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EPA STRIVE Programme 2007–2013

Predicting the Impact of Coexistence-Guided, Genetically Modified Cropping on Irish Biodiversity

(2006-B-MS-46)

STRIVE Report

Prepared for the Environmental Protection Agency

by

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Executive Summary

At present no genetically modified (GM) crops are grown in Ireland because the current suite of commercialised GM crops is not suited to the Irish agri-environment. Farmer surveys clearly show willingness on the behalf of Irish farmers to adopt specific GM traits (e.g. blight tolerance, see http://www.gmoinfo.ie/index.php?option=com_content&task=view&id=63&Itemid=64) if they will provide an economic and/or environmental benefit. Therefore as the second and third generations of GM crops proceed through research pipelines, it is broadly accepted that in the near future Irish farmers will be afforded the choice as to whether they wish to adopt GM technology into their systems. Their choices will be heavily influenced by the economic realities of the day. Considering the future environmental (e.g. climate change) and legislative challenges (e.g. pesticides regulations), the crops with the most potential for modification from an Irish perspective include oilseed rape, maize, potato, barley and wheat. The principal traits that would benefit Irish farmers would be herbicide tolerance (HT), nitrogen-use efficiency (NUE) and enhanced fungal resistance (EFR).

While assessing the potential biodiversity impacts associated with each of these traits, it became evident that minimal research has been completed into gauging the impact of conventional agriculture on species and habitats in the Irish landscape. Only 21 papers investigating the impact of conventional crop cultivation on Irish biodiversity have been published within the past 30 years. Principally, these studies have concluded that conventional crop cultivation has had an adverse impact on biodiversity on Irish farms, with 15 of the 21 studies demonstrating negative trends for the taxa investigated.

It is clear that as with all forms of tillage agriculture, there is a high likelihood that the potential impacts of GM crops on Irish biodiversity will be both positive and negative. When this issue is examined at a macro scale, the net potential impacts are likely to be beneficial towards the wider diversity of the Irish landscape. The potential modifications that would suit current Irish agricultural practices are designed solely to assist deriving greater profitability from lower inputs, implying that management regimes on Irish GM farms will be different from non-GM farms. As a follow-on consequence of these new management schemes, GM farms will have lower inputs, less disturbance and lower resource requirements. The benefits to biodiversity are therefore expected to be broadly beneficial but this will be dependent upon the GM trait adopted and the level of compliance by the GM farmer to the recommended crop management.

Based on the number of field trials under way across the EU (http://gmoinfo.jrc.ec.europa.eu/) at present, it is predicted that the first GM crops suited to the Irish agri-environment (e.g. HT maize) will be available to farmers by 2015. While it was not possible to complete a comparative analysis between the potential impact of GM and the actual impact of non-GM tillage systems for this study due to a paucity of data on non-GM systems, an opportunity exists to rectify this through the establishment of a national biodiversity monitoring and evaluation programme for tillage systems which would provide a baseline against which biodiversity loss, mitigation or gain may be assessed and scientifically reviewed prior to GM crop adoption in Ireland.

1. Introduction

1.1 Background

In 2008 the number of countries growing GM crops reached 25 across an accumulated global area (from 1996 to 2008) of ca. 800 million hectares. Managed by over 13 million farmers, the first generation of GM crops include traits of insect resistance and/or herbicide tolerance in maize, soybean and cotton. Insect-resistant maize (conferred through the expression of the *Bt* gene) is the only commercial GM crop grown within the European Union (EU) with an approximate hectarage of 110,000 ha across Spain, France, Portugal, the Czech Republic, Germany and Slovakia (James, 2008).

In 1998 a de facto moratorium on the cultivation of GM crops within the EU was established in response to public concerns regarding the perceived biosafety of GM technology when applied to food production. Up to 2003, the response of the EU was to introduce a series of legislative measures (Directive 2001/18 (European Commission, 2001); EU Regulation 1829/2003 (European Commission, 2003e); EU Regulation 1830/2003 (European Commission, 2003c); EU Regulation 1946/2003 (European Commission, 2003f)) to ensure informed consent, adequate labelling and traceability, and to safeguard against the introduction of a GM crop that presents a hazard to human/animal health and/or the environment. The moratorium was lifted in 2004 and since then the European Commission (EC) has affirmed its intention to progress with incorporating GM crops into the EU in response to global competition and in light of concerns about food security (European Commission, 2009).

Combined with the fact that 'next generation' GM crops (e.g. blight-tolerant potato) with more relevance to the Irish tillage sector are near to commercialisation,[1] it is clear that Irish farmers will, in the near future, be afforded a choice as to whether they wish to adopt GM technology into Irish agricultural systems. There are several policy-based instruments that will have a bearing on this outcome as a result of the necessity to complete focused research on the potential ecological impacts of GM cropping in Ireland.

The National Biodiversity Plan (NBP[2]) (2002–2006) raises concerns over the possible introgression of transgenes into natural systems and highlighted the necessity for more research into the potential impact that GM crops may have on biodiversity in the Irish landscape. The Convention on Biological Diversity drives conservation of all diversity (CBD, 2000) and was adopted by Ireland in November 2003. This agreement advocates a precautionary approach to the issue of biotechnology in crops and the release of GM crops. To ensure the genetic integrity of conventional and organic (non-GM) crops is not compromised post-release of a GM crop, segregation strategies have been devised to ensure the effective coexistence of GM and non-GM crops (McGill et al., 2005). From an agricultural context, coexistence relates to the potential economic impact arising as a result of the inadvertent admixture of GM and non-GM material. Yet, achieving successful coexistence (or segregation) is wholly dependent upon the introduction of novel crop management practices (McGill et al., 2005), which must be tailored to minimise the potential for pollen and/or seed spread (i.e. gene flow) from GM cultivated fields. For both conventional and GM systems, coexistence-based tillage will likely exert direct and indirect impacts on the biodiversity within, and adjacent to, coexistence-managed fields.

1.2 Evaluating Impacts

1.2.1 Biodiversity

It is now recognised that farmland biodiversity has a significant role to play in agricultural productivity (Bullock et al., 2007; Gowdy, 1997) and there are signs

[1] See http://gmoinfo.jrc.ec.europa.eu/gmp_browse.aspx

[2] See www.npws.ie/en/Biodiversity/Ireland/NationalBiodiversityPlan/

that agricultural management regimes may be having a significantly deleterious effect on biodiversity particularly on those species that have the greatest potential for productive processes such as earthworms (Curry et al., 1995; Curry et al., 2002; Curry et al., 2008; Schmidt and Curry, 2001) and bees (Fitzpatrick et al., 2007; Purvis et al., 2009). From an Irish context, ecosystem services, which include all wild species and habitats, are critical for the rural economy (Bullock et al., 2008), particularly in light of climate-change scenarios (Coll et al., 2009). Thus, there is now a strong global move towards greater efficiency in existing agricultural systems which is seen as having a greater potential to protect biodiversity (Trewavas, 2001).

The impact of GM crop cultivation on biodiversity has been the focus of numerous studies, with specific emphasis on *Bacillus thuringiensis* (*Bt*) crops (Griffiths et al., 2006; Icoz and Stotzky, 2008; Kramarz et al.; O'Callaghan et al., 2005). *Bacillus thuringiensis* crops (e.g. cotton and maize) are modified to express insecticidal proteins aimed at controlling pests such as the European corn borer (*Ostrinia nubilalis*) which, at present is not relevant for Ireland as it is not a pest of Irish maize crops. Of more significance to Ireland, however, are the herbicide tolerant (HT) crops, and these have been the subject of biodiversity-based research through the large-scale, farm-scale evaluations (FSEs) (Firbank et al., 2003b) and the botanical and rotational implications of GM herbicide tolerance (BRIGHT) studies in the UK (Sweet et al., 2004). The FSEs have examined the impact of GM HT sugar beet, maize and oilseed rape on flora and fauna within the crops during the growing season. The primary objective of the FSEs was to determine if the changes in management associated with the cultivation of HT crops would result in benefits for farmland biodiversity or exacerbate the already substantial impact of conventional crop regimes on weed and associated invertebrate trophic groups (Firbank et al., 2003b). Farm-scale evaluations were conducted over three years and across multiple sites in heterogeneous landscapes similar to the Irish landscape in the UK.

The HT crop-management strategy employed for the trials imposed small but consistent shifts in plant and insect abundance and it was noted that current farm management techniques may not be sufficiently skilled to manage GM crops. In general, when a standard crop-management regime was imposed, weed biomass was reduced under HT sugar beet and HT oilseed rape management, and increased in HT maize; with each scenario initiating a knock-on effect on higher trophic levels (Hawes et al., 2003). This underlined the importance of optimising specific management systems for each GM crop; a subject subsequently addressed in the four-year BRIGHT study. Studying the implications of altered rotations, BRIGHT concluded (for HT oilseed rape and HT sugar beet) that management systems could be developed to ensure that there were no long-term differences in weed populations between GM and non-GM cultivated fields. Moreover, the report concluded that HT crops have the potential to improve plant diversity through the further modification of the cropping regimes. Hence, it may be possible to refine the management of certain HT crops in order to achieve beneficial environmental targets as well as agronomic objectives (Sweet et al., 2004).

1.2.2 Economics and Rural Development

The relative contribution of agriculture to rural livelihoods in Ireland is changing, with increasing proportions of incomes derived from non-farming activities (Slee, 2005; Woods, 2005). In contrast to conventional systems, some GM crops may introduce significant flexibility ('convenience factor') into crop-management systems (Beringer, 2000; Keelan et al., 2008). In addition to the provision of a potential economic benefit, such 'convenience' systems could present an appeal to Ireland's part-time farmers (34%), who may not benefit directly in terms of profitability but rather in terms of improved labour productivity (Flannery et al., 2004). Indeed, this could provide a significant impetus for the adoption of GM crops by the farming community if appropriate GM crops are authorised for commercialisation across EU member states.[3]

Though there are many stakeholders active in the debate on the use of GM technology, the landowners are rarely involved in such consultations (McGaughey et al., 1998; Russell, 2008). Contrary to popular belief, the receptivity of Irish farmers to cultivate GM varieties has been demonstrated (Hogg et al., 2000). However, the time frame as to when significant GM crop adoption by Irish farmers and agribusiness may occur is difficult

[3] See http://gmoinfo.jrc.ec.europa.eu

to predict. While HT GM lines (e.g. HT maize) may be authorised for cultivation in the near future, GM crops conferring resistance to such economically important Irish pathogens as winter wheat leaf blotch (*Septoria tritici*) and potato blight (*Phytophthora infestans*) are still several years from commercialisation, even though such crops are presently being trialled.[3] Fortunately, this time frame provides a window of opportunity to evaluate the primary issues centred on the potential impacts (negative, neutral and/or positive) that GM crops may have for Irish biodiversity.

1.3 Proposed Research

The increased demand for information on the environmental safety of GM crops has resulted in the creation of a number of internet-based databases that carry not only ecologically related information but also socio-economic, legislative, health, post-release monitoring and labelling, and traceability information (Degrassi et al., 2003). Unfortunately the biodiversity-related data/information which is most pertinent to Ireland are currently too fragmented across these resources. This points towards a need to harmonise existing bibliographic data into a publicly accessible and user-friendly internet resource that provides an ongoing detailed insight into the potential impact of a particular GM crop/trait on Irish biodiversity, through the transfer of its transgene (via seed and/or pollen) or through the coexistence-based management of the GM crop.

While the propensity of a crop species for gene flow, be it pollen or seed mediated, is a natural phenomenon that occurs in all plants and underpins both plant evolution and diversity dynamics (Dale, 2001), the primary issue with the transfer of transgenes from GM crops relates not to whether gene flow will occur, but to what will happen once it has occurred. To answer this, attention must focus on a case-by-case basis on the GM trait and the crop species (including its wild and weedy relatives). Critical is whether the novel trait will confer a selective advantage on any resulting hybrid progeny. A range of studies (Ammitzbøll et al., 2005; Conner et al., 2003; Firbank et al., 2006; Hansen et al., 2001; Stewart Jr. et al., 2003) outside Ireland have recently addressed this issue, but the applicability of this research to Irish biodiversity must be gauged in order to determine the potential for transgenes to transfer and negatively affect wild populations of Irish plant species.

The overarching aim of this project was to predict the impact of coexistence-based GM crop cultivation upon the Irish agri-environment for each of the primary tillage crops (wheat, barley, potato, maize, sugar beet and oilseed rape) that were cultivated in Ireland at the time the project was proposed. In the intervening period the growing of sugar beet has ceased in Ireland and the crop was therefore omitted from the study. In short, the project had five primary objectives:

1. A determination of which GM traits would be most suited to Irish crop management systems and hence have the highest probability of adoption by Irish farmers/growers (Section 2).
2. The collation and assessment of pre-existing research data and conclusions which describe the impact of conventional crop cultivation on Irish levels of biodiversity (Section 3).
3. An assessment of how the proposed National Coexistence Strategy (NCS) will affect the agri-environment for each of the six crops to be considered in this study (Section 4).
4. The collation and assessment of pre-existing research data and conclusions which describe the biodiversity impact of GM crop cultivation but which are comparable to Irish cropping systems/environment (Section 4).
5. The development of an internet-based information system which will facilitate the dissemination of results and pertinent information gathered during the course of the project (Section 5).

2. Determining which GM Traits Would Be Most Suited to Irish Crop-Management Systems up to 2030

2.1 Introduction

Over the next 20 years it is highly likely that GM crops suited to Ireland's agri-environment will be commercialised, thereby affording Irish farmers an additional choice as to which cropping system (i.e. organic, conventional, GM) to adopt. However, this decision making will be conducted against a backdrop of challenging agricultural changes and management practices that will need to be constantly refined in response to the macro-challenges facing the sector. For example, while the Common Agricultural Policy (CAP) encouraged member states to focus on elevating crop yields through increased pesticide and fertiliser inputs (Harvey, 1997), it is now accepted that such unrestricted agriculture intensification is no longer sustainable (Jackson et al., 2007; Paoletti, 1995). Therefore, prior to determining which GM crops are most likely to be available to farmers and subsequently assessing their potential impact on Irish biodiversity, it is critical to first consider the numerous challenges the tillage industry has to address in order to maintain its competitiveness into the future.

2.2 Challenges Facing the Irish Tillage Sector

2.2.1 Climate Change

Climate change is the single greatest challenge to crop production in Ireland and throughout the globe. Climate-change predictions for the Irish landscape show that, by 2040, temperatures in Ireland may increase by 1.25–1.5 °C. Rainfall is expected to increase by up to 15% in the winter months and decrease by up to 20% over the summer (McElwain and Sweeney, 2003), resulting in more intense rainfall in the north and west coasts and decreases or small increases in the south and east (McElwain and Sweeney, 2007). The viability of potato as a commercial crop in these regions will be very much dependent on environmental stress reduction to offset drought and/or flooding episodes and the degree to which possible rainfall increases in spring and autumn will interfere with sowing and harvesting operations, respectively (Holden et al., 2003). In comparison, it is predicted that barley will remain viable, with a diminutive change in the crop's geographical distribution beyond its present core in the east and south-east of the country (Holden and Brereton, 2003). In addition, an increase in temperature and CO_2 levels could possibly extend the growing season. There is thus a potential for the introduction of new crops, with forage maize likely to increase in importance in the coming decades (Holden and Brereton, 2003). At the same time some weeds may adapt to climate changes more rapidly than arable crops due to their genetic advantage (Bunce and Ziska, 2000) and there will be a tendency for pests and diseases that are currently found further south in Europe to migrate northwards (Holden and Brereton, 2003).

2.2.2 EU Environmental Legislation

The EU Water Framework Directive (2000/60/EC) requires member states to protect, enhance and restore all bodies of surface water to good status by 2015 (European Commission, 2000). Agriculture contributes significantly to the eutrophication of Irish rivers and estuaries, with 70% of phosphorus (P) and 82% of nitrogen (N) loads attributed to agricultural sources (Environmental Protection Agency, 2006; Stapleton et al., 2000). It has been estimated that the mean N loss from ploughed land to rivers can be as high as 76 kg/ha/yr (Neill, 1989). As the aim of the Nitrates Directive (91/676/ECC) is to reduce such pollution (EEC, 1991b) tillage farmers who import organic manures are now limited to 170 kg organic N/ha (Environmental Protection Agency, 2006). The EU Dangerous Substances Directive (Directive 76/464/EEC) requires control of P and its compounds (EEC, 1976), with complementary regulations applying to Irish local authorities (Government of Ireland, 1998).

