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Opinion paper

The CINMa Index: Assessing the potential impact of GM crop management across a heterogeneous landscape

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While significant progress has been made on the modification of crops for the benefit of producers, the same cannot be said in regards to eliciting the potential impact that these crops may have on the wider landscape and the diversity of life therein. Management impacts can create difficulties when making policy, regulation and licensing decisions in those countries where agriculture has a significant social and ecological position in the landscape. To begin to gauge the potential impacts of the management of a selection of GM crops on an agricultural landscape, four key biodiversity stressors (Chemicals, Introgression, Nutrients and Management: CINMa) were identified and a grading system developed using published data. Upon application to five selected GM crops in a case study area, CINMa identifies areas in the wider landscape where biodiversity is likely to be negatively or positively impacted, as well as agricultural zones which may benefit from the land use change associated with the management of GM crops and their associated post market environmental monitoring.

Keywords: biodiversity / CINMa / GM crops / landscape impact / oilseed rape / potato

INTRODUCTION

As the EU strives to meet the current and future demands for food/fuel security, species and habitat diversity in rural landscapes will be subjected to continual and increased stress (Sutherland et al., 2010). An urgent need exists therefore to mainstream sustainable agricultural and land management practices (Tilman et al., 2001, 2002). In order to monitor the possible ecological impacts, there is also a need to significantly augment, and ultimately harmonise, risk assessment strategies especially when technologies such as GM crops are incorporated into established agricultural landscapes (Sutherland et al., 2008). Under the terms of Directive 2001/18/EC (EC, 2001) post-market environmental monitoring of GM crops within the European Union (EU) must adopt both case specific monitoring and general surveillance (GS) strands of assessment. GS is intended to ascertain the possible unintended effects of a GM crop release, but is not adequately defined from a practical point of view (Bartsch et al., 2006; Sanvido et al., 2005). Wilhelm et al. (2009) discuss the difficulties of both types of assessment and call for the integration of the impact literature, field analysis and communication of risk to be drawn upon to provide a more realistic GS solution. In this paper we propose an assessment index which will begin to address the ambiguity centred on GS, while also facilitating a move towards the harmonisation of risk assessment approaches across the EU. Since heterogeneous landscapes consist of multiple elements, when seeking to make predictions on the future implications of a GM crop release it is judicious to isolate these elements and the stressors thereon. This paper explores the proposal of using an index of biodiversity stressors using case study research applied to the Irish agri-environmental landscape. Drawing primarily on GM crop research for illustration, the potential of this index will be discussed in relation to its wider use for alternative crop releases.

BACKGROUND

Many of the comparative studies describing the impacts of conventional cropping systems on rural ecology demonstrate the negative impact of crop production on biodiversity (*e.g.* O'Brien et al., 2008). The impact of GM crops on local species has also been extensively researched in some locations (Barton and Dracup, 2000; Dunfield and Germida, 2004; Sanvido et al., 2007; Turner, 2004), yet there is little evidence to link their cultivation to adverse biodiversity impacts at a local level (Ammann, 2005; Cerdeira and Duke, 2006). Much of

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the GM crop research completed thus far has focussed on issues such as crop co-existence (*e.g.* Petti et al., 2007; Schiemann, 2003), genetic introgression (*e.g.* Chandler and Dunwell, 2008) and volunteer dynamics (Owen and Zelaya, 2005), often in the context of the on-farm environment. Far less is known about the possible impacts of crop management (GM or non-GM derived) on the wider landscape.

Assessment of impact usually takes a species-centred approach, where indicator species are identified either individually or by holistic sampling (Hoffmann and Greef, 2003), with the European Food Safety Authority (EFSA) identifying, among other things, the need for unified methodologies and models (EFSA, 2010). Multi-scaled assessments that have been used for case specific monitoring have shown that it is difficult to distinguish the impacts from background conditions (Aviron et al., 2006). Overall, impact assessment research is fraught with the difficulty of identifying, from the outset, what is to be assessed, what an impact may be and where to look for this impact (Raybould, 2006). While there is the need to focus on GM crops in order to satisfy requirements, little attention has been focussed on non-GM crops and this imbalance (Sanvido et al., 2007) may have served to reinforce concerns on GM crop impact. It is generally accepted that GM crop farming may have similar impacts to non-GM crop farming (Conner et al., 2003) in relation to biodiversity stress in the wider agricultural landscapes. We believe that the impact of GM and non-GM crops can be jointly assessed using a broad index that encapsulates the management of both cropping systems and the corresponding stresses each may cause to landscape biodiversity. To test this theory and for purposes of illustration we have focussed on those GM crops with a high potential of uptake in the Irish agri-environment, where GM crops are *de facto* prohibited despite the high degree of acceptance by growers (Thorne et al., 2008), thus providing an ideal case study area.

