): conventional maize	Average ai/ha (kg): Bt maize	Average field EIQ: conventional maize	Average field EIQ: Bt maize
1996	0.66	0.61	19.3	18.1
1997	0.65	0.59	19.0	17.7
1998	0.71	0.63	20.3	18.4
1999	0.63	0.61	18.4	18.3
2000	0.62	0.54	18.2	16.4
2001	0.51	0.49	15.5	14.4
2002	0.48	0.30	15.0	10.5
2003	0.55	0.41	16.0	12.5
2004	0.57	0.30	16.7	10.3
2005	0.43	0.33	12.8	11.2
2006	0.53	0.34	15.4	10.5
2007	0.39	0.24	11.9	7.9
2008	0.31	0.27	9.6	8.3

2009	0.26	0.21	8.7	7.0
2010	0.51	0.4	17.1	14.0

Source: Brookes and Barfoot (2012) derived these estimates from GfK Kynetec database.

In the EU where farmers have been allowed to cultivate MON810 maize to combat pressure from stem borer pests, economic benefits have often been achieved (Demont *et al.* 2007, Dillen, *et al.* 2009, Gomez-Barbero *et al* 2008), in part due to reductions in insecticide applications in areas of heavy pest infestation. The advantage of IR transgenic crops is only relevant in regions where pest pressure is both severe and recurrent. A range of climatic and other factors cause insect populations to fluctuate meaning that the economic advantage can also fluctuate, although this can be difficult to predict at the time of planting. WCR arrived in Europe, in Serbia, in 1992, and spread rapidly with serious economic impact on European maize crops in some areas. Containment measures have been partially successful, and the European and Mediterranean Plant Protection Organisation monitors the annual changes in distribution (EPPO 2009). Further spread of both ECB and WCR is possible, and may be linked to climatic change, the consequences of which are difficult to predict. In this context access to GEIR technology in the future may become increasingly important to minimize pesticide use.

Similar reductions in insecticide loading have been reported for cotton. For instance, in Australia, with reference to Bt cotton, Knox et al.(2006) considered the impact of the transgenic proteins Cry1Ac and Cry2Ab on EIQ values. While the average insecticide EI for conventional cotton was 135 kg a.i. ha^{-1}, the value for the Bt variety with two inserted genes was only 28 kg a.i. ha^{-1}. Results of the EI evaluation indicate that there was a net reduction of at least 64% in EI from growing Bt cotton compared with conventional non-transgenic cotton.

Overall, it would appear that there is considerable potential to reduce pesticide loading through the introduction of GM seed. However, there is increasing concern re the potential emergence of secondary pests (see section 1) and issues around resistance (see below). The emergence and popularity of stacked events may help to overcome some of the concerns re secondary pests and it is likely that sensible farm management practices (if implemented) can help to overcome issues associated with resistance. Indeed resistance to pesticides is common place in conventional systems as well.

3.3 Resistance and gene flow issues

Given that HT crops are associated with the use of broad spectrum herbicides such as glyphosate there have been concerns about its widespread and continued use and the subsequent development of resistant weeds, For instance, Smythe *et al.* (2011), cite Young (2006), who reports a decline in the average number of active ingredients applied to HT cotton and soya bean of around 50% between 1994 and 2001. There is no doubt that the widespread and continuous use of herbicides such as glyphosate has started to lead to resistance. It is reported in the literature (see, for example, Brookes and Barfoot, 2013) that weed resistance to glyphosphate has become a problem in some countries, such as the USA where there are 13 weeds recorded as having glyphosphate resistance.

Another concern relates to the growth of resistant volunteers. In the previously reported survey of Smythe *et al.* (2010) (n=600) they found that "more than 94% of the respondents reported that weed control was the same or had improved following the commercialisation of GM Canola, less than one quarter expressed any concern about herbicide resistance in weed populations, 62% reported no difference in controlling for volunteer GM Canola than for conventional Canola and only 8% indicated that they viewed volunteer GM Canola to be one of the top five weeds they need to control".

In relation to controlling the build-up of resistance this can often be viewed as part of general good farm practice which would include careful consideration to rotations, use of multiple herbicides and/or mechanised control measures. The "ease" of management that can be provided by GM crops may in some cases lead farmers into a "false sense of security" and may facilitate a movement toward more simplified farming systems which in the medium term enable the build-up of resistance.

The arguments concerning gene flow have been well rehearsed elsewhere and nation states of the EU have a variety of co-existence measures in place. This relates to concerns that the growing of GM crops may facilitate gene flow (cross-pollination) from GM crops to non-GM crops and wild relatives, which may have implications for plant diversity and ecological systems (Dunwell and Ford, 2005). For instance if a GM OSR was introduced within the EU it would have the potential to hybridize with wild relatives. Similar concerns would apply if GM crops such as wheat, barley and oats were to come to market. Transfer could occur either through pollen transfer or escape of seeds during harvest, transport and processing (Dunwell and Ford, 2005).

As a result, EU policy recognises that "European farmers should have a sustainable possibility to choose between conventional, organic and GMO production", underlining that economic damage or losses derived from the introduction of GMO have to be avoided (European Council, 2006). The EU legislation establishes a threshold of 0.9%, above which the marketed products containing GMO authorised to be used have to be labelled as a GM product. In order to avoid cross-pollination, the EU policy established recommendations for isolation distances that aim at reducing the risk of cross-pollination. Such distances have varied over time and vary between countries. It is worth noting that implementation of isolation distance may slow down adoption particularly in the early phases of adoption (Areal *et al.*, 2012) and, therefore, it is important to have information on the relationship between separation distance between a GM crop and its conventional counterpart and the probability of gene flow. For GM maize, the distances suggested to ensure a 95% level of confidence to meet the 0.9% threshold established by the EU, are 12 m of border rows (or buffer strips) plus 12 m of fallow isolation (Marceau *et al*., 2013). It is worth noting that gene flow may also occur during the harvest, transportation and processing stages (Dunwell and Ford, 2005).