Following a vote in the European parliament in 13 January 2009, the legislation governing the application of pesticides and the revisions of the Pesticide Directive (91/414/EEC) (EEC, 1991a) has been sent for adoption to the European Council. This could make the new directive active in 2010 and should substantially reduce the types of chemical fungicide available to farmers. The ratification of this directive will seriously undermine the existing programmes of disease control for potato, wheat and barley, whose economic viability is reliant upon fungicide programmes to control diseases caused by *Phytopthora infestans*, *Mycosphaerella graminicola* and *Rhynchosporium secalis*, respectively.

2.2.3 Common Agriculture Policy (CAP)

In 2003 the CAP was reformed to facilitate the decoupling of subsidised income from agricultural production (European Commission, 2008). This fundamental change to the CAP will be a major driver of agricultural change as the new single farm payment (SFP) is now linked to environmental, food-safety and animal-welfare standards. It is expected that full decoupling will change the pattern of land use in Ireland, with some farmers increasing the intensity of their production in order to minimise unit costs, while others may decide that the cost and effort required to work the land is not warranted, given the possibility of low or negative returns in the competitive world market. In certain instances this could result in a gradual withdrawal from farming which would have knock-on, land-use implications.

It follows that intensification is likely to result in an increased use of fertilisers and chemicals for crop-management purposes, which could exacerbate water-quality degradation and thus biodiversity decline, particularly where it leads to clustering of intensive agricultural practices within an area. At the other extreme, land abandonment and the withdrawal of traditional farm-management practices may result in the loss of existing farmland diversity (Hobbs and Cramer, 2007) because traditional farming contributes to safeguarding certain existing natural or semi-natural habitats (Bennett et al., 2006; Marzluff and Ewing, 2001; Olea and Mateo-Tomás, 2009).

2.2.4 Mitigating Biodiversity Loss

Modern agricultural has produced field systems with few weed species or invertebrates, which results in low food availability for birds (Purvis et al., 2009). The intensification of modern agricultural practice, such as the switch from spring to winter crops, loss of marginal hedgerows, and the decline in the area under cultivation, have over the past three decades caused a dramatic decrease in many species that are dependent on traditional arable practices (Butler et al., 2007; Farming and Wildlife Advisory Group., 1983; Feehan and Keena, 2001; Leakey, 1999; Paoletti, 1995). Ireland has now committed itself to significant reductions of biodiversity loss by 2010 (CBD, 1992) and while most farmers seek to enhance the environmental quality of their farms, they are constrained from doing so by the need to return a profit (Beringer, 2000). However, significant efforts have been made to minimise the ecological impact of tillage agriculture through the promotion of sound management practises and/or organic systems with such EU initiatives as the Rural Environment Protection Scheme (REPS). As with all tillage operations, the potential impacts upon biodiversity will depend on the crop, its management, density, duration and distribution on the landscape. Given the range of potential bioenergy crops (from tall grasses to trees), impacts on biodiversity will vary (The Royal Society, 2008), and if, as has been suggested, set-aside land is used to grow biofuel crops, it will clearly have a greater ecological impact relative to intensively cropped land (Bracken and Bolger, 2006; Critchley and Fowbert, 2000).

2.2.5 Challenge of Producing Sustainable Biofuels

Biofuels will only provide a worthwhile contribution if they are economically, socially and environmentally sustainable (The Royal Society, 2008). Whilst indicative targets of 5.75% for biofuel market penetration by 2010 and 10% by 2020 have been set by the EC (Department of Communications Marine and Natural Resources, 2007), the logistics of achieving these outputs in Ireland are significant as up to 250,000 ha of tillage land would be required to achieve the target of 5.75% alone (Rice, 2007). In the short term, ethanol from cereals and biodiesel from rapeseed could contribute to the solution (Department of Communications Marine and Natural Resources, 2007), but unless large tracts of set-aside or pasture are returned to arable cropping, the increased hectarage of oilseed rape required for competitive biodiesel production will be in direct competition with land cultivated for food use.

2.3 Conceivable Impacts of Specific GM Traits

2.3.1 Reducing Fungicide and Herbicide Inputs

The goal of crop protection is not the elimination of pests but to reduce crop losses to an economically acceptable level (Sanvido et al., 2007). In 2004, total chemical inputs for arable crops in Ireland (based on active substances) totalled 1520 tonnes, including 663 tonnes of herbicide, 619 tonnes of fungicide, 29 tonnes of insecticide and 209 tonnes of other products (e.g. growth regulators, molluscicides, etc.) (Department of Agriculture and Food, 2007). Overall, there has been an 18.4% increase in pesticide usage (based on sales) since 1990 (OECD, 2002; 2004), although the average amount of pesticide used in 2001 was 0.5 kg active ingredient per hectare of Irish agricultural land which was the lowest in the EU 15. However, the low level of pesticide usage in Ireland would seem to reflect the relatively small proportion of land dedicated to arable farming compared to other EU countries and the lower quantity of pesticide usage on grassland farms (Department of Agriculture and Food 2006b). Hence, novel crops modified to express durable disease resistance could present farmers with the opportunity to reduce chemical applications; thereby diminishing the quantity of residues in food/feed, in soil and in watercourses. From an Irish context, the significance of such a development cannot be overstated. After herbicides, fungicides are the second most used plant-protection product in Ireland (41% of the weight of active substances) (Department of Agriculture and Food, 2007). The control of fungal diseases is a constant challenge for Irish potato and cereal growers. The introduction of alternative control options would underpin the production of improved grain and/or tuber quality, possibly reduce production costs and, in the case of cereals, offset the potential health hazards caused by mycotoxin-producing *Fusarium* species.

Herbicides are the most widely used of all plant-protection products in Ireland (44% of the weight of active substances; Department of Agriculture and Food, 2007). The main crops currently grown in Ireland that would benefit most from being herbicide tolerant (based either on kg of active substances applied per ha or/and total hectares grown) include potato, maize, winter oilseed rape, wheat and barley and to a lesser extent oats (Table 2.1). Potato cultivation receives almost a 14-fold higher application of herbicides than all other crops, mainly because of their slow emergence from the ground and their relatively poor ability to compete with weeds in their early stages.

Enhanced flexibility in timing of weed control and reduced herbicide application frequency are widely claimed reasons to cultivate HT crops (Graef et al., 2007). In addition, GM HT-associated herbicides (glyphosate, glufosinate) are less persistent than conventional herbicides such as atrazine (Hails, 2002), which is now prohibited across the EU (Halford, 2004) and control of certain broadleaf and grass weeds can be achieved with a single herbicide (Sanvido et al., 2007). Yet, disquiet remains as to whether GM HT crops will benefit crop systems or mitigate weed-control regimes through the emergence of HT weed populations over time (Owen, 2008; Sanvido et al., 2007). Crucially, the development of herbicide resistance in weeds is not a question of genetic modification, as HT weed biotypes were prevalent long before the introduction of GM crops,[4] and with appropriate management control, the control potential of glyphosate systems can be protected (Powles, 2008).

2.3.2 Reducing Nitrogen and Phosphorus Inputs

The quantities of N and P used on Irish farms increased from 48 tonnes in 1966/67 to 275 tonnes in 1980 (Murphy, 1982), and have continued to increase from 370 tonnes in 1990 up to 444 tonnes in 1998 (OECD, 2004). As the cost of N fertiliser has increased in recent years and the EU Water Framework Directive has come

[4] Refer to Anon. (2009) for a complete worldwide list.

Table 2.1. Hectares planted and pesticide and fertiliser usage for six common crops grown in Ireland.

Crop	Predominant use(s)*	Hectares planted in 2007[a]	Total plant protection products (active substances, kg)[b]	Plant protection products (active substances, kg/ha)[b]				Fertiliser usage (kg/ha)[c]	
				Herbicide	Fungicide	Insecticide	Others[d]	Nitrogen	Phosphorus
Barley	Food and feed	167,500	473,269	1.2	1.2	0.1	0.2	123–167	26–30
Wheat	Food and feed	84,300	507,937	1.7	1.9	0.1	1.3	152–203	23–24
Oats	Food and feed	21,300	68,006	0.7	1.0	0.1	1.7	113–138	25–26
Maize	Feed	20,900	39,186 [e]	2.5[e]	0.0[e]	<0.1[e]	0.1[e]	?	?
Potato	Food	11,700	364,106	13.0	14.1	0.2	0.2	115	102
Oilseed rape	Energy and feed	8,200	1,278	0.6	0.2	<0.1	0.1	?	?

* Food = food for human consumption; Feed = feed for livestock consumption; fuel = biofuel; ? = Not applicable.

[a] Central Statistics Office, 2008.

[b] In 2004, unless stated otherwise.

[c] Between 2001 and 2003 (Coulter et al., 2005).

[d] Growth regulators, seed treatments and molluscicides.

[e] In 2003.

into force in Ireland, there has been some reduction in usage. In 2003, 388 tonnes of N were used on Irish farms, with land for arable crops receiving a higher application per unit area (Coulter et al., 2005) (see Table 2.1). Yet, only 30–50% of applied N is assimilated by crops, with a significant amount of applied N fertiliser lost (Tilman et al., 2002). The modification of plant genotypes to express greater nitrogen use efficiency (NUE) would permit a reduction in N-fertiliser use without a decrease in yield, or, alternatively, increase overall yield at existing levels of N usage. Additionally, crops expressing a NUE trait could present the opportunity to expand the possible area of cultivation to include less productive soils.

After N, P is considered to be the most important nutrient-limiting agricultural production. To reduce P deficiencies and ensure plant productivity, up to 44 tonnes of P-based fertiliser is applied annually to Irish farmland, with arable crops receiving a higher unit application (Coulter et al., 2005). It is estimated that up to 80% of P fertiliser applied to land is unavailable for plant uptake because of adsorption, precipitation or conversion to organic forms. Crops modified with an increased level of citrate exudation have a higher capacity to use insoluble forms of P, yielding higher biomass when grown in P-limiting conditions (Lopez-Bucio et al., 2000). Engineering Irish-specific arable crops with a similar trait could reduce the use of P fertilisers. Additionally, better utilisation of P in pig and poultry feeds can reduce the quantity of P spread on the land (see 2.2.5).

2.3.3 Reducing CO_2 Emissions

An associated beneficial impact accruing from reductions in the previously described crop protectants and/or fertilisers includes a reduction in direct and indirect CO_2 emissions arising from chemical manufacture, transport and field operations (Advisory Committee on Releases to the Environment, 2007), indicating that agricultural land could be used to moderate the impacts of climate change. Specifically, this relates to the cultivation of HT crops in conjunction with minimum tillage (min-till) to reduce CO_2 emissions from soil. Only 4% of arable land in Ireland is established by min-till methods. This is in contrast to ca. 30% in the UK (European Conservation Agriculture Federation, 2008). Min-till systems have a much lower fuel demand at approximately 50% of that of the plough-based system (Forristal, 2008). In addition, with reduced soil disturbance, more carbon remains in the soil and therefore less CO_2 is released to the atmosphere. Yields of winter wheat in Ireland have been shown to be similar for both min-till systems and plough-based systems (Fortune and Murphy, 2003) with no loss of productivity expected.

2.3.4 Developing Sustainable Bioenergy Crops

While localised oilseed rape cultivation in Ireland could potentially meet the biodiesel demand of cooperative-based farmers, a theoretical maximum of ca. 80,000 ha is currently available for oilseed rape production (due to rotational constraints). This will not meet the national targets set by the EU Biofuels Directive (European Commission, 2003d). While modifications to the biology of oilseed rape, including decreased pod shatter and elevated oil content could potentially assist in attaining EU targets, a shift towards second-generation biofuels, produced primarily from lignocellulosic biomass, is clearly required and encouraged by the EU (European Commission, 2006). The Irish climate is better suited to lignocellulosic crops (mainly consisting of perennials such as *Miscanthus* spp.) and it is expected that the emergence of new second-generation biofuel technologies will eventually allow these crops be converted to liquid biofuels (Department of Communications Marine and Natural Resources, 2007). In the medium term, lignocellulosic biomass from currently cultivated crops (which are mainly annual) such as small-grain cereal straw, oilseed rape stalk and maize (whole plant) could provide alternative sources of bioenergy by their conversion to cellulosic ethanol or use as a solid biofuel (Tuck et al., 2006). The possibilities that genetic engineering can offer to increase bioethanol production from these crops include modifying biomass properties to reduce processing costs or increase biomass yield as well as reducing agricultural inputs (Torney et al., 2007). Although, cellulose is more difficult and expensive to saccharify than starch (Ragauskas et al., 2006), the modification of several crops with plant-produced hydrolytic enzymes to convert cellulose into glucose is showing potential (Sticklen, 2007). Similarly, the reduction in, or modification of, lignin structure may reduce the need for a pretreatment process (Ragauskas et al., 2006; Sticklen, 2007).

2.3.5 Enhancing the Quality of Livestock Feed

Although grass and grass silage is the foundation for most ruminant production systems in Ireland, it does not contain optimal protein–carbohydrate ratios (McGee, 2000) and therefore the provision of concentrate feed is a critical requirement for both the Irish beef and dairy sectors. The pig and poultry sectors have also a large requirement for concentrate feed. This feed is currently derived from imported GM soybean and GM maize products (corn gluten feed, distillers dried grain). Yet, it is now apparent that as global land area shifts to non-food production, food and feed prices are more volatile. The persistence of this food versus fuel competition will create a significant incentive to devote greater Irish hectarage to domestically produced feed of higher protein and energy content. Consequently, as land availability becomes an extenuating factor, farmers are likely to seek novel crops with elevated protein, energy or enhanced feed-digestibility characteristics, thereby reducing Ireland's dependence on imported feedstocks. Irish oilseed rape hectarage is predicted to increase by 440% (3700 to 20,000 ha) by 2015 (Teagasc, 2008), the meal that remains post-crushing will become an increasingly important source of animal-feed protein that could displace current imports. Growth in inter-farm trading of high-protein/energy forage and grain crops may also help reduce global greenhouse gas emissions by reducing 'feed miles'. Advancements in agriculture biotechnology could further improve the nutritional quality and digestibility of whole-crop forages. Technology developed for producing high-lysine maize (see 2.3.1) could be transferred to other crops such as wheat and barley to enhance their levels of important amino acids (Ufaz and Galili, 2008). Even though straw can be fed to ruminants for roughage, little nutrition is derived from it. Increasing the ruminant-digestible material of straw by 20% would upgrade its nutritional value to that of hay (Gressel and Zilberstein, 2003). Furthermore, increasing the bioavailability of P in cereal-based feed by enhancing phytase production may reduce the costs for farmers to meet the nutritional needs of pigs and poultry. Although cereal grains contain P, most is in the form of phytic acid, which non-ruminants such as pigs and poultry cannot digest efficiently. In addition, phytic acid is considered to be an important anti-nutritional factor, preventing the uptake of other important minerals. As phytase supplementation is expensive, the most versatile and cost-effective attractive alternative is to deal with the problem at its source by developing low-phytate crops (Brinch-Pedersen et al., 2002).

2.4 GM Traits with the Highest Probability of Adoption by Irish Farmers

There are no GM crops currently grown in Ireland because the current suite of GM varieties authorised for cultivation in Europe are not suited to the Irish agri-environment. Taking into consideration the extensive list of crops that are being field tested within the EU,[5] it is likely that this scenario will change in the future and Irish farmers will be afforded the choice as to whether they wish to grow GM varieties. Crops with the greatest potential for genetic modification, from an industry perspective, are those under large hectarage and/or requiring high levels of chemical input, which for Ireland includes barley, wheat, maize and potato. For the likely early adopters, the issues will centre on the potential economic returns, logistics of complying with coexistence regulations[6] and whether there would be a market for the resulting GM commodity. This last point will prove critical, as markets for animal feed and biofuels are likely to develop first and could be met through the cultivation of GM oilseed rape for biodiesel and GM maize for animal feed/bioenergy output.