MODEL DESCRIPTION

From the outset, numerous stressors were examined and used to inform the development of the index. To test impact, one must examine all aspects of land management – such as crop rotations and treatments, crop type and variety and length of operations. While geography, biology and taxonomy are key areas of ecological impact (Byrne and Stone, 2011) and will exert stress on biodiversity, it was decided that such scalar stressors would be unmanageable on a practical level. Therefore, we use the four main areas where data are available and upon which farmers can exert the most control. The impact grading system underscoring our biodiversity impact index (CINMa) was designed around the four principle biodiversity stressors that GM (or conventional) cropping may have on the landscape.

Chemicals (C)

Agricultural activities are dependent on the use of a host of synthesised crop protectants. For the 19 400 ha of crops grown in Ireland, around 1520 tonnes of formulated chemicals are applied each year (Department of Agriculture and Food, 2007). Chemical residues can occur as a result of over-use, misuse, storage and after-use of herbicides, pesticides and fungicides within a cropping area and throughout the landscape. There are numerous possibilities for un-intentioned contamination or release not only on the farm itself but also in the transport to the field and the removal from the farm (for disposal).

Introgression (I)

The potential for inter-species gene flow has caused concern in relation to the potential impact of GM traits on biodiversity (Snow, 2002; Stewart Jr. et al., 2003), and while Conner et al. (2003) point out that for some traits this is no more relevant to GM crops than non-GM crops, other traits such as nitrogen use efficiency (NUE) by their nature may well have an impact. The introgression of a GM trait into a related species may occur *via* hybridisation events with a feral population, a neighbouring crop, crop volunteers or wild relatives. Building on previous work (Flannery et al., 2005), the significant criteria adopted here is whether the hybrid population (arising from the F_1) is able to thrive and persist in the landscape for up to ten years (Lutman et al., 2004). In natural conditions, the rate of plant population increase (λ) is usually stable (*i.e.* $\lambda = 1$). It has been demonstrated that the novel traits of some crops, *e.g.* GM disease resistant sunflowers, will introgress into related weed species and proliferate therein ($\lambda > 1$) (Snow et al., 2003). In contrast, traits such as GM herbicide tolerant (HT) oilseed rape, have been shown to gradually diminish in weed species over time ($\lambda < 1$) (Warwick et al., 2008). Critically, the presence of hybrids do not necessarily indicate ecological alterations (Wilkinson et al., 2003) and it is known that they arise through natural processes (Ellstrand et al., 1996). So, while persistence is not necessarily predicated solely on a crop having a novel trait (Wilkinson and Tepfer, 2009), crop to wild relative introgression must be considered as a potential biodiversity stressor in light of future GM traits that could be commercialised (Sanvido et al., 2007).

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Nutrients (N)

In 2008, 308 960 tonnes of nitrogen, 26 350 tonnes of phosphorous and 69 584 tonnes of potassium were applied across the Irish landscape (Connolly et al., 2009; Lalor et al., 2010). Such a significant input warrants a separate stressor from other chemical inputs described earlier. While natural and synthetic crop fertilisers are a prerequisite for commercial crop production, the EU has attempted to mitigate their impact (EC, 2000; EEC, 1991). Less than 50% of field-applied nitrogen and phosphorous is assimilated by crop plants (Smil, 1999, 2000) and excess nutrient inputs have had an impact on landscape biodiversity (Swift et al., 1998), especially in aquatic systems (Kelly et al., 2007). In turn, this will impact on soil carbon ratios, ion exchange alteration and general nutrient loading, which can impact on nutrient cycling and contribute to acidification processes (Aherne et al., 2002). In addition, increased nutrient loads can flow to field boundaries and marginal areas of the farm (Viaud et al., 2004) and can give rise to virulent plant growth, often at the expense of other flora (Mette et al., 2001).