In summary issues surrounding both resistance and gene-flow are well-known and are being faced and dealt with in agricultural systems across the world. The EU already has issues with herbicide resistance weeds (for instance black grass) and farmers utilise alternative methods of control where necessary (for instance cultivation, break crops and rotation). The “fight” against resistance is thus on-going and requires good farm management practice in both conventional and GM systems. It also requires constant technological innovation and development of new chemicals by the supply industry.

3.4 Water Impacts

One of the potential indirect impacts is via water quality. Most of the evidence suggests that the use of transgenic can lead to the use of less pesticides or the use of less toxic pesticides, thus providing a potential benefit to society. James (2009) presented data that suggested that between 1996 and 2007 transgenic crops had led to an accumulated pesticide “saving” of 359000 tonnes of active ingredient which equated to a 17% reduction in associated environmental impact, in part because of the replacement of very toxic pesticides by relatively benign glyphosate. For instance the introduction of transgenic crops in the US in the late 1990s led to the replacement of some persistent residual herbicides with short half life contact herbicides which are more environmentally benign (Fernandez-Cornejo and Caswell 2006). A study by Shipitalo *et al* (2008) confirmed this trend. In Australia Crossman and Kennedy (2005) suggested that the introduction of HT crops could reduce the probability of surface run-off and reduce the risk of water contamination when compared with regimes used with conventional cropping.

It is difficult to estimate exactly but in the 1970 the WHO suggested there were in excess of 500000 pesticide poisonings resulting in 5000 plus deaths. Although problems of pesticide poisoning may be more acute in developing countries the EPA estimates that there are between 10000 and 20000 incidents of poisoning in the US alone. Lack of awareness and education in developing countries means the problems can be more acute. For instance Rother (2000) noted that women in South Africa knew that pesticides were poisons but were still seen mixing the chemicals with their bare hands and that they did nothing to prevent run-off into water courses from which they derived drinking water. Rola and Pingali (1993) noted in field studies that half of the farmers related sickness to pesticide use.

Thus in the EU it would appear, that depending on the level of uptake of GM, the likely impacts on water quality are likely to be positive as there is potential for both the amount and toxicity of the pesticides used to be reduced.

However, there are potentially more widespread benefits in terms of water quality that would accrue from precision farming, IPM and reduced cultivation practices, all of which could reduce pesticide loading in water. In terms of the health of workers it is likely that the use of less, and less toxic pesticides can only provide benefits.

4. Implications for the EU

4.1 Summary

Scientific evidence so far seems to indicate that there is no environmental damage associated with the growing of GM crops that is above and beyond the normal practices associated with the growth of conventional crops (Dunwell and Ford, 2005) and that there may possibly even be benefits to the environment (Brookes and Barfoot, 2012; Park *et al*., 2011; Wesseler *et al*., 2011). Generally the growing of GM varieties results in fewer pesticide applications than their conventional counterparts thus reducing the amount of chemicals in the environment, lowering the risk of pesticide residues in food and feed crops and potentially increasing on-farm diversity of insects and other pollinators (Nickson, 2005; Sanvido *et al.,* 2007; Wesseler *et al.,* 2011; Wu, 2006).

That said, the research reported in section 1 of this report suggests that it is sensible to be cautious in terms of wider agro-ecosystem changes. It is clear in some established GEIR systems the removal of primary pests has enables a rise in secondary pest populations. The research reported here suggests that in some cases a regime of both Bt and targeted insecticide application can render the most profitable solution to the farmer. However, it should be noted that a range of "stacked" events (as yet not approved in the EU) are being used successfully in other parts of the world.

In terms of GHG the calculations presented in section 2 suggest that there are potential saving to be made if the use of GM reduces pesticide use or leads to reductions in cultivations. If for instance the use of HT crops in the EU lead to rotational changes which further reduced cultivation this could lead to a direct saving in emissions from cultivation, but could also lead to increased carbon sequestration in the soil.

There is also little doubt that the use of GM can lead to reductions in pesticide use in some cases. There may also be a benefit derived from the use of less toxic broad spectrum herbicides. However, it is dangerous to view transgenic technology as a "fix all". In terms of insect pests, section 1 clearly illustrates the need for close observation of pest dynamics and the possible emergence of secondary pests. Further, issues related to herbicide resistance are well documented in both conventional and GM systems. This suggests that the farmers need to give careful thought the use of transgenics in their overall farming system and to combine their use with "normal" high quality farm management practices and not be lured into thinking the use of GMOs will allow for a simplification of their systems.

In terms of water quality the main benefits elsewhere in the world derive from less pesticide loading in the environment and there is no reason to believe that such benefits would not also derive in the EU. However, the use of transgenics on their own is only likely to have a small impact on some of the environmental issues facing farming. The new CAP in the EU, with a further strengthening of environmental aspects, the encouragement of IPM, lower levels of cultivation and rotations we all be needed to reduce the footprint of agriculture on the environment. The research reported here suggests that in some cases GM crops can contribute to such agricultural sustainability.

This has implications for pre-approval documentation which could potentially contain a section on "potential positive contributions to agricultural sustainability" which could include information related to GHGs, pesticide loading, water quality and cultivation. It may also be appropriate for such documentation (in the case of GEIRs) to comment on the likelihood of issues related to secondary and tertiary pests.

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