2.4.1 GM Maize

Until recently, maize was a marginal crop in Ireland with the crop's restricted growing range due to its requirement for a soil temperature in excess of 8 °C, which has precipitated a trend to sow maize using the plastic-mulch system. This system permits earlier sowing and rapid establishment and can increase dry-matter yield by ca. 3000 kg/ha and ensure consistency in yield and quality. A cold-tolerant maize variety, as described by Zhang et al., (2004), would eliminate the (production, disposal and visual) costs associated with plastic mulch by permitting earlier planting, which could lead to the expansion of the crop's growing range. This has the potential for increasing national yields.

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[5] For a detailed list of crops see European Commission Joint Research Centre, 2009.

[6] See Section 4 for detailed explanation of the consequences of coexistence-based crop management.

An additional trait that should be considered is the inclusion of HT in GM maize varieties. Maize that is engineered for tolerance to herbicides such as glyphosate or glufosinate-ammonium would be highly suited to the Irish agri-environment because maize is unable to compete with weeds during the first month after sowing and mid-to-late season chemical control is hampered by the maize crop canopy. The recent removal from the market of the most effective weed-management agent, atrazine, will only hasten the need for an alternative weed control strategy.

In the UK's FSEs, GM HT maize received one application of herbicide at rates averaging 3.5 L/ha, representing a reduction of 57% compared with conventional herbicide use. Owing to the high level of similarity between farming systems in the UK and Ireland, it is likely that a comparable reduction in herbicide use could be achieved in Ireland, therefore providing a prerequisite economic potential to the Irish farmer. The availability of a GM maize variety with enhanced NUE would also be of benefit, considering the increasing costs of fertiliser and the comparatively high demand of maize for nitrogen to produce economically satisfactory yields (Boehmel et al., 2008).

Enhancing the protein content and/or the digestibility of forage maize would benefit the agricultural sector in light of Ireland's dependence on imported animal feed. Virtually all maize grown in Ireland is forage maize. However, the protein content in forage maize is low and farmers must supplement with urea or soya in order to meet the ruminant's protein requirement. Maize varieties that produce ripe grain are not available for cultivation in Ireland, so in the short-to-medium term there would be substantial interest among farmers in elevating the protein content of current maize varieties. While quality attributes of forage maize have been neglected by plant breeders (Kingston-Smith and Thomas, 2003), recent advancements have demonstrated the potential to increase the protein content of maize, with the lysine content of US varieties of maize grain enhanced from 2400 mg/L up to 5000 mg/L (Huang et al., 2006). Indeed, a high lysine variety (LY038) has recently been approved for commercial use in the livestock feeding industry in a number of countries (Ufaz and Galili, 2008). Cell-wall digestibility is also recognised as a major target for improving the feeding value of maize, with the crop having already been developed with reduced lignin content and higher digestibility (He et al., 2003; Piquemal et al., 2002).

2.4.2 GM Oilseed Rape

Although this crop falls short of an ideal environmentally friendly alternative to fossil fuels, biotechnology may provide some near-term solutions to any drawbacks, at least until a better means of producing renewable energy is found. For example, in a preliminary study, the over-expression of a yeast glycerol-3-phosphate dehydrogenase (gpd1) in oilseed rape showed a 40% increase in the final lipid content of the seed (Vigeolas et al., 2007). For a timely production of seeds, floral induction is a key developmental switch in *Brassica* spp. used for oil production. The relatively short growing season in Ireland (ca. 5–6 months) can reduce the amount and quality of the harvest considerably. A GM oilseed rape variety has been developed expressing a 35S:*MADSB* transgene from mustard that showed accelerated flowering and seed ripening. In addition, the over-expression of *MADSB* caused an altered carpel development, preventing seed loss through pod shatter in winter oilseed rape varieties (Chandler et al., 2005).

As a crop, oilseed rape is prone to high seed loss before and during harvest. In a two-year study, seed loss at harvest on Irish farms varied from 2000 seeds/m^2 (~ 60 kg/ha) to 13,000 seeds/m^2 (~ 530 kg/ha). This equates to between 2% to 18%, respectively, of potential yield, which in financial terms translates to a loss of up to €152/ha (Flanagan et al., 2008). Therefore, increases in harvestable seed yield arising from reduced pod shattering could potentially result in significant economic benefits for farmers and additionally reduce the seed contamination of the soil. This latter benefit is likely to be of increasing importance if the oilseed rape variety is genetically modified and the farmer has the responsibility of preventing both temporal and spatial gene flow to neighbouring non-GM oilseed rape crops through the reduction of volunteer plants. Between 1996 and 2002, there have been up to nine notifications of deliberate releases for field trials of oilseed rape with pod-shatter resistance (European Commission Joint Research Centre, 2009), but data from these trials have yet to be published.

GM NUE oilseed rape is currently under development, with preliminary results indicating that the transgenic material can maintain an equivalent yield with that of conventional varieties but with a 50% less N requirement.[7] Other studies concur with this potential output, with GM NUE oilseed rape generated through the over-expression of the barley alanine aminotransferase, requiring 40% less N fertiliser to achieve yields equivalent to non-GM conventional varieties (Good et al., 2007). In a life-cycle assessment of the potential environmental impact of growing GM NUE oilseed rape compared to a conventional variety, savings in energy of up to 22% are predicted (Strange et al., 2008).

For Irish farmers, yields of between 3000 to 3500 kg/ha for winter rape and 2500 kg/ha for spring rape are required to make the crop economically viable. Yet, even when intensive management practices are adopted, oilseed rape is still considered a 'high' risk crop due to the crop's sensitivity to competition from broadleaf and grass weeds such as volunteer cereals and wild oats which can depress the crop's yield potential. The availability of GM oilseed rape varieties resistant to either glyphosate or glufosinate-ammonium could assist farmers in achieving more efficient weed control through the application of a single post-emergence broad-spectrum herbicide from seedling stages to early bolting (Graef et al., 2007). Under certain agronomic conditions, GM HT oilseed rape can deliver increased yields of up to 10% (Phipps and Park, 2002). The critical advantage to the farmer would be the greater flexibility in application timing afforded by the HT systems, allowing farmers to assess the need for herbicide treatment once the crop and weeds were well established, and thus avoid applications where it was not justified by the level of weed infestation (Sweet et al., 2004).

2.4.3 GM Wheat

Fungicide usage is a prerequisite for wheat cultivation in Ireland. *Septoria tritici* blotch (STB) is by far the most damaging of all foliar diseases, resulting in significant yield losses (up to 50%) and grain degradation (Angus, 2008; Burke and Dunne, 2008). Fungicide control of STB in Ireland can cost up to €180/ha (Burke and Dunne, 2008), but this strategy has been undermined due to the rapid emergence of STB isolates resistant to the strobilurin-based chemistries (O'Sullivan, 2004). More recently, there has been a prevalence of STB isolates with high tolerance to the remaining class of fungicides (bemzimidazoles) (Kildea, 2008; Fraaije et al., 2005). As the global demand for wheat continues to rise, Irish wheat hectarage is predicted to increase by 26% (95,000 to 120,000 ha) by 2015 (Teagasc, 2008). For this to be achieved, the continued sustainability of the crop in Ireland is of paramount importance. While there are no new fungicide chemistries in production, or GM varieties for the control of STB, progress continues to be made using conventional plant-breeding strategies (Angus, 2008; Goodwin, 2007).

Second only to STB, *Fusarium* head blight (FHB) disease can significantly reduce grain quality and yield (Parry et al., 1995) and leads to the production of mycotoxins in infected grain. These have adverse effects on human and animal health (Diaz, 2005). *Fusarium culmorum* is the dominant species in Ireland (Dardis and Walsh, 2002), with the mycotoxin deoxynivalenol detected in up to 70% of grain samples contaminated with *Fusaria* (Fröhlich, 2005). Partial protection against FHB has been reported in wheat plants expressing the *Fusarium sporotrichioides* gene *FsTRI101* (Okubara et al., 2002), the maize RIP protein (Balconi et al., 2007), *Arabidopsis NPR1* (Makandar et al., 2006) and β-1,3-glucanase (Mackintosh et al., 2007). Indeed, GM *Fusarium*-resistant wheat is being tested in Canadian field trials (Sanvido et al., 2007).

As with all arable crop systems, the absence of adequate weed control will result in significant losses. GM glyphosate-tolerant wheat has been developed and awarded regulatory approval for cultivation in the US. While, it was not brought to market owing to a lack of support from the wheat industry (Castle et al., 2006), attitudes have begun to change and the debate has been reignited in regard to its potential use, especially as China and India intend to commence growing GM wheat in the coming years.[8]

High concentrations of N are required to underpin the Irish wheat crop. In the long term this will be both environmentally and economically unsustainable and alternatives are therefore required. One study has shown that the expression of the *Phaseolus vulgaris*

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[7] For example see Anon. (2007).

[8] See http://greenbio.checkbiotech.org/news/boffins_say_gm_wheat_reality_2014

gs1 gene in transgenic wheat will result in improved N assimilation (Habash et al., 2001). More recently, Subbarao et al. (2007) reported high production levels of biological nitrification inhibition (BNI) in a wild relative of wheat and its successful introduction and expression in cultivated wheat under laboratory conditions.

Efforts to increase seed biomass and protein content are ongoing in wheat. Smidansky et al. transformed wheat using the maize *Shrunken2* gene. Compared to a control population, the GM wheat lines recorded a 38% increase in seed weight and corresponding 31% increase in biomass (Smidansky et al., 2007). Similarly, modifications focused on increasing grain protein content in winter wheat recorded a 30% increase in protein content under glasshouse conditions and these GM wheat lines are currently undergoing field trials in Germany (European Commission Joint Research Centre, 2009). Significantly, GM wheat plants expressing the *Aspergillus niger* phytase encoding gene (*phyA*) have been recorded to accumulate phytase in their seed (Brinch-Pedersen et al., 2000), which could provide significant benefit to pig and poultry producers if the line were commercialised.

2.4.4 GM Potato

Several GM lines designed to resist late blight disease (caused by *P. infestans*) have been created (Gao et al., 2000; Osusky et al., 2000; Song et al., 2003; van der Vossen et al., 2005; 2003) and trials are ongoing in the UK, Germany, Sweden, the Czech Republic, France and The Netherlands (European Commission Joint Research Centre, 2009). Although a licence governing a regulated field trial in Ireland is yet to be invoked, a cost–benefit analysis has highlighted the cost savings such a crop could provide (up to €199/ha) if a market materialised (Flannery et al., 2004).

Given that an increased seasonality of water supply is predicted due to climate change, the limiting factor in potato production in the coming years will be the availability of irrigation water in drought prone parts of the country (Holden et al., 2003). As farmers contemplate large capital investment in irrigation infrastructure, the alternative and potentially more sustainable option would be to generate novel drought-tolerant germ plasm. There have been several attempts to create drought- (and saline-) tolerant potato plants by introducing abiotic stress genes for functional proteins, such as proline synthesis protein, osmotin-like protein, trehalose synthesis protein, and regulatory proteins such *as StEREBP*, *CBF* and *StRD22* (reviewed in Byun et al., 2008), and European trials are commencing.[9] While existing potato crop management in Ireland is efficient, it would benefit from the availability of a GM HT potato, which has already been created (Hutchinson et al., 2003). Potato crops would also benefit from greater NUE because of their high requirement for this mineral.

2.4.5 GM Barley

The genetic engineering of barley has not progressed at the same rate as the previous crops mentioned. Similar to wheat, the Irish barley crop is also susceptible to fungal pathogens with *Rhynchosporium secalis* (leaf scald) a major disease of both winter and spring varieties. Adequate control can be achieved through fungicide applications or disease-resistant cultivars, but in 2006 this genetic resistance was overcome with the emergence of a new race of *Rhynchosporium*, leaving farmers having to readopt fungicide mixes to protect their crop (O'Sullivan et al., 2007). While we are not aware of any GM *Rhynchosporium*-resistant barley varieties currently being developed, such a trait could be attractive to the Irish tillage sector.

Enhancing the digestibility of barley grain is a research target as poultry in particular are unable to breakdown endosperm cell walls due to their deficiency in glucanases, hence their poor growth rate when fed conventional barley. A GM barley variety has been developed expressing a protein-engineered, thermostable β-glucanase during germination (Jensen et al., 1996; Jensen et al., 1998) and subsequent feeding studies have shown that poultry fed GM barley with heat-stable glucanase gained more weight than poultry fed on a conventional barley diet (von Wettstein et al., 2000). Increasing the digestibility of barley for feeding to ruminants would also be a trait highly sought after by livestock farmers. Other useful traits that have received very little attention to date include increasing the grain protein content, increasing nitrogen-use efficiency and improved resistance against FHB.

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[9] See http://gmoinfo.jrc.ec.europa.eu/gmp_report.aspx?CurNot=B/HU/07/06

2.5 Conclusion

Between 1985 and 2006 Irish cereal production increased by 4.6%, yet the area under cereals declined from 0.38 to 0.27 Mha (–29%) during the same period (Department of Agriculture and Food, 2007a). However this yield increase came with a significant social and environmental cost. The number of agricultural workers in Ireland today has declined to ca. 40% of what it was in 1973 (Department of Agriculture Fisheries and Food, 2007) and Ireland's environment has suffered an enormous deterioration in both water and soil quality and a very noticeable reduction in biological diversity on farms (Feehan, 2003). Any changes that may occur in agriculture up to and beyond 2030 will probably be equally, if not more, dramatic than previous decades. There is now a firm consensus among the scientific community of the need to farm in a more sustainable manner. Thus we have seen an increased awareness among the agricultural sector of the necessity to reduce the environmental impact of farming, as underpinned through the commitment of farmers (> 50,000) to the REPS.

Since the EU-wide moratorium on the cultivation of GM crops was lifted in 2004, the number of notifications seeking authority for the environmental release of a GM organism GMO for trial purposes (Class B) has increased (European Commission Joint Research Centre, 2009). If GM crops that are compatible to the Irish agri-environment become available within 5 to 10 years, it is likely that their rate of adoption by Irish farmers would be dependent on whether the end use of the crop is for human consumption or for non-food purposes (animal feed, biofuel). It is reasonable to assume that farmers will be more receptive to those GM crops used to feed livestock (e.g. maize) or for bioenergy (e.g. oilseed rape). On the other hand, when the end use of a GM crop is for direct human consumption (e.g. potato) it may be the case that these crops will be more difficult to market domestically and in the EU due to the current level of consumer scepticism.

The predominant crops that have been genetically modified and are undergoing field testing in the EU include maize, oilseed rape and potato, with HT in maize and oilseed rape having undergone the largest number of field trials and are the closest to commercialisation in the EU. The crops with the biggest potential for genetic modification in Ireland are those grown on a large scale, namely barley, wheat, oilseed rape and maize and/or currently receive very high applications of pesticides and fertilisers (e.g. potato). Although barley and oats are the first and third most predominant crop grown in Ireland on a per hectare basis (see Table 2.1), respectively, minimal research has been conducted on the genetic enhancement of these crops to date (European Commission Joint Research Centre, 2009). The GM crops most suited to Ireland's agri-environment and having the highest probability of adoption by Irish farmers are presented in Table 2.2. Research to enhance various other beneficial traits has either yet to begin (e.g. resistance to leaf scald in barley) or is still at the very early stage (e.g. increased P use efficiency (PUE)). The focus in this section has been on those producer-driven traits which are believed are most applicable to Ireland (and other EU member states) up to 2030. Beyond this time frame, certain food staples could become available with improved quality and/or nutritional content, with benefits which are readily apparent to the consumer. Given the important role of potato in the Irish diet, for example, a folate-enriched potato variety could prove popular and replace current practices of industrial food fortification and supplementation by folic acid pills (Bekaert et al., 2008). Indeed, French fries/potato chips modified to ensure lower levels of harmful acrylamide could make for a healthier alternative (Rommens et al., 2008). Crops grown for therapeutic production/delivery have been identified as a potential opportunity for Irish farmers into the future (Teagasc, 2008) as such crops would be expected to have a high market value. Research into the use of crops (especially potato) to produce pharmaceutical products is already quite far advanced (Twyman et al., 2005). However, these crops are likely to be grown on small hectarage, possibly in a contained environment (e.g. greenhouse) and under highly regulated conditions. They are unlikely therefore to have a significant impact on the overall economics of farming in Ireland over the next 15 years. Indeed it is likely that the commercialisation of crops with either improved quality/nutritional characteristics or for pharmaceutical use will follow only after input traits (e.g. HT, disease resistance, etc.) aimed at the farming industry become commonplace in Irish agricultural systems.