Management (Ma)

Farm management regimes have a high impact on the landscape (Büchs, 2007), locally by way of compaction and physical disturbance and on a wider scale by releasing emissions to air, soil and water. Such carbon fluxes may have a bearing on soil biodiversity in both a positive and negative sense (Anderson, 2003) and they may also have an impact on ecosystem services (Dale and Polasky, 2007) and soil processes (Laggoun-Défarge et al., 2008). Soil structural impacts also include recurrent compaction in gateways and drainage activities which in turn may change soil composition, impede the growth of roots, soil infiltration capacity and the availability of some nutrients. Traffic movements, vehicular disturbance, excavation and noise can contribute to direct and indirect species impact, despite the tolerance ability of some species (Håkansson et al., 1988). Other management activities will also impact on landscape biodiversity. For example, water (for equipment cleaning and chemical mixing) is sourced on many Irish farms, from aquifers as well as local watercourses, resulting in potentially negative impacts such as groundwater pollution (EPA, 2006; Taylor et al., 1983). The intensification of farming has also resulted in the removal of landscape features such as ditches and hedgerows as well as the draining or infilling of micro habitats such as field ponds (Petit et al., 2003), all of which place a high stress on landscape biodiversity.

CINMa DESCRIPTION

The CINMa index was designed as a semi-quantitative representation of a qualitative analysis of the literature (published and peer-reviewed material and expert-driven reports). Thus some of the underlying variables have been derived using ontologically different sources, landscape locations and experimental methodologies. The grades shown here were derived from sources with relevance to heterogeneous landscapes and allocated based on significance to Irish landscapes or species located within those landscapes. This approach is comparable to existing models (*e.g.* Breckling et al., 2011; Thompson et al., 2003) and is common in life cycle assessments that are used predominately in environmental impact statements, though Haas et al. (2000) caution that such assessments must specifically identify the impact area. To address this we identified four impact zones across a typical agricultural landscape (Fig. 1).

Each zone was assessed and graded with a negative (−)/positive (+) linear scale, indicating that the net potential impact was considered to be negative/positive compared to an equivalent conventionally managed crop variety. Crops that are not currently commercialised were assessed on the basis of their specific trait in combination with current agronomic conditions. Hence, the impact of each of the four biodiversity stressors was graded from 2 ("high probability of impact"), through 1 ("low probability of impact") to 0 (indicating neutral impact and/or there are no relevant data for this scenario). The assigned scores were averaged over all four zones as if each had an equal biodiversity value, so as to afford a spatial "levelling field" and thereby permitting an holistic assessment at a landscape level which is the ultimate aim of GS, coupled with the fact that a generic GS is by nature undefined (Wilhelm et al., 2009). This implies that the stressors can have a "parity of impact", *i.e.* an equal weighting. This weighting is untested in real-world scenarios and it is not equally represented or researched in the literature. However, the spatial and temporal impacts of the four stressors across the four zones may ultimately amount to the same cumulative impact, and minor alterations in values may ultimately amount to the same practical outcomes. It is doubtful that a weighting system could be devised that is acutely sensitive to the complexity of impact issues, particularly in the timeframe envisaged for GS. In addition, it would not be possible without significant time and finances to identify a hierarchy of actual and relative landscape impacts. As the goal of the CINMa index is to simplify the process to a more manageable level, equal weighting is assumed, though not critically evident. Thus, a linear relationship is used here, though in time and with better understanding of the interrelationships in the landscape, this may evolve to more accurate calculations and transformations.

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Figure 1. Illustration of the four landscape zones addressed within the CINMa index that encompass the managed field itself (zone 1), semi-natural landscape features (*e.g.* hedgerows, coppice, hay meadows, etc.) within 10 m of zone 1 (zone 2), the soil column (zone 3) and nearby water courses – drains, rivers or still water bodies as well as groundwater within the influence of zone 1 (zone 4).

CINMa IMPLEMENTATION

The methodology was applied to five GM crops, which have specific relevance to the Irish tillage sector (O'Brien and Mullins, 2009). The proposed scores for each crop following consideration of each stressor interaction with each zone are presented in Tables 1–5, with supporting rationale and literature described below each table.