Table 2.2. GM crop traits with the highest probability of adoption by Irish farmers in the next 20 years.[a]

Crops	Herbicide tolerant	Enhance fungal resistance	Nitrogen-use efficiency	Phytase enhanced seeds	Higher protein content feed	Enhance feed digestibility	Enhanced crop yield	Enhanced bioenergy crops	Enhanced resistance to abiotic stresses
Barley						√[d]			
Wheat	√	√[b]	√	√	√		√[f]		
Maize	√		√		√	√[e]		√[g]	√[i]
Potato	√	√[c]							√[j]
Oilseed rape	√		√					√[h]	

[a] Potential examples given for each trait

[b] *Fusarium* head blight resistant

[c] *Phytophthora infestans* (late blight) resistant

[d] *in vivo* produced β-glucanase

[e] reduced lignin and higher digestibility

[f] increased seed weight and biomass

[g] reduced lignin; *in vivo* produced cellulases

[h] accelerated flowering and seed ripening; increased oil content; reduced pod shatter

[i] cold tolerant

[j] drought tolerant

3. Collating and Assessing Pre-existing Research Data and Conclusions which Describe the Impact of Conventional Crop Cultivation on Irish Levels of Biodiversity

3.1 Introduction

The high degree of physical manipulations (ploughing, irrigation, etc.) and inputs of pesticides and fertilisers inherent in many farming models also impacts on biodiversity (see McLaughlin and Mineau, 1995). While the 'green revolution' of the twentieth century significantly increased the extent and intensity of these impacts, they have nonetheless been a feature of agriculture since the very beginning (Diamond, 2005). A timeline of agricultural development in Ireland has seen the loss of primary broadleaf forest cover on the island, reductions of floral diversity in natural grasslands, persecution of animals such as wolves and eagles and the drainage of wetlands resulting in the loss of bird species such as the bittern (*Botaurus stellaris*) (Feehan, 2003; Mitchell and Ryan, 1997). Alternatively, successive waves of agricultural development have been responsible for many species introductions to Ireland, whether as introduced domesticated or edible species such as the rabbit (*Oryctolagus cuniculus*), plantains (*Plantago* spp.) or dandelion (*Taraxacum officinale*), or as weedy species such as wild oats (*Avena fatua*) and darnel (*Lolium temulentum*) (Reynolds, 2002; Stokes et al., 2004).

Tillage and land-use systems in Ireland continue to change; for example, the cessation in flax or sugar-beet cultivation, or increases in maize or oilseed-rape cultivation mentioned above. New floral and faunal elements appear from overseas all the time, so current arable farmland biodiversity should be properly interpreted as part of a longer-term flux where change is the norm (Antrop, 1998). Baseline data regarding biodiversity change will therefore have to be anchored towards specific tillage systems and also define the timescales of biodiversity change that are of relevance. Equally, these measurements require analysis both of numbers of species, and also the density and diversity of individuals and populations within species.

Perhaps the most striking knowledge gap evident from the literature is that the direct contribution of tillage-based agriculture to species decline, as opposed to that caused by other land uses (e.g. grassland, peat removal, conifer afforestation, etc.), has not been quantified for Ireland. Arable land receives heavier applications of pesticides (Meade and Mullins, 2005) and is cultivated more frequently (annually) than grassland (ca. 53% of pastures in Ireland have not been reseeded in more than 10 years; O'Brien et al., 2008). Therefore, there is greater pressure on species and habitats. While environmental pressures faced here may differ from other European countries, many EU studies suggest that major recent declines in biodiversity are associated with agricultural change, particularly since the 1950s, and we might expect a similar trend to be evident here (Donald et al., 2001; Robinson and Sutherland, 2002). These apparent changes have been a major driver for legally binding conservation policy at an EU level (as outlined in 2.2 above).

Ireland is unique in Europe in that agriculture is overwhelmingly grassland orientated with a predominance of small fields; just 10% of farmland is arable (some 0.42 m/ha), mostly comprised of cereals (0.31 m/ha); the remaining 90% (3.8 m/ha) is devoted to pasture, meadow and silage (Department of Agriculture and Food, 2006; European Environment Agency, 2007). Within the 10% arable farmland it is evident that recent changes have significantly impacted on habitat quality, for example arterial and field drainage, land reclamation (including the removal of small-scale farmland habitats such as trees, hedges, dry-stone walls, remnant woodlands and scrub), and the increasing use of fertilisers and pesticides (insecticides, fungicides and herbicides) (Feehan, 2003). As farming has intensified, the use of artificial (inorganic) N fertiliser has also increased, both to increase yields and improve nutritional status (Smil, 2002). However, only a fraction of the N applied is used in plant growth or retained in food products; the excess is implicated in eutrophic conditions as well as numerous other impacts on species and habitats.

This section reviews existing research data and conclusions from peer-reviewed publications regarding the impact of crop cultivation on biodiversity on Irish tillage farms. Although there is an abundance of literature on this topic collated from other regions (e.g. McLaughlin and Mineau, 1995 (Canada); Robinson and Sutherland, 2002 (Great Britain)), such a record does not exist for Ireland. Notwithstanding the varied climate and different agronomic systems in Ireland, we cannot rely too heavily on ex-situ studies because, in comparison with Britain and continental Europe, the terrestrial fauna and flora of Ireland is relatively impoverished, reflecting Ireland's isolation by sea since the last glaciation (Costello, 1993; Mitchell and Ryan, 1997). Given the relative lack of Irish research on this issue in general, this section seeks to ascertain through published, peer-reviewed scientific literature current knowledge of both the positive and negative impacts of conventional crop cultivation on inter- and intra-species biodiversity on Irish farms. Research on the effects of agricultural practices on Irish levels of biodiversity was collated from a literature search carried out using ISI Web of Science® (1945–2006), BIOSIS Previews® (1980–2006) and CAB Direct (1973–2006).

3.2 Impact of Conventional Crop Cultivation on Biodiversity on Irish Tillage Farms

Reduced levels of biodiversity are associated with increased intensity of management and reduced environmental heterogeneity (Erwin, 1996). A number of species and species assemblages in Ireland have been identified to be dependent upon the continuation of specific agricultural practices for their survival. However, changes and intensification of modern agricultural practice, such as the switch from spring to winter crops, loss of marginal hedgerows, and the decline in the area under cultivation, have over the past three decades caused a dramatic decrease in many species that are dependent on traditional arable practices, such as bristle oat (*Avena strigosa*) and darnel (*Lolium temulentum*) (Curtis et al., 1988; Hickie et al., 1999; Taylor and O'Halloran, 2002). Similarly, the loss of overwintering stubble and the abandonment of small-scale rotational cropping have had an adverse impact on many species (Hickie et al., 1999; McMahon et al., 2003; Taylor and O'Halloran, 2002). Marginal hedgerows and wet flush areas are a characteristic feature of the Irish farming landscape and form important wildlife habitats for animals and plants (Feehan, 2003; Mitchell and Ryan, 1997). Webb (1988) estimated that approximately 16% of all hedges have disappeared since 1938, and the total area drained under various Acts and schemes is 2.02 Mha or almost 38% of the total land area farmed on the island of Ireland. Although the focus in this current paper is on arable systems, it is possible that the impacts of such changes are also likely to be as great on the biodiversity of pastoral systems (Green and Stowe, 1993; Hutton and Giller, 2003; Purvis et al., 2009).

Considering the importance of agriculture to the Irish economy and the increasing national interest in biodiversity, it is of some concern that only 21 published peer-reviewed scientific articles have investigated the impact of crop cultivation on farmland biodiversity in Ireland over the last three decades (20 studies in the Republic of Ireland and one study in Northern Ireland; Table 3.1).[10] Three of the studies investigating the impact of crop cultivation on farmland biodiversity in Ireland were published in the 1980s and three in the 1990s. However, since 2000 the rate of publication has increased, with 15 scientific papers published in the last seven years. The majority of this research has focused on improving soil management practices (i.e. crop rotation/effects of cultivation and intercropping, 9 of 21 studies), benefits of maintaining hedgerow/forests crossing or bordering tillage fields (3/21) and the adverse effects of intensification (3/21). Other research areas studied included analysis of pesticide usage, set-aside and stubble, organic farming and the REPS. Fifteen studies assessed the effects of cropping, using biodiversity 'indicator' species such as various invertebrate groups (of agronomic importance), five others focused on birds (that were either very rare or very common) and one each focused on vascular plants

[10] There are several PhD and MSc theses on this subject, many by the authors in Table 3.1, but these are not referenced here as they are not publicly available.

Table 3.1. Pre-existing peer-reviewed research data describing the impact of conventional crop cultivation on Irish levels of biodiversity (1980–2006).

Investigated species/group	Crop(s)	Study	Statistical analysis	Study duration	Results	Impact on biodiversity[1]	Ref.
Arthropod fauna	Barley and grass–white clover mix	Successional changes in arthropod fauna of a newly established ley pasture that was previously cultivated arable land	Yes	1975–1977	Soil and foliage communities increased in species richness after grassland was established on arable land	↓	Purvis and Curry (1980)
Carabid beetles	Sugar beet	Comparison of manure application at the time of sowing and unrestricted weed growth with controls	Yes	1979	Manure application immediately encouraged early-season carabid communities	↓	Purvis and Curry (1984)
Arthropod fauna	Winter wheat	Effects of various methods of methiocarb application on non-target invertebrates	Yes	1980–1981	Single applications of methiocarb granules did not adversely affect the predatory and decomposer fauna	↔	Kelly and Curry (1985)
Staphylinid beetles	Spring cereals, winter cereals, hay meadow, lightly grazed pastures and silage fields	Effects of different cereal and grass management regimes on summer staphylinid assemblages	Yes	1986	Large differences in staphylinid assemblages occurred between undisturbed meadows and pastures, and disturbed silage fields and cereals	↓	Good and Giller (1991)
Carabid beetles	Winter wheat	Effect of repeated annual application of methiocarb-based slug pellets on carabid beetle activity	Yes	1987–1991	Even thought methiocarb application can severely depress winter-active carabid populations, the long-term environmental harm of this non-target effect appears to be relatively slight	↔	Purvis and Bannon (1992)
Pterostichus melanarius (beetle)	Mixed tillage	Comparison of four differently timed cultivation histories	Yes	1992–1994	Spring soil cultivation reduces larval/pupal survival, but rapid inter-field dispersal by adults masks the effects of soil cultivation on individual fields	↔	Fadl et al. (1996)
Earthworms	Winter wheat and winter wheat–white clover mix	Effect of low input, direct drill intercropping system to conventional monocropping	Yes	1993–1997	The results show unequivocally that the wheat–clover cropping system supported larger earthworm communities than conventional wheat monocropping	↓	Schmidt et al. (2001)

Investigated species/group	Crop(s)	Study	Statistical analysis	Study duration	Results	Impact on biodiversity[1]	Ref.
Carabid beetles	Mixed tillage and grassland	Effect of different timing of annual soil cultivation on numbers and types of beetle	Yes	1992–1994	In a mixed farming system, a greater degree of species coexistence and biodiversity is possible compared to monoculture farming with synchronised soil cultivation	↓	Purvis et al. (2001)
Earthworms	Winter wheat and winter wheat–white clover mix	Effect of winter wheat-white clover intercropping system (low input, direct drill) to conventional monocropping	No	1994–1996	The combination of absence of tillage and continuous supply of plant residues of high nutritional value in the wheat–clover intercropping system was beneficial to earthworms	↓	Schmidt and Curry (2001)
Earthworms	Wheat, potato and spring barley	Impact of intensive cultivation	No	1994–2000	Earthworm populations can be virtually eliminated within a single season by drastic forms of soil cultivation	↓	Curry et al. (2002)
Carabid beetles	Mixed tillage and uncultivated grass leys	Compare crop rotations and soil cultivation effects on beetles	Yes	1993–1995	Autumn-breeding carabid species were less common in early summer when soil cultivation was carried out in late spring, compared with uncultivated or autumn-sown fields	↓	Purvis and Fadl (2002)
Bats	28 habitat types	Species richness in the Northern Ireland countryside	No	1996–1998	Reduction in areas and quality of habitats such as field boundaries may impact bat populations	↓	Russ and Montgomery (2002) [2]
Corn bunting	Cereals and other tillage crops	Survey of potential corn bunting habitats in counties Donegal, Mayo and Galway	No	1998	No corn buntings were seen or heard at any of these sites	↓	Taylor and O'Halloran (2002)
Carabid beetles	Potato	Compare carabid beetle communities in an organic and conventional potato crops	No	1999	A greater abundance and diversity of carabid beetles in the organic plots	↓	O'Sullivan and Gormally (2002)
Birds	Stubble, set-aside, grassland and winter wheat	Species richness in farmland	Yes	2001–2002	Stubble supports the greatest species richness and diversity, with the lowest being recorded on improved grassland	↑	McMahon et al. (2003)

Investigated species/group	Crop(s)	Study	Statistical analysis	Study duration	Results	Impact on biodiversity[1]	Ref.
Plant flora and carabid beetles	Mixed tillage	Species richness in field boundaries with and without REPS	Yes	2000	Species richness of plants and carabid beetles were similar on REPS and non-REPS tillage farms	↔	Feehan et al. (2005)
Birds	Mix of tillage, forest and grassland	Species richness and abundance in three landscape units of either intermediate or low-level forest cover	Yes	2001–2002	Although, farmland bird species richness and abundance between partially forested and open sites did not differ, the presence of trees in the surrounding landscape did positively influence the abundance of blue tits, robins and blackbirds	↑	Pithon and Halloran (2005)
Bumblebee	Mixed tillage and grassland	Bumblebee diversity and abundance on farmland	No	2003–2004	The findings suggest an impoverishment of bumblebee species diversity on Irish farmland	↓	Santorum and Breen (2005)
Collembola	Winter wheat	Compare collembola assemblages in plots ploughed in a conventional way with plots subjected to conservation tillage	Yes	2003	The number of collembola in conservation tilled plots was significantly higher than in the plots which were conventionally tilled, but had little effect on species richness	↓	Brennan et al. (2006)
Birds	Mixed tillage and grassland	Investigate whether farmland bird species showed preferences for set-aside over tillage and grassland fields	Yes	2003	Species diversity and richness were greater in the 18 set-aside sites compared with their paired grass and tillage sites	↓	Bracken and Bolger (2006)
Robin	Spring barley	Role of habitat and structural hedgerow components in determining breeding densities of robins	Yes	1999	Significantly fewer robin territories per hectare in arable sites due to lower hedge density	↓	Fennessy and Kelly (2006)

[1] Impact of conventional crop cultivation on biodiversity either (i) prior to the land being used for other purposes (e.g. meadow, pastures), (ii) compared to alternative environment-friendly farming practices such as intercropping, minimum tillage, timing of cultivation, organic farming, set-aside, winter stubble and farming under the REPS or (iii) resulting from the general intensification of farming practices.

↓ implies a negative impact; ↑ implies a positive impact; ↔ implies a neutral impact.

[2] Northern Ireland.

and mammals (bats). The most studied invertebrates in these papers are earthworms, carabid beetles and collembola (springtails). Bats and bumblebees are the only mammals (Russ and Montgomery, 2002) and airborne insects (Santorum and Breen, 2005) studied as biodiversity indicator species, respectively. The choice of species to be used as indicators of biodiversity change remains a somewhat contested question, in addition to the ecological questions that such indicator species can answer. As in many countries and ecosystems, biodiversity-change studies in Ireland have mainly taken a community ecology approach, often on a few groups of organisms including invertebrates, songbirds and small mammals (Pereira and Cooper, 2006; Thompson, 2006).