Genetically Modified Herbicide Tolerant (GMHT) oilseed rape (winter)

Farm scale evaluations in the UK noted a small but non-significant reduction in weed biodiversity in the crop zone (Firbank, 2003) but the time of spraying would now favour diverse field "weeds" of wildlife value (Dewar et al., 2003). Beckie et al. (2006) contend that weed diversity has not declined as a result of weed tolerance and there is no evidence linking HT oilseed production and unrelated species evolution herbicide tolerance as a result of farm management (Ellstrand et al., 1999). A score of −1 for introgression (I) is allocated since in the Irish landscape it is possible for a non-native wild relative, *Brassica rapa*, to hybridise with oilseed rape (*Brassica napus*), though these hybrids are less likely to be selected for because semi-natural areas in Ireland are not, in reality, managed using herbicides, but unintentional drift may occasionally occur and so a precautionary −1 is allocated. However, there is a minimal impact on the semi-natural zones. The benefits of GMHT crops are best realised through a no-plough system (Sanvido et al., 2007). Therefore, it is likely that minimum tillage (min-till) or no-till regimes will suit these crops and their managers. This form of management can have a significantly beneficial impact on soil biodiversity (Holland, 2004) and thus, a score of +2 is allocated. Lower emissions and more precision management, combined with a wider window for spraying management, could have significant benefits to soil biota (Schloter et al., 2003) and higher levels of plant residues may act as buffers (Locke et al., 2008) as well as increase soil carbon. Indeed, the lowering of farm management activity may benefit some species in semi-natural habitats, but this has not been quantified. Impacts on watercourses are not fully quantified though glyphosate, being less toxic than products in current usage, may have a low impact on freshwater habitats (Cerdeira and Duke, 2006) but would be an improvement on existing herbicides in terms of toxicity and residual persistence (score of +1). The issue of nutrients is not relevant for this scenario.

Genetically Modified Nitrogen Use Efficient (GMNUE) oilseed rape

Yet to be commercialised, GMNUE oilseed rape has been developed through overexpression of the barley alanine aminotransferase, which has generated material requiring up to 40% less nitrogen to achieve yields equivalent to non-GM conventional varieties (Good et al., 2007). The cultivation of such a crop will lead to the introgression of the NUE trait into the interfertile relative, *B. rapa*, over time. While previous work indicates that introgressed

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Table 1. CINMa scoring for GMHT oilseed rape.

Zone	C	I	N	Ma	Mean zone score
1 – Managed cropping area	1	–1	0	1	0.25
2 – Semi-natural area	0	–1	0	0	–0.25
3 – Soil	1	0	0	2	0.75
4 – Watercourses	0	0	0	0	0
Mean biodiversity stressor score	0.5	–0.5	0	0.75	

Table 2. CINMa scoring for GMNUE oilseed rape.

Zone	C	I	N	Ma	Mean zone score
1 – Managed cropping area	0	–1	1	0	0
2 – Semi-natural area	0	–2	1	0	–0.25
3 – Soil	0	0	2	0	0.5
4 – Watercourses	0	0	1	1	0.5
Mean biodiversity stressor score	0	–0.75	1.25	0.25	

traits into *B. rapa* can persist for 5 to 10 years, providing a weed population with enhanced nitrogen use efficiency will undoubtedly increase the population's rate of increase due to the inability of neighbouring species to compete, hence justifying a score of −2. The lower level of nutrient application will be of benefit to all zones, and any wild relatives that acquire the NUE trait may become problematic in off farm areas (such as roadsides or rail lines) rather than in well managed hedgerows, where shading and vigorous perennials may be limiting factors. Because species diversity may be affected by excess nutrients (Forman and Baudry, 1984) and hedgerows can intercept nutrient flows (Le Cœur et al., 2002), a lower level of nutrient applications in the field may benefit hedgerow diversity. Thus, a score of +1 is allocated in zones 1, 2 and 4. A higher score of +2 is allocated to zone 3 since the likelihood of soil nutrient loading and potential eutrophic episodes should decrease. Finally, there could also be less management interference and use of water for mixing and equipment cleaning which could lessen the need for water use as well as reduce soil compaction, but NUE crops will not eliminate nitrogen and still require applications, though total nitrogen will decrease.

GMHT maize

Providing farmers with the ability to exert weed control outside of the strict "window of opportunity" in existing conventional maize may favour the in-field "weeds" (Firbank, 2003; Heard et al., 2003) that may be found in zone 1. A reduction in management activity will also imply a decrease in emissions (Forristal, 2008) and management disturbance, thus zone 1 scores are in the positive spectrum, as was shown in the FSEs (Champion et al., 2003; Weekes et al., 2007). There are no issues with the semi-natural habitats for the same reasons as discussed under Table 1. Also, as glyphosate becomes inert upon contact with the soil, this will likely lead to increased soil detritivore activity (Powell et al., 2009). The effects of glyphosate on soil micro-organisms in GM crops will be no different than those in non-GM systems (Krogh and Griffiths, 2007), but the change of management to a min-till regime should benefit the abundance and diversity of soil species. The introgression stressor recorded a zero across each of the four zones as no wild relatives of maize exist in Ireland, nor can maize thrive outside a managed environment.