3.2.1 Soil Management Practices

Earthworms are one of the most important groups of beneficial soil invertebrates in cropping systems in north-west Europe, contributing to soil fertility and productivity (Lee, 1985). Carabid beetles in agricultural crop systems have a beneficial role as polyphagous predators of pest species (Luff, 1987; Thiele, 1977) and springtails are either microphages, feeding on soil microflora, and/or detritivores, scavenging on dead organic matter and plant litter (Bardgett et al., 1993). Under Irish conditions, conventional soil cultivation (i.e. mechanical ploughing, tilling, etc.) has been found to have an adverse effect on species diversity of soil organisms such as earthworms (Curry et al., 2002; Schmidt and Curry, 2001; Schmidt et al., 2001), carabid beetles (Fadl et al., 1996; Purvis and Fadl, 2002; Purvis et al., 2001), collembola (Brennan et al., 2006) and other arthropods (Purvis and Curry, 1980). In contrast, min-till (Brennan et al., 2006), min-till with intercropping (Schmidt and Curry, 2001; Schmidt et al., 2001), the reversion of land from tillage to grassland (Purvis and Curry, 1980) and timing of cultivation (Fadl et al., 1996; Purvis and Fadl, 2002; Purvis et al., 2001) have all been shown to be less detrimental to populations of these organisms. Farmyard manure application to soil at the time of sowing has also been shown to significantly encourage early 'breeding' carabid communities (Purvis and Curry, 1984). The use of manure replenishes N and other elements in the soil and builds up soil organic matter content. This generally supports a greater abundance of invertebrates that rely on undegraded plant matter as a food source (Hole et al., 2005).

3.2.2 Hedgerows and Woodlands

Up to 1.5% of the total land area of Ireland is accounted for by hedgerows (Feehan and Keena, 2001; Webb, 1988), but this may be greatly underestimated and the actual extent of hedgerow cover is unknown (Collier and Feehan, 2003). Hedgerows can accommodate a greater total of breeding birds than any other farmland feature by providing nesting, feeding and roosting sites, movement corridors and protection from predators (Lack, 1992; O'Connor and Shrubb, 1986; Pollard et al., 1974). The presence of hedgerows and woodlands in and around tillage farms has had a positive effect on populations of bats, and certain birds such as the blue tit (*Parus caeruleus*), robin (*Erithacus rubecula*) and blackbird (*Turdus merula*) (Fennessy and Kelly, 2006; Pithon et al., 2005; Russ and Montgomery, 2002). The loss of hedgerows represents a direct reduction of foraging habitat of several bat species (Russ and Montgomery, 2002). Fennessy and Kelly (2006) show that this also represents a reduction in feeding, nesting and roosting sites for bird species such as the robin and that arable sites had significantly fewer robin territories per hectare than either improved or semi-improved grassland sites. They contend that this may be explained by the fact that hedge density was significantly lower in arable land than in the other two farmland groupings.

3.2.3 Intensification of Farming

The intensification of Irish agriculture has been implicated in the impoverishment of bumblebee species' diversity (Santorum and Breen, 2005) and the decline and extirpation of the corn bunting (*Miliaria calandra*) from much of its range (Taylor and O'Halloran, 2002). Bumblebees are an important part of the Irish fauna, particularly as pollinators both of wild plants and agricultural crops. Bumblebees that would be naturally rare are now very scarce or absent from the typical agricultural landscapes surveyed (Santorum and Breen, 2005). With regard to the corn bunting, the most important factors of its demise in western European countries, including Ireland, are thought to be the decline in mixed farming and the loss of temporary grasslands, hay meadows and undersown cereals, especially spring cereals and overwinter cereal stubbles. These crops provided the preferred breeding and overwintering habitats, and the use of pesticides is proposed to have possibly reduced the availability of invertebrate and seed food supplies (Taylor and O'Halloran, 2002).

Predatory staphylinid beetles comprise one of the groups of polyphagous natural enemies of pest insects in cereals and agricultural grasslands (Good and Giller, 1988). Good and Giller (1991) examined the effects of different cereal- and grass-management regimes on summer staphylinid assemblages in hay meadows, lightly grazed pastures, silage fields, spring cereals, and winter cereals with routine pesticide applications. Large differences in staphylinid assemblages occurred between undisturbed meadows and pastures (without cultivation, cutting, heavy grazing and fertiliser use), and disturbed silage fields and cereals. Application of dimethoate insecticide resulted in a reduction in species richness in cereals, but no effect was evident from the use of the fungicide propiconazole. Overall, rapid recolonisation in heterogeneous landscapes, as in this study, lessened the perceived impact of disturbance factors (Good and Giller, 1991).

3.2.4 Pesticide Usage

Two studies have analysed pesticide usage on Irish biodiversity (Kelly and Curry, 1985; Purvis and Bannon, 1992). A single application of methiocarb-based slug pellets was found not to adversely affect predatory and decomposer fauna (Kelly and Curry, 1985), but repeated annual broadcast and drilled applications severely depressed the populations of winter-active carabid populations to less than 5% and 10–15%, respectively, compared with untreated plots (Purvis and Bannon, 1992). However, the long-term environmental harm of applying methiocarb-based slug pellets on non-target organisms appeared to be relatively slight in those authors' opinion (Purvis and Bannon, 1992). Although the effect of herbicides have only been tentatively studied on arable farms (Feehan et al., 2005), it is believed that their use over the past half century has halved the number of wild plants and animal species associated with farmland and greatly reduced the overall population size of most species (Feehan, 2003).

3.2.5 Winter Stubble and Set-Aside

Winter stubble and spring sown cereals have been relatively common features of the Irish landscape in recent centuries up to the spread of winter sowing in the 1980s (Feehan, 2003). Winter stubble comprises an important food source for many species of farmland birds over the winter months; spring sown cereal crops provide favourable nesting conditions for ground nesting birds such as skylarks (*Alauda arvensis*) which have suffered a decline of 25–50% in their breeding populations over the last 25 years (McMahon et al., 2005; Newton et al., 1999; Taylor and O'Halloran, 2002). Set-aside was initially introduced in 1992 to reduce over production and agricultural surpluses in the EU (Buckingham et al. 1999). 'Green' set-aside has since emerged within the context of multifunctional agriculture in the EU to also become part of some agri-environment schemes (Sotherton, 1998). Rotation set-aside helps to maintain more land under winter stubble, as farmers previously would plough their fields soon after harvest in readiness for sowing the following year's crop. On the other hand, non-rotational set-aside is land that is left fallow for several years and may be sown either with grass or with naturally regenerated vegetation. McMahon et al. (2003) showed that arable farms that retained stubble throughout the winter supported the greatest diversity of birds. Bracken and Bolger (2006) found birds exhibited a significant preference for set-aside over non-set-aside fields (i.e. grass and tillage sites); with non-rotational set-aside having the greatest abundances of species, such as skylark and meadow pipit (*Anthus pratensis*).

3.2.6 Rural Environment Protection Scheme

Following the implementation of Council Regulation 2078/92/EEC (European Commission, 1992), the REPS was introduced to the Republic of Ireland in 1994 (the Northern Ireland equivalent is the Environmental Sensitive Area (ESA) Scheme and/or Countryside Management Scheme). The REPS is intended to monetarily reward farmers for carrying out their farming activities in an environmentally friendly manner and to bring about environmental improvement on existing farms. The fifth CAP reform established common conditions for direct payments to farmers under the various income support schemes and provided support for the agri-environment. Since its launch in 1994, over 45,000 Irish farmers have joined the REPS, and approximately 39% (or 1.7 Mha) of the utilisable agricultural area of Ireland is farmed under the REPS guidelines.

One of the original stated objectives of the REPS was to protect wildlife habitats and endangered species of flora and fauna, but throughout the scheme's specifications the main emphasis has been on water-pollution reduction and extensification (Feehan et al. 2005). However, investigating the plant flora and carabid beetle species richness in field boundaries on REPS and non-REPS tillage farms, Feehan et al. (2005) found species richness was actually similar on both. The authors concluded that farms that had participated in the scheme for at least four years, so far showed little beneficial impact on the diversity of flora and surveyed fauna groups. As the study relied on data from short- and medium-term monitoring, the authors acknowledged that a longer-term study is required. There has been little effort made to support research in this area, despite the fact that ongoing research is mandated in the conditions of funding for agri-environmental schemes in the EU. In addition to this serious lack of information on the effectiveness of the REPS, there is some concern over the lack of efficacy of agri-environmental schemes across Europe (Kleijn and Sutherland, 2003; Wilson et al., 2007). Taken as a whole, though there are some data to show a rise in some generalist species (Reid et al., forthcoming),[11] many agri-environmental programmes in the EU have not resulted in significant benefits to rare species and there have been no Red Data-listed species successes (Kleijn et al., 2006).[12] Ireland currently makes agri-environmental benefits available to any applicant (with supplementary measures for targeted landscapes and species), resulting in a patchwork approach to nature conservation. This approach has been heavily criticised (Whittingham, 2007), and is in contrast to the more targeted approach of the UK (Kleijn and Sutherland, 2003).

3.2.7 Organic Farming

At the end of 2006 there were ca. 72 organic arable farmers in the Republic of Ireland farming 620 ha, which represented approximately 0.1% of the tillage land area (Shortle et al., 2007). Organic agriculture is based on a broad set of principles applied to agriculture which include the way people tend soils, water, plants and animals in order to produce, prepare and distribute food and other goods. These are set out in the International Federation of Organic Agriculture Movements' (IFOAM) norms for organic production and processing (IFOAM, 2006). Organic farming systems tend to rely on crop rotation, crop residues, animal manures, N-fixing plants and mechanical cultivation to maintain soil productivity, to supply plant nutrients and to control weeds, insects and other pests. While there are many environmental claims that organic agriculture is more beneficial to biodiversity and the environment (Holzschuh et al., 2007; Maeder et al., 2002), only one study has compared the biodiversity of organisms in organic versus conventionally grown crops in Ireland. O'Sullivan and Gormally (2002) compared carabid beetle communities in organic and conventional potato crops and found a greater abundance (78% higher) and diversity of beetles in the organic plots.

3.3 Conclusion

It is important to note that the long-term impacts of conventional agricultural practices and cropping systems is poorly understood and rarely researched (O'Brien et al., 2008). It is known, however, that the cumulative effect of farming on the landscape has been significantly detrimental to wildlife and habitats in the 'bocage' landscapes of north-west Europe (Baudry et al., 2000; Butler et al., 2007; Firbank, 2003a; Firbank et al., 2003a; Harvey, 1997; McMahon et al., 2008; Petit, forthcoming). Some studies have shown that conventional farming-management techniques may have the effect of conserving or improving diversity of some species (McMahon et al., 2005; Purvis et al., 2009), whereas others have indicated an opposite trend (Fitzpatrick et al., 2007; Rundlöf et al., 2008; Sheridan et al., 2008). This indicates that there is now a more pressing need to assess the environmental and ecological footprint of conventional agriculture and farm management.

In agreement with the international literature, there is evidence that conventional methods of crop cultivation have had an adverse impact on the levels of biodiversity

[11] There are also growing examples of some rare species becoming extinct when agri-environmental schemes are introduced into some landscapes (e.g. Konvicka et al., 2008).

[12] See http://ec.europa.eu/environment/nature/conservation/species/redlist

on Irish farms, with 15 of the 21 studies (Figure 3.1) to date showing negative trends for the species/groups studied. However, many of these studies found that when more environment-friendly farming practices are used on arable farms, adverse impacts on biodiversity can be reduced. Some studies listed in Table 3.1 clearly show the potential benefits of intercropping, min-till, timing of cultivation, set-aside and winter stubble as possible approaches for increasing biodiversity of the selected indicator taxa studied. Therefore, it is clear that arable farming per se is not detrimental to biodiversity and that in many cases it is likely that more biodiversity-friendly farming practices can be devised and applied, possibly as a result of the heterogeneous landscapes that occur in tillage areas (Benton et al., 2003).

Within the next 10 to 20 years, agriculture in Ireland will face a number of challenges (detailed in Section 2) that will have an unknown impact on farmland biodiversity. To be in a position to measure the impact of these new challenges on Irish biodiversity, baseline data of current levels of biodiversity under existing crop cultivation are necessary. However, publications on many crucial biodiversity aspects of conventional crop cultivation in Ireland are either scarce or non-existent, and many important taxa have never been studied at all. No peer-reviewed studies could be found that examined the impact of crop cultivation on soil micro-organisms (i.e. bacteria, fungi and protozoa), land mammals and other important insects such as ladybirds and butterflies, or any impacts from the use of integrated pest management as an alternative to conventional pesticide usage. No Irish-based studies have assessed the impact of growing oilseed rape on farmland biodiversity (e.g. bees), in a time when hectarage planted under rape is expected to increase in the coming years with the removal of sugar beet as the traditional break crop in cereal rotations and the increased interest in rape seed oil for biodiesel production.

Habitat inventories are largely confined to areas of special conservation concern such as Natural Heritage Areas (NHAs) or Special Areas of Conservation (SACs) (Fitzpatrick et al., 2006). This covers a small proportion of the Irish landscape and can ignore on-farm habitats. The main issue in assessing impacts of arable farming on biodiversity in Ireland remains the paucity of baseline data that targets different arable cropping systems

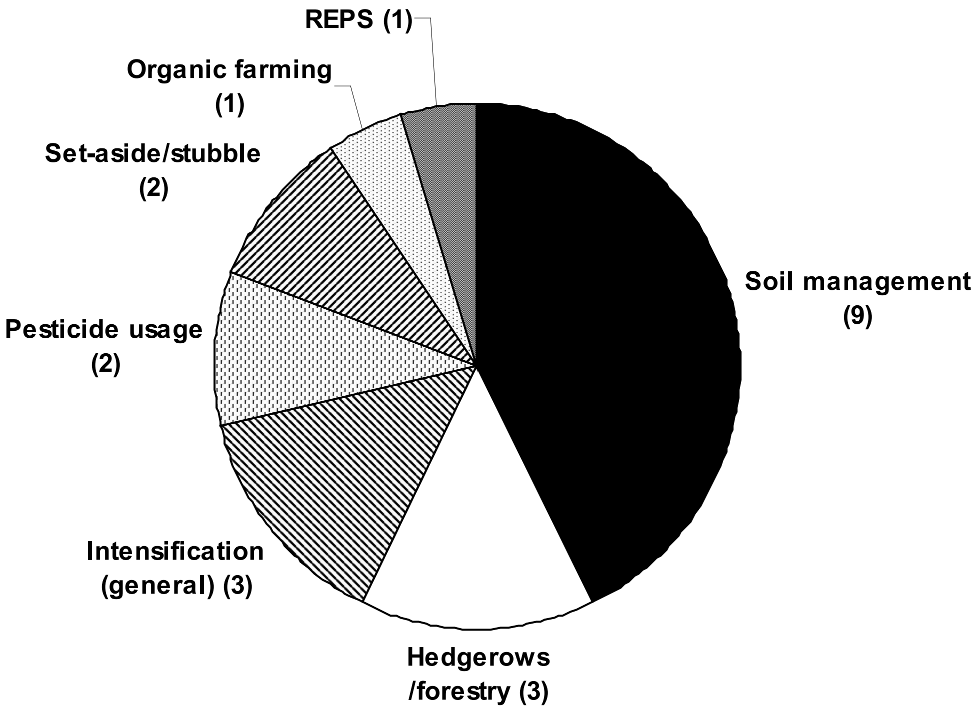

Figure 3.1. Arable farming operations and practices that have been shown as having either a positive or negative impact on Irish levels of farmland biodiversity (*n* = 21, published studies).

(e.g. winter versus spring crops, conventional versus organic, etc.) and an absence of long-term monitoring programmes specifically designed to assess positive or negative effects. While a National Biodiversity Data Centre (NBDC)[13] has now been established by the Irish government, there is, as yet, no comprehensive land-use monitoring system in place which allows changes in the landscape over decades to be investigated. While this will not impede biodiversity studies on GM crops, it does prevent the accumulation of a comprehensive 'control' data set which would greatly complement any future planned research on the biodiversity of crop management systems.

13 See www.biodiversityireland.ie.

4. The National Coexistence Strategy and Gauging the Potential Impact of GM Crop Cultivation on Ireland's Agri-Environment

4.1 Introduction

In July 2003 the EC recommended a set of guidelines on the issue of the coexistence of GM and non-GM crops (European Commission, 2003a). These guidelines are not concerned with the implications of landscape biodiversity or human health, rather they address the economic implications of coexistence with GM crops – such as might occur with proximity to organic farming systems – and affirm the landowners' right to choose what they wish to farm. Accordingly, the guidelines recommend that each member state establishes a code of best practice to ensure the segregation of GM and non-GM crops. In response, the Department of Agriculture, Fisheries and Food established a working group to address the issue in August 2003 since the possible cultivation of GM crops would likely take place in the same areas as non-GM crops in Ireland. The crops that were considered to be the major agricultural crops in Ireland, and which have been, or may be, modified to suit the Irish climate and landscape, were examined.[14] Those that have no likelihood of modification, or that did not suit the Irish climate of landscape, were omitted. As a result a concise and proactive set of GM coexistence guidelines for Ireland were published in the National Coexistence Strategy (NCS) (McGill et al., 2005).[15]

Coexistence permits the cultivation of GM and non-GM crops in proximity to each other in the landscape in a manner that provides minimal opportunity for admixture and that conforms to legal requirements for labelling. Such admixture events could occur in several ways:

- Cross-pollination from GM crops, volunteer or wild relatives.
- Seed transfer via management activities (e.g. harvesting, transport, etc.).
- Volunteers may arise from 'escaped' GM crop seed.
- Seed persistence in waste.
- Seeds from GM crops being found in non-GM crop seed stocks.

For certain crops, how best to achieve efficient coexistence in a real-life, day-to-day situation will be a challenge to individual landowners and food producers. However, potential arrangements that could better facilitate these measures, and one of the key tools for managing GM crops in the landscape, would be to have a coexistence zone arrangement between several producers and their neighbours (as stated in Guideline 9 of the NCS). The formation of such 'GM clusters' could be achieved whereby several landowners collaborate in the management and production of specific GM crops and ensure the separation distance between their GM crops and their nearest non-GM-producing neighbours are maintained; thereby minimising the potential for intra-crop gene flow. It is likely that this kind of arrangement (an example of which is illustrated in Figure 4.1) would suit the Irish landscape as Ireland has a history of cooperative arrangements in farming and has built a great deal of experience in dealing with the issues that arise in cooperative farming.

4.2 GM Clustering Scenarios

Land-use change has, in the past, given rise to species decline, especially in arable landscapes (Sotherton, 1998). Much of this was due to increased inputs of nutrients, herbicides and pesticides as well as drainage and semi-natural habitat removal. It was also due to management-regime change, new machinery and technology, and the move towards year-round agriculture. In Ireland, for example, the move from a single annual crop of hay to two crops of silage, and the ensuing extensive use of perennial ryegrass (*Lolium perenne*), has resulted in a significant decline in species-rich meadows, and thus species decline (Aalen et al., 1997; Feehan, 2003). Section 3 contains

[14] As was discussed extensively in Section 2.
[15] See www.agriculture.gov.ie/gm_coexistence/.

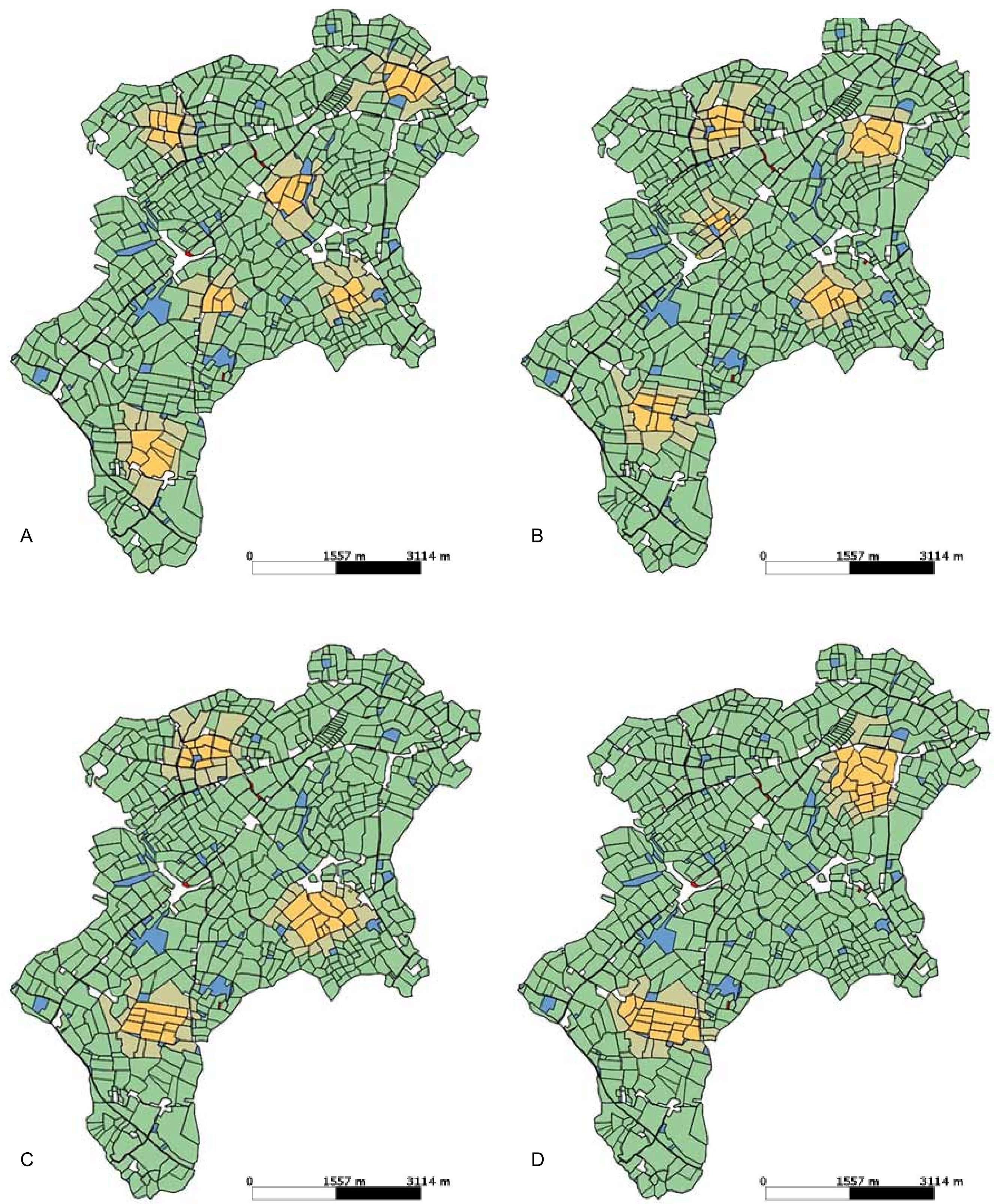

Figure 4.1a. Illustration of field clustering of GM oilseed rape across a randomly selected rural landscape in south-east Ireland as simulated for with GENESYS-IE for combinations of (A) 6 × 5 fields, (B) 5 × 6 fields, (C) 3 × 10 fields and (D) 2 × 15 fields (Tricault et. al., unpublished).

Figure 4.1b. An illustrative example of a contact zone between a cluster of GM fields and surrounding conventional fields, separated by a buffer zone.

references to the few Irish studies in this area, all of which point to land-use change as one limiting factor. From the context of examining the ecological impact of future GM cropping in Ireland, it is important to note that Irish agricultural land is currently subject to considerable inputs (nutrients, herbicides, fungicides, molluscicides and other pesticides) wherever arable farming is practised, as was discussed earlier. Furthermore, present EU-supported agri-environmental instruments (e.g. REPS), which were intended to improve farmland biodiversity, have yet to be shown to be of ecological benefit to the Irish agri-environment (Feehan et al., 2002; Feehan et al., 2005; Flynn et al., 2002), though throughout the EU there is a distinct lack of adequate research in this area (Kleijn et al., 2006; Kleijn and Sutherland, 2003). As discussed, the impact on biodiversity of any crop consists of the combined effects of the crop and the management of that crop. From an agro-ecological context, the question of whether GM crops are damaging to the environment might be phrased: Are such novel crops more or less damaging than conventional crop-production systems? More succinctly, it may be asked whether GM crops will exert a net beneficial or detrimental effect on countryside biodiversity and whether that potential is likely under Irish agroecological conditions.

Because the management regime inside a GM cluster is likely to differ significantly from the management of the farm landscape beyond the cluster, there is the likelihood that the farmland diversities may differ over time. Changing land use to GM cropping may not necessarily be to the detriment of biodiversity. With a less input-orientated management system there is the possibility of the decline in diversity of some species lessening, stopping or reversing over time. This would primarily be as a result of less herbicides and pesticides in use in the landscape (Ammann, 2005; Sanvido et al., 2007). Indeed, there may even be a scenario where some species flourish within a GM cluster and thereafter migrate outwards to the non-GM areas as feeding and shelter opportunities arise outside the cluster zone (Pywell et al., 2006). Thus, because the introduction of any new crop into the landscape will offer opportunities to some species and may threaten others, which is a feature of any ecological process when resilience is impacted upon, the impacts on biodiversity can take differing pathways.

In addition to this, for crops that are modified with traits that enable them to be more efficient nutrient users, the same hectarage or perhaps less may be required to maintain output. The result of this would be that marginal and boundary habitats may not need to be removed, drained or otherwise 'improved', since GM crops may prove to result in high yields without increased land use. Finally, these issues, in combination with warmer climates in the near distant future, may alter the land under tillage in Ireland and so create a new matrix of landscapes (Donald and Evans, 2006; Vandermeer and Perfecto, 2007) and thus both opportunities and/or threats for some species.

Another scenario that may arise is the possibility that, within a GM cluster, there is a desire to maximise the agricultural productivity. Regulatory and legislative restrictions may prove costly and thus the landowner may have to expand operations to ensure profit. In doing so, hedgerows and other semi-natural refuges may be severely managed (and thus lower their species suitability) or may be removed altogether. It is known that hedgerow removal has had a detrimental effect elsewhere (Barr and Petit, 2001; Pollard et al., 1974; Reif and Schmutz, 2001; Watt and Buckley, 1994), and it is known that Irish hedgerows are, in many locations, poorly managed for wildlife diversity (Feehan and Keena, 2001; Foulkes and Murray, 2005a; b; Webb, 1988).[16]

For now, with differing management regimes between adjoining farms in a coexistence strategy, this scenario may result in increased landscape heterogeneity, which could have a net beneficial effect on diversity (Burel and Baudry, 2005; Roschewitz et al., 2005; Weibull et al., 2003). Most of Ireland's wildlife is interdependent with agricultural activities to some extent (directly or indirectly) and so it is logical to assume that if farming declines then there will be impacts on some species and habitats. As there are fewer farmers, there is the increased likelihood of land abandonment and potentially an increase in non-agricultural habitats (such as scrub). It is clear that the most overwhelming challenge to biodiversity (from the introduction of coexistence regimes for GM crops as well as non-GM crops) will be the enactment of new management techniques as well as formalising existing codes of conduct.

[16] Hedgerow removal may also increase the diversity of some species (Lack, 1992) and this highlights the difficulty of having little data on which to base assumptions.

4.3 Biodiversity Impacts

To assess the potential impact of biodiversity on future GM cropping systems, the following traits were considered, based on the findings of Section 2:

- Herbicide tolerance (HT).
- Enhanced fungal resistance (EFR).
- Nitrogen-use efficiency (NUE).
- Phytase enhanced seeds (PES).
- Higher protein content feed (HPCF).
- Enhanced feed digestibility (EFD).
- Enhanced crop yield (ECY).
- Enhanced bioenergy crop (EBC).
- Enhanced resistance to abiotic stresses (ERAS).

Three of these traits (HT, EFR and NUE) are plant modifications that enhance the performance of the crop in the field and are therefore in situ management orientated. The remainder are traits that are not as yet specifically defined for crops currently grown in Ireland. Crops with traits such as PSE, HPCF and EFD are designed to enhance or mitigate the output from livestock with the specific GM crop. Their in situ potential impacts are not known but their ex situ potential impacts are likely to be very positive environmentally. For example, the development of PES and EFD traits is motivated by the need for considerable reductions in farm emissions and farm waste, respectively. While these and other GM traits are obviously beneficial to the wider environment, there are no data used to extrapolate on the potential impact on Irish biodiversity. In order to make this study relevant to the traits that are most likely to have the greatest direct impact on the biodiversity of the agri-environmental landscape, the key traits of HT, EFR and NUE will be used. To begin to assess the potential impacts of these traits in different crop backgrounds in the Irish landscape, five key biodiversity stressors (defined using the acronym CINMa) were identified to permit the use of an impact grading system.

The list of CINMa variables takes into account that there already exists a gene-flow index for GM traits under Irish landscape conditions (Flannery et al., 2005) and it is known that the potential for gene flow has caused concern in relation to the potential impact on biodiversity (O'Callaghan et al., 2005; Raybould and Gray, 1993; Snow, 2002; Stewart Jr. et al., 2003). However, some of the more overt impacts on biodiversity have been brought about by agricultural activities over the long term (Butler et al., 2007) and in this regard Ireland is no different (Feehan, 2004). This is why agri-environmental schemes often focus on modifying management regimes in order to conserve species and habitats (Fish et al., 2003; Schmid and Sinabell, 2007; Schmitzberger et al., 2005). Therefore, when designing an impact model for GM crops it is necessary to adopt an holistic paradigm where management activities and the associated supporting activities have a role to play in impacting the wildlife and habitats of farmland. The following five biodiversity stressors were selected as they are the principal areas of impact of change in land use.

4.3.1 Chemicals (C)

Chemical residues can occur with overuse, misuse, storage and after use of herbicides, pesticides and fungicides within a cropping area and throughout the landscape. Despite good farming practices, there are numerous possibilities for unintended contamination or toxic release not only on the farm itself but also in the transport to the farm and the removal from the farm (for disposal). Conversely, the expression of a novel trait that substitutes for a specific chemical input must also be considered.

4.3.2 Introgression (I)

The introgression of a GM trait into a related species will occur via hybridisation events with a feral population, a neighbouring crop, crop volunteers or wild relatives. A feral crop is a 'reproducible plant that has arisen from a seed-mediated gene-flow event from a crop and is growing outside the confines of a managed agricultural system (e.g. hedgerow, roadside)'. A volunteer crop refers to a 'plant that has arisen from a seed-mediated gene-flow event from a crop and is growing within the confines of a managed agricultural system' (taken from Flannery et al., 2005, p. 32; adapted from Devos et al. (2004)). A third potential avenue for introgression is via crop-to-wild-relative hybridisation. For the purposes of this model, the significant criterion adopted is whether the hybrid population (arising from the F1) is able to persist in the landscape for up to 10 years (Lutman et al., 2004). As mentioned above, land-use change facilitates an alteration of species and habitats and new crops may give rise to the persistence of some new organism, and it should be remembered that no agricultural crop has been shown to be invasive in natural systems in Ireland, though many agricultural 'weed' species (e.g. poppy, dandelion, etc.) do persist. Though novel trait persistence is not necessarily predicated on the crop being GM or otherwise, however, as a biodiversity stressor it is included under introgression in the CINMa model.

4.3.3 Nutrients (N)

Excess nutrient inputs impact on biodiversity. Such excess may occur as a result of overuse, misuse, storage and after use of N, P and K. In turn, this may impact on the soil C:N ratio and result in the promotion of acidification processes, cation-exchange alteration and nutrient loading. Increased nutrient loads can give rise to virulent plant growth at the expense of other flora. Removing nutrients or the nutrient-rich soil is often the first stage of establishing species-rich wildlife meadows. The nutrient loading can impact nutrient cycling and contribute to acidification processes (Anon., 2001; 2002).[17]

4.3.4 Management (Ma)

Emissions are a by-product of agricultural and other land-management activities and may impact the diversity of the wider landscape. These include CO_2 release, particulates and water and airborne toxins that may occur as part of farm management such as ploughing and vegetation burning or cutting. Carbon fluxes may have a bearing on biodiversity in both a positive and negative sense, in particular they may have an impact on ecosystem services (Dale and Polasky; Metzger et al., 2006), peat soil processes (Laggoun-Défarge et al., 2008) and in soil biodiversity in general (Anderson, 2003). It is known that farm-management regimes can have a high impact on the landscape (Büchs, 2007). Such morphological impacts that have an effect on diversity include land compaction, poaching and

[17] For more, refer to the FAO dedicated portal http://www.fao.org/ag/AGL/agll/soilbiod

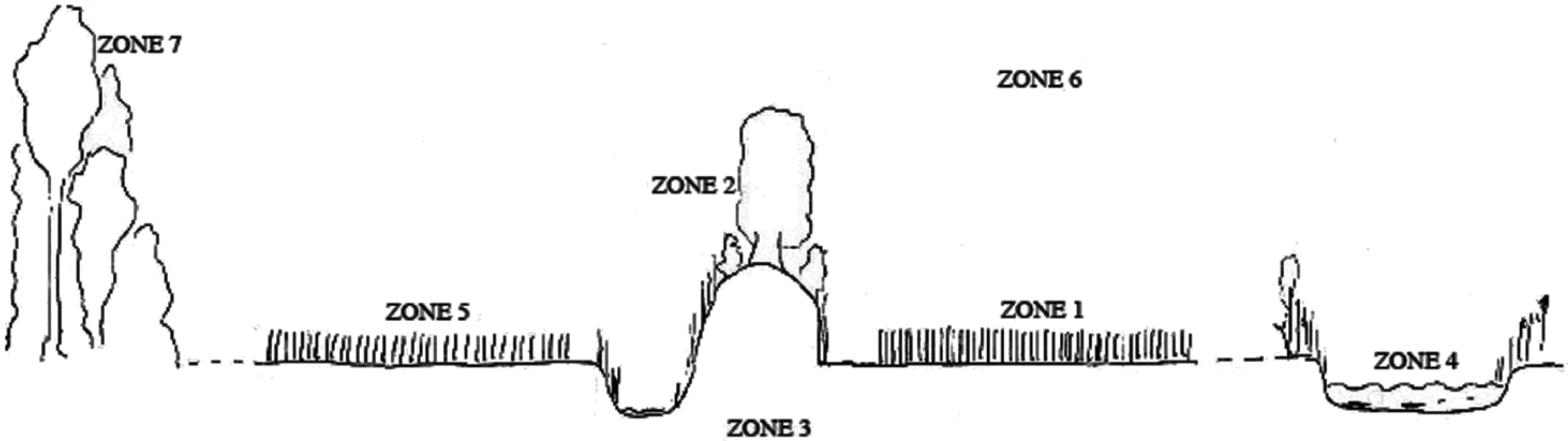

Figure 4.2. Stylised depiction of zones in the CINMa model. Also shown are other zones in the Irish agri-environment not used in this model but may be useful at a later stage or with other land-use changes. These are the biodiversity in zone 5 (crops in neighbouring fields), zone 6 (the air column), zone 7 (natural habitats) and zone 8 (human occupied and farm buildings – not shown). There are no relevant data on the potential biodiversity impacts of new crops upon zones 7 and 8. There are no data on the biodiversity of zone 6 in agrarian landscapes.

drainage activities which in turn change soil composition and impede the growth of roots, infiltration capacity and the availability of some nutrients. Traffic movements, vehicular disturbance, excavation and noise all contribute to species impact, despite the ability of some species to tolerate these. Other management activities have a wider impact in the immediate landscape and over time. Water (for equipment cleaning and chemical mixing, for example) is sourced, on many farms, from aquifers as well as local watercourses, and the use of water in tillage landscapes is particularly high (Taylor et al., 1983; Unger and Howell, 1999).

4.4 Impact

Eight potential impact zones were identified beginning with the in-field diversity where a GM crop would be grown (Table 4.1, Figure 4.2).

Table 4.1. Zones of potential impact on biodiversity in the agricultural landscape (see Figure 4.2).

Zone 1	The crop field itself
Zone 2	Semi-natural landscape features (e.g. hedgerows, callows, hay meadows, etc.) within 10 m of zone 1
Zone 3	The soil column
Zone 4	Watercourses – drains, rivers or still water bodies as well as groundwater within 500 m of zone 1

Zones 1 and 2 cover the majority of the above-ground diversity in the Irish agri-environmental landscape. Zone 3 is the biodiversity in the soil column and zone 4 covers the diversity in nearby watercourses. It may be assumed that the biodiversity of the soil column below some fields may differ from that within the column below, say, semi-natural woodlands or hedgerows, or even stone-wall systems. However, data for this are very poor. In any case, soil processes are often slow and therefore it is difficult to assess from what activity any impact may be assigned. Similarly, for watercourses, impacts from the GM crop alone may be difficult to assign. However, zone 4 is retained in the CINMa grading system in this case, as there are data that show the impact of farm-management regimes on nutrient flows and chemical residues that have considerable downstream impacts (Bennett et al., 2001). In addition, the requirement to use water for cleaning machinery and washing out mixing vessels must be considered.

4.5 Grading Typology

Table 4.2 shows the grading of each GM trait with respect to each of the stress zones. In order to make the grades relevant, each zone is graded on a linear scale and awarded on a positive/negative basis and is devised from the published literature that has been discussed in earlier sections.

Table 4.2. Grading chart.

Zone	C	I	N	Ma	Total[a]
1 – crop					
2 – semi-natural area					
3 – soil					
4 – watercourses					
CINMa[b]					

[a] Indicating the total potential impact of the GM trait on biodiversity.

[b] Indicating cumulative biodiversity stress for all zones for each stressor.

The grades used in the model are shown in Table 4.3. A '–' preceding the grade indicates that the net potential impact may be negative, and a '+' preceding the grade indicates that the net potential impact may be positive. The '0' symbol may mean that the GM trait has no potential impact and/or there are no data for this scenario. A positive impact equates to a scenario where the net influence of the GM crop is potentially beneficial to biodiversity, and negative impact refers to a scenario where the net influence is potentially detrimental to biodiversity. This scenario is common in life-cycle assessments that are used predominately in environmental impact statements. But here we confine our attention to on-farm species and habitats.

Table 4.3. Grading system.

–1 to +1 = Minimal
–2 to +2 = Moderate
0 = Not applicable/relevant

4.6 Predicted Impacts of GM Crops in the Irish Landscape

Table 4.4 to Table 4.13 contain an evaluated and predicted grade for each of the GM traits HT, NUE and EFR for oilseed rape, wheat, maize and potato. It should be noted that the grades used to indicate the potential impact on biodiversity within the above zones are presented in a sequential, numerical manner for illustrative and clarification purposes only. This model is therefore a quantitative representation of a qualitative analysis, and many of the underlying variables may be from ontologically different sources, landscape locations, experimental methodologies, etc. However, all grades were derived from sources with relevance to the Irish landscape and are allocated based on published data. In time, these scores may be adjusted as new sources of information become available, or as new evidence on impacts, as yet not carried out, is published. Research into genetic modification is rapidly evolving and constantly being updated. The CINMa model also considers recent studies that indicated that the farmers that are likely to adopt GM crops will be more likely also to carry out min-till, conservation agriculture (Flannery et al., 2004) and that GM cereals have been engineered to be most suitable to min-till management systems. For example the HT crop tables (Table 4.4, Table 4.6, Table 4.9 and Table 4.11) are existing HT crop varieties whose benefits are best realised through a no-plough system (Sanvido et al., 2007).

Table 4.4. Crop name: Oilseed rape (winter); Trait: Herbicide tolerance (post-emergence).

Zone	C	I	N	Ma	Total
1 – crop	–1[a]	0	0	+1[b]	0[c]
2 – semi-natural area	0	0	0	0	0
3 – soil	0	0	0	+2[d]	+2
4 – watercourses	0	0	0	0	0
CINMa	–1	0[e]	0	+3	

[a] The farm-scale evaluations noted a small reduced biodiversity in the crop (Firbank, 2003b; Wilkinson et al., 1995).

[b] No herbicides in spring would mean a herbicide change from a broad spectrum to glyphosate.

[c] The neutral score here can be explained by the min-till management regime that HT traits make possible.

[d] Lower emissions and less management with a wide window for spraying management.

[e] The persistence issue is the same for GM as non-GM crops as the persistence of oilseed rape is in the biology of the plant not the genetic traits (D'Hertefeldt et al., 2008; Lutman et al., 2004; Pessel et al., 2001).

Table 4.4 illustrates that while there is some potential for biodiversity impact, this is negated by the alterations of management systems. The soil is the zone where there is likely to be a positive biodiversity impact.

Table 4.5. Crop name: Oilseed rape; Trait: Nitrogen use efficiency.

Zone	C	I	N	Ma	Total
1 – crop	0	0	+2[b]	+1[f]	+3
2 – semi-natural area	0	–2[a]	+1[c]	0	–1
3 – soil	0	0	+1[d]	+1[g]	+2
4 – watercourses	0	0	+1[e]	+1[h]	+2
CINMa	0	–2	+5	+3	

[a] There is a possibility for introgression as was discussed earlier with persistence for between 5 and 10 years (Pessel et al., 2001). This may be due to management after harvesting.

[b] Nutrient enrichment can lead to local biodiversity decline due to the inability of some species to compete (Jeffries, 2006, p. 57), and with lower soil fertility more species are able to compete.

[c] Nearby hedgerows can intercept nutrient flows, and species diversity may be affected by excess nutrients (Forman and Baudry, 1984; Le Coeur et al., 2002; Philippe, 1999; Viaud et al., 2004).

[d] Inputs could be significantly less than those needed for cereals, lowering impact on soil processes.

[e] Lower nutrients ought to reduce potential eutrophic episodes.

[f] Less management interference, emissions and use of water for machinery cleaning necessary.

[g] Lower nutrients in the soil lessens impact on C:N ratios and possible acidification processes.

[h] Excess or episodic nutrient flow to watercourses could be minimised or reduced.

Table 4.5 shows that there may be a negative biodiversity stress from introgression and that there may be significantly less biodiversity stress in the areas of nutrients and management. The crop, soil and watercourses zones are the zones of the least impact from the GM trait, though there may be some impact on an on-farm, semi-natural area.

Table 4.6. Crop name: Wheat; Trait: Herbicide tolerance.

Zone	C	I	N	Ma	Total
1 – crop	+1[a]	0	0	+1[d]	+2
2 – semi-natural area	0	0	0	0	0
3 – soil	+1[b]	0	0	+2[e]	+3
4 – watercourses	0	0	0	0	0[f]
CINMa	+2	0[c]	0	+3	

[a] Time of spraying would now favour diverse field 'weeds' of wildlife value (Dewar et al., 2003; Firbank, 2003b).

[b] Glyphosate becomes inert in the soil, but less usage may mean more detritivore activity (Duke and Powles, 2008; Owen, 2008; Powell et al., 2009).

[c] There are no wild relatives of wheat in Ireland, nor is it able to survive in an unmanaged environment. Thus there are no issues of persistence.

[d] Diesel consumption and thus emissions are reduced (Forristal, 2008).

[e] Less management and no ploughing/harrowing necessary: less travel across the land, less compaction and disturbance.

[f] While it is likely that glyphosate may have a reduced influence on watercourses, there are no studies that explore this definitively.

Table 4.6 indicates that it is the soil of the crop field where the greatest influence of the GM trait can be seen and that the least stress on biodiversity comes from lowering of chemical usage and management-regime change.

Table 4.7. Crop name: Wheat; Trait: Enhanced fungal resistance.

Zone	C	I	N	Ma	Total
1 – crop	+1[a]	0	0	+1[d]	+2
2 – semi-natural area	0	0	0	0	0[g]
3 – soil	+1[b]	0	0	+2[e]	+3
4 – watercourses	0	0	0	+1[f]	+1
CINMa	+2	0[c]	0	+4	

[a] The EFR trait means less saturated spraying: from three times per annum to once or no spraying.

[b] There would be less toxic build-up in the soil as a result and the benefit to species could be significant (McLaughlin and Mineau, 1995).

[c] Wheat is unable to survive in an unmanaged environment and thus there are no issues of persistence.

[d] Less use of water for mixing and cleaning of equipment.

[e] Significantly less management would be needed for EFR wheat and thus the impact on soil would be lower.

[f] There would be less potential for discharge to watercourses and as a result of lower management regimes there may be less particulate discharge.

[g] Of the few studies that have been carried out on the effects of EFR wheat none show negative impacts on fauna (Jörg et al., 2003).

Table 4.7 indicates that it is the soil of the crop field where the greatest influence of the GM trait can be seen and that there may be some beneficial impacts on watercourses. The least stress on biodiversity comes from lowering of chemical usage and management-regime change.

Table 4.8. Crop name: Wheat; Trait: Nitrogen use efficiency.

Zone	C	I	N	Ma	Total
1 – crop	0	0	+2[a]	+1[d]	+3
2 – semi-natural area	0	0	+1[b]	0	+1
3 – soil	0	0	+1[c]	+1[d]	+2
4 – watercourses	0	0	+1[c]	+1[d]	+2
CINMa	0	0	+5	+3	

[a] Nutrient enrichment can lead to local biodiversity decline due to the inability of some species to compete (Jeffries, 2006, p. 57) and with lower soil fertility more species are able to compete.

[b] Nearby hedgerows can intercept nutrient flows and species diversity may be affected by excess nutrients (Forman and Baudry, 1984; Le Coeur et al., 2002; Philippe, 1999; Viaud et al., 2004).

[c] Beneficial impacts due to less eutrophic potential in watercourses and less C:N ratio interruption.

[d] Lower management impacts positively.

Table 4.8 indicates that there are potentially high positive biodiversity impacts, especially in-field and in soils and watercourses, from this trait. It also indicates less biodiversity stress from nutrient loads and management regimes.

Table 4.9. Crop name: Maize; Trait: Herbicide tolerance.

Zone	C	I	N	Ma	Total
1 – crop	+2[a]	0	0	+1[d]	+3
2 – semi-natural area	0	0	0	0	0
3 – soil	+1[b]	0	0	+2[e]	+3
4 – watercourses	0	0	0	0	0
CINMa	+3	0[c]	0	+2	

[a] Time of spraying would now favour diverse field 'weeds' of wildlife value (Dewar et al., 2003; Firbank, 2003b).

[b] Glyphosate becomes inert in the soil but less usage may mean more detritivore activity (Duke and Powles, 2008; Owen, 2008; Powell et al., 2009).

[c] There are no wild relatives of maize in Ireland, nor can maize survive outside a managed environment.

[d] Less emissions due to less activities (Forristal, 2008).

[e] The effects of glyphosate on soil micro-organisms in GM crops are generally no different than those in non-GM systems (Griffiths et al., 2008; Krogh and Griffiths, 2007), but less farm traffic and less use of local resources will benefit soil species.

Table 4.9 indicates that it is the soil and the in-field crop area where the beneficial impact of the GM trait can be seen and that the least stress on biodiversity comes from lowering of chemical usage and management-regime change

Table 4.10. Crop name: Maize; Trait: Nitrogen use efficiency.

Zone	C	I	N	Ma	Total
1 – crop	0	0	+2[a]	+1[a]	+3
2 – semi-natural area	0	0	+1[b]	0	+1
3 – soil	0	0	+1[c]	+1[d]	+2
4 – watercourses	0	0	+1[c]	+1[d]	+2
CINMa	0	0	+5	+3	

[a] Maize is a more efficient user of light and thus it is a faster grower than a cereal crop. Thus the availability of nutrients is a limiting factor. The NUE trait makes it less necessary to input nutrients. Nutrient enrichment can lead to local biodiversity decline due to the inability of some species to compete (Jeffries, 2006, p. 57) and with lower soil fertility more species are able to compete.

[b] Nearby hedgerows can intercept nutrient flows and species diversity may be affected by excess nutrients (Forman and Baudry, 1984; Le Coeur et al., 2002; Philippe, 1999; Viaud et al., 2004).

[c] Beneficial impacts due to less eutrophic potential in watercourses and less C:N ratio interruption.

[d] Maize may suit a min- or no-till management system without loss of productivity (Boehmel et al., 2008) and soil quality may not be affected (Bohanec et al., 2007).

Table 4.10 indicates that there are potentially high positive biodiversity impacts, especially in-field and in soils and watercourses from this trait. It also indicates less biodiversity stress from nutrient loads and management regimes.

Table 4.11. Crop name: Potato; Trait: Herbicide tolerance

Zone	C	I	N	Ma	Total
1 – crop	+1	0	0	+1[b]	+2
2 – semi-natural area	0	0	0	0	0
3 – soil	+1	0	0	0	+1
4 – watercourses	+1	0	0	0	+1
CINMa	+3[a]	0	0	0	

[a] Potato farming uses much stronger (broad spectrum) herbicides than cereals and thus the cumulative toxicity in the soil would be more significant. Herbicide tolerance permits a changing to glyphosate which would yield a similar lessening of biodiversity stress as cereals.

[b] Management emissions would therefore be less.

Table 4.11 indicates that management of GM and non-GM potato would be same and thus would not suit a min- or no-till system. Biodiversity stress would be less in the area of chemical inputs.

Table 4.12. Crop name: Potato; Trait: Enhanced fungal resistance.

Zone	C	I	N	Ma	Total
1 – crop	+2[a]	0	0	+2[a]	+4
2 – semi-natural area	0	0	0	0	0
3 – soil	+1[b]	0	0	+2[d]	+3
4 – watercourses	+1[b]	0	0	+1[e]	+2
CINMa	+4	0[c]	0	+5	

[a] An EFR modified potato crop could reduce the annual spraying from 15 times to zero per growing season and this would greatly benefit diversity in the crop field by reducing disturbance (numbers of spray applications).

[b] There would be less likelihood of chemical build-up in soils and watercourses due to the possible elimination of fungicides.

[c] There are no wild or indigenous relatives of potato in Ireland. The use of GM EFR potatoes may cause the blight pathogen to mutate to resist this, but it cannot be counted as a negative impact as it is known that potato blight has mutated naturally in response to non-GM breeding of potato varieties.

[d] Whilst the management is the same for GM and non-GM potatoes, there would be significantly less soil impact than with a non-GM potato crop.

[e] Less emissions of particulates to watercourses as well as a diminished need for using local water supplies to clean equipment and dilute the mix.

Table 4.12 shows that the areas of least biodiversity stress are in the use of chemicals and intensity of management. The crop field and soil are the zones where the GM trait may have the greatest benefit.

Table 4.13. Crop name: Potato; Trait: Nitrogen use efficiency.

Zone	C	I	N	Ma	Total
1 – crop	0	0	+2[a]	+1[e]	+3
2 – semi-natural area	0	0	+1[b]	0	+1
3 – soil	0	0	+2[c]	+2[f]	+4
4 – watercourses	0	0	+1[d]	+2[g]	+3
CINMa	0	0	+6	+5	

[a] It is often necessary to use up to 150 units of N/ha/annum. This could be reduced with the NUE trait and thus could have a beneficial impact on the diversity of ‘weed’ species. Nutrient enrichment may lead to a lowering of in-field diversity.

[b] Nearby hedgerows can intercept nutrient flows and species diversity may be affected by excess nutrients (Forman and Baudry, 1984; Le Coeur et al., 2002; Philippe, 1999; Viaud et al., 2004).

[c] Inputs could be significantly less than those needed for cereals, lowering impact on soil processes.

[d] Lower nutrients ought to reduce potential eutrophic episodes.

[e] Less management interference, emissions and use of water for machinery cleaning necessary.

[f] Less soil compaction and less impact on the C:N ratio.

[g] Excess or episodic nutrient flow to watercourses could be minimised or reduced.

Table 4.13 illustrates that the areas where biodiversity stress is lower are nutrients and management. It also shows that all zones may benefit, especially the soil.

4.7 Conclusion

In order to facilitate a programme of coexistence in the Irish landscape, the management of GM crops will have to be based on several key factors. First, it will be necessary to cluster GM areas and therefore separate crops by a distance that will mitigate the transfer of genes. The creation of buffer zones is well established in modern land management (silviculture, agriculture, etc.). Landscape buffers are central to some of the measures in the REPS (such as nutrient mitigation in wetlands and watercourses). Second, it will be necessary to control ‘escapes’ to the broader landscape, i.e. ‘weed’ species and volunteers, through appropriate management practices. This is best carried out by enacting a rotational management programme (as stated in Guideline 10 of the NCS). The third factor will be to restrict accidental losses of seeds during management and transport of the crop. However, tillage land in Ireland is not homogeneous and it is not an unbroken, contiguous landscape. Farmers often rent land (conacre) and management agreements are rarely part of such rental agreements. Thus, constructive communication between neighbours on a voluntary basis, in relation to GM crop cultivation especially, may be problematic and unworkable in some instances and in others it may be relatively easy and constructive, socially. Indeed, some separation distances may not be possible at all, and thus a farmer may not be able to grow a GM crop even if it is desired. Initial uptake of GM crops may be low in the short term, and so the need to alter farm management to ensure rotational regimes will be relatively easy to apply.

While there are no data available on the potential impact of GM crops to on-farm habitats, the CINMa model redresses the lack of field trials in the Irish landscape and therefore data specific to Irish agricultural conditions. The CINMa model provides an insight into the potential impacts of GM crops on the Irish landscape, and it is shown that these impacts on biodiversity could largely be positive in tillage landscapes. This can be explained as being due to changes in management and a more stricter and coordinated management system across landscapes. The model is being used here for the first time, and with modification and clarification the scope of the model may be expanded to encompass the potential impact of non-GM crops (conventional and organic). This is an area where there are few data available. Compounding much of this discussion is the fact that agri-environmental impact research for tillage landscapes in Ireland has not been carried out. The CINMa model offers a unique opportunity to gain insight into the possible impact of Irish-specific GM traits on biodiversity in the wider landscape, and it is shown that, taken as a whole, GM cropping may not adversely affect species and habitats in Ireland but it will be necessary to assess each specific trait and the associated management regime individually and not as a whole. However, the model established a baseline for future comparison and direction of future research endeavours as GM crops become a more prevalent feature of tillage in Ireland.

5. Developing an Internet-Based Information System which Will Facilitate the Dissemination of Results and Pertinent Information

5.1 Introduction

The difference between GM crop cultivation in European and other OECD countries has arisen as a result of the EU de facto moratorium on the cultivation of GM crops. This was established in 1998 in response to public perceptions and concerns regarding the biosafety of GM technology when applied to food production. Between 1998 and 2003, the response of the EU to public concerns was to introduce a series of legislative measures to ensure informed consent, adequate labelling and traceability, and to safeguard against the introduction of a GM crop, which presents a hazard to human/animal health and/ or the environment (European Commission, 2003b). The need for public access to information relating to GM crops is of paramount importance since a number of high-profile food issues have served to influence consumer confidence and hence the market. As is evident from the previous sections, there is a significant level of research and innovation in the area of crop biotechnology from a production viewpoint. Though it is not the scope of this report to examine public concerns and issues of conflict, there is, nonetheless, a high level of misunderstanding and suspicion on this topic, and it is often portrayed in emotive and perhaps alarmist language, further complicating the matter. Thus there is an onus on researchers and the industry as a whole to be as open as is possible. This section will outline the establishment of Ireland's response to the public demand for information.

5.2 www.gmoInfo.ie

The website was conceived as a project website, initially, but soon thereafter it was recognised that there was a lack of publicly accessible information on the area of GM crops. Thus the website, version 2, was designed to be an impartial representation of the current state of knowledge. One feature of the website, the news feed, is updated regularly with verified information that is up to date and relevant. The aim of the website is to support the public in understanding the issues associated with GM crop cultivation. Thus, the site is updated regularly with research findings of most relevance to Ireland. The website is written in clear and unambiguous language and much of the site content is made up of answers to commonly asked questions. Until the creation of this site, there were no publicly accessible locations with comprehensive information for consumers, researchers and producers.

5.2.1 Consumers

In order to address the concerns of consumers, the website has a question and answer approach. Early research showed that GM-derived food caused little consumer concern, but when the issue became more publicised consumers started to be worried (Aerni, 2005; Saba and Vassallo, 2002), and their concern broadly follows one of three areas – environmental, economic and ethical (Lassen and Jamison, 2006). Many have commented on the role of the media and advocacy coalitions for their part in drawing in unbalanced or biased attention to the issue (Lockie, 2006) and this conflicts with the scientific paradigm. Irish consumers have been shown to have a low level of knowledge of the GM issue (Morris and Adley, 2001), and thus it is in the interest of all concerned to ensure that there is publicly available information on the issue of GM crops in Ireland. The website identifies of what a GM organism consists and goes on to explain why GM crops have been developed, why they are an issue and what the perceived risks may be. The site also illustrates that Ireland currently imports GM animal feed and that there are GM food products currently available in Irish supermarkets. With all the commonly asked questions, there are further links to enable the consumer to verify information or to carry out further research.

5.2.2 Farmers

The site contains a series of relevant questions that farmers may have and thus is agronomically based. Surveys indicate that a cohort of farmers will be keen to adopt GM technology (Keelan et al., 2008), especially in light of tightening profit margins and perceived economic stress (Thorne et al., 2008). However, there is also evidence that farmers are as wary of the issue as are consumers (Hall, 2008). The website provides a context for Irish farmers by indicating the current status of GM farming in Europe, the market for GM food and the discussions on coexistence. It also shows, in relation to blight-resistant potatoes, that two thirds of farmers indicate that they would use the technology.

5.2.3 Researchers

The site intends to be a 'one-stop shop' for those engaged in academic research in Ireland, with links to all papers publicly available on the GM topic. Though many researchers will have access to wider databases and to specific scientific data, this site offers a portal to those who wish to begin the research process. It also offers a sample of papers from the international arena that may have particular relevance to Irish crops and Irish farming conditions. In addition the website contains information on impacts on biodiversity and the wider environment as well as the relevant legislation and specific crops.

5.3 Conclusion

There is quite a large amount of publicly available information today, compared to when the GM issue first began to cause consumer concern, resulting in the moratorium of GM crops in the EU. However, much of this information is biased or inaccurate due to the many advocacy coalitions who derive their motivations from differing ethical, political, philosophical and ecological viewpoints. In addition, the GM issue has transgressed into wider discussions on globalisation, justice and morality, and so it is difficult to find impartial advice and accurate, up-to-date information. There are also other sources of information, derived from scientific databases and promoted in order to allay fears, explain GM traits and to bring the discussions on GM crops to a level of clarity. Many of these sources are updated regularly and many contain surveys which also aim to allay consumer concerns. However, scientific databases and peer-reviewed publications are not normally available to the general public, nor are they usually understandable by non-scientists. The Teagasc 'gmoInfo' website is designed to filter the global information, in addition to the realities of the Irish farming landscape, and to convey this in a manner that is accessible and understandable to consumers, farmers and researchers.

6. Conclusions

A key challenge for countries like Ireland is to produce sufficient supplies of food, feed and fuel, without compromising on public health or negatively impacting the environment. As we progress through the technology era, certain agricultural technologies (e.g. GM crops) have been championed to maximise production while minimising environmental impact. Yet, multiple arguments have been made to counter such a claim, which has led to a polarisation of opinions and a plethora of generic commentaries being made in regard to the impact of this technology. Yet, few studies within the EU have conducted a critical needs analysis to assess the potential of specific GM traits in light of issues such as climate change, increased environmental legislation (e.g. the EU Water Framework, Nitrates Directive, proposed reform to the Pesticide Directive, CAP reform), mitigating biodiversity loss and sustainable biofuel production. This report collates a register of GM traits, such that a list of potential GM crops could be prioritised against the backdrop of the challenges facing the tillage sector. Clearly the crops with the most significant potential for genetic modification are those that are grown widely; barley, wheat and maize currently receive high applications of pesticides and/or fertilisers (e.g. potato). GM traits with significant agronomic potential include late blight-resistant potato, *Fusarium* head blight-resistant wheat and *Septoria*-resistant wheat and herbicide-tolerant winter oilseed rape and maize. Following on from these, crops with enhanced nitrogen use efficiency could provide significant input to the tillage sector in light of EU-based restrictions on nitrogen usage. Crops with elevated protein content could offset the costs of imported animal feed, and crops with modified oil content/lignocellulose composition could assist in biodiesel/bioenergy production. In time, new GM crops may become available as the technology changes and as global conditions alter.

In parallel to the development of these second- and third-generation crops, and to help understand and counteract future agronomic challenges to farmland biodiversity, it is essential to know how present farming practices have impacted biodiversity on Irish farms. This report presents an overview of existing research data describing the impact of crop cultivation on biodiversity on Irish arable farms. An extensive literature review clearly indicates that peer-reviewed publications on research conducted in Ireland on this topic are quite scarce: just 21 papers investigating the impact of conventional crop cultivation on Irish biodiversity have been published within the past 30 years. These studies have concluded that conventional crop cultivation has had an adverse impact on biodiversity on Irish farms, with 15 of the 21 studies demonstrating negative trends for the taxa investigated. Compared to other EU states, the relative dearth of baseline data and absence of monitoring programmes designed to assess the specific impacts of crop cultivation on Irish biodiversity highlights the need to develop and support long-term research studies.

The potential adoption of GM crops in Ireland will occur in tandem with the introduction of the National Coexistence Strategy. This is in keeping with all EU countries who have devised similar strategies and with the ultimate goal of addressing farmer and consumer concerns on this matter. One of the key guidelines from the coexistence working group is the establishment of GM clusters, where GM crops could be grown via cooperative management agreements in specific locations. This will allow for buffering agreements to be made and, perhaps, economies of scale. Such clustering arrangements operated using collaborative methodologies are recommended as being an ideal mechanism for ensuring a minimal impact on neighbouring lands. The GM coexistence issue illustrates that holistic production arrangements and correct land management are key to mitigating biodiversity impact and that a successful coexistence strategy would ensure a higher standard of management. The CINMa model was devised in order to assess and predict the impact of coexisting GM crops in the Irish landscape. The model uses several biodiversity stressors – chemicals, introgression, nutrients and management – to establish where key impacts may be. The model then superimposes these stressors on four zones – the crop field, nearby semi-natural habitats, soil and watercourses – and grades the potential impact as either minimal or moderate. Using the model for the crops and traits that would most suit the Irish tillage landscape, the CINMa model shows that the potential impact of GM crops would be minimal and, indeed, with the correct management regimes in place, the overall impact may be more beneficial to biodiversity in the wider landscape.

In completing this research, several issues have come to the fore. For example, we have shown that there is a lack of baseline data on the impact of tillage farming on biodiversity within the Irish landscape. This knowledge deficit hampers any progress towards eliciting the impacts of novel farming methods, newer cropping systems and responding to consumer demands. Therefore, this study utilised extrapolated data from external sources whose studies were conducted on landscapes similar to Ireland. Such issues have been noted in other predictors of land-use change in Ireland (for example, see Collier and Farrell, 2007) and other studies that attempt to devise habitat grading systems (Collier and Feehan, 2003). In addition to this lack of baseline data, there is also a lack of data on programmes designed to protect and enhance the agri-environment and on-farm biodiversity of tillage crops.

This study holds a lens over the paucity of landscape-wide assessments as well as long-term ecological and agri-environmental monitoring in Ireland. This must be seen in the context of the newly established values that society has placed on biodiversity and the landscape. It is therefore necessary to propose further research. This study indicates that the possible impact of crop management – GM as well as non-GM – should be examined and the assessment of impact of GM crops on biodiversity ought to be comparative to both organically and/or conventionally managed systems in order to provide an egalitarian assessment. Thus the impacts of GM crop management should be studied in parallel with the impacts of non-GM crops. It is also necessary to ascertain the impacts by focusing on each trait individually prior to commercial release, and to establish, on an ongoing basis, additional traits that may be necessary under changing environmental conditions. Further, it will be necessary to establish if the GM traits discussed here could facilitate the evolution of pathogen biology, to establish the efficacy of the trait over time and how it may impact on biodiversity of the target species.

In conclusion, the possible impact on biodiversity depends on both the GM trait and the associated management regime on the farm. Neither can be taken in isolation and the entire system must be taken as a whole. However, using the CINMa model, and supported by both the international and national literature, the indications are that GM traits specific to the Irish agri-environment (as listed here) have the potential to impact positively on farmland biodiversity.

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Acronyms and Annotations

BNI	biological nitrification inhibition
BRIGHT	botanical and rotational implications of genetically modified herbicide tolerance
Bt	*Bacillus thuringiensis*
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
EBC	enhanced bioenergy crop
EC	European Community
ECY	enhanced crop yield
EEC	European Economic Community
EFD	enhanced feed digestibility
EFR	enhanced fungal resistance
ERAS	enhanced resistance to abiotic stresses
ESA	Environmentally Sensitive Area
EU	European Union
FHB	*Fusarium* head blight
FSE	farm-scale evaluation
GM	genetically modified
GMO	genetically modified organism
HPCF	higher protein content feed
HT	herbicide tolerant
IFOAM	International Federation of Organic Agriculture Movements
min-till	minimum tillage agriculture
NBDC	National Biodiversity Data Centre
NBP	National Biodiversity Plan
NCS	National Coexistence Strategy
NHA	Natural Heritage Area
NUE	nitrogen use efficiency
OECD	Organisation for Economic Co-operation and Development
PES	phytase-enhanced seed
PUE	phosphorous use efficiency
REPS	Rural Environment Protection Scheme
SAC	Special Area of Conservation
SFP	single farm payment
STB	*Septoria tritici* blotch