Genetically Modified Late Blight Resistant (GMLBR) potato

Growing GMLBR potato (resistant to *Phytophthora infestans*) can be expected to reduce the number of spraying applications from up to 15 per growing season to approximately two applications per season, when included as part of a crop-specific integrated pest management strategy; thereby impacting positively on crop biodiversity due to reduced disturbance and chemical input (numbers of spray applications). Impact on semi-natural areas will be minimal with the possible exception of reduced spray drift. For zones 3 and 4, there would be less likelihood of chemical build-up and the ensuing run-off or toxic accumulation, due to the significant decrease in the level of active ingredient applied to the crop.

Table 3. CINMa scoring for GMHT maize.

Zone	C	I	N	Ma	Mean zone score
1 – Managed cropping area	1	0	0	1	0.5
2 – Semi-natural area	0	0	0	0	0
3 – Soil	1	0	0	2	0.75
4 – Watercourses	0	0	0	0	0
Mean biodiversity stressor score	0.5	0	0	0.75	

Table 4. CINMa scoring for GMLBR potato.

Zone	C	I	N	Ma	Mean zone score
1 – Managed cropping area	2	0	0	2	1
2 – Semi-natural area	1	0	0	0	0.25
3 – Soil	1	0	0	2	0.75
4 – Watercourses	1	0	0	1	0.5
Mean biodiversity stressor score	1.25	0	0	1.25	

There would be significantly less soil impact in zone 2 than in a comparable non-GM potato crop. In zone 3, with fewer emissions of particulates to watercourses as well as a diminished need for using local water supplies to clean equipment and dilute the mix, there is a potential for beneficial impact. There is no impact on nutrient requirements and there are no introgression issues because there are no wild or indigenous relatives of potato in Europe.

GMNUE potato

Up to 150 units of nitrogen.ha^{-1}.annum^{-1} is required for growing potatoes in Irish soils (Teagasc, 2004). A NUE potato variety could reduce this significantly and thus have a net beneficial impact on the diversity of in-field "weed" species, as nutrient enrichment has been implicated in biodiversity loss (Haines-Young, 2009). While there will be reduced nitrogen application levels during the growing season (+1 under N) it is unlikely that there would be a lowering of the application frequency owing to the biology of the potato crop. As established hedgerows (such as those that pervade the Irish agrarian landscape) can intercept nutrient flows and species diversity will be affected by excess nutrients, the lower application levels result in a positive scenario for semi-natural areas. Inputs could be significantly less than those needed for cereals, thus lowering the impact of excess nitrogen on soil processes and, ultimately, watercourses where lessened nutrients ought to reduce the potential for eutrophic episodes.

DISCUSSION

Using indices to convey pathways has proven itself effective and illustrative in the area of gene flow to the wider local landscape (Devos et al., 2008, 2009; Flannery et al., 2005). However, concern over gene flow is just one aspect of the potential impact of the introduction of GM crops, especially where management regimes change with the particular trait and across different landscapes. With the possible increase in novel trait crops arriving on the market, there is a need to devise an integrated assessment of the potential impacts (positive and/or negative) of these crops on landscape biodiversity. In proposing an impact index for GM crops we deemed it necessary to adopt a holistic paradigm (Cockburn, 2002); one where management practices and the associated supporting activities have a role to play in impacting the wildlife and habitats of farmland. Adopting this approach the CINMa index was designed and applied to five GM crops. Cognisant of the need to simplify the process for policy- and/or decision-makers, it was necessary to average scores evenly across the four biodiversity stressors and give equal weighting to each of the impact areas. We acknowledge that this could be contested, and will therefore require more research. However, in order to illustrate the potential of this index for GS and how the individual tables may be used to transform the data, the following two tables contain summaries of CINMa score ranges for potential impact on the landscape (Tab. 6) and the four farming zones (Tab. 7).

For GMNUE oilseed rape, CINMa indicates that while there may be additional biodiversity stress applied to some semi-natural areas, the overall benefit from

Table 5. CINMa scoring for GMNUE potato.

Zone	C	I	N	Ma	Mean zone score
1 – Managed cropping area	0	0	1	0	0.25
2 – Semi-natural area	0	0	1	0	0.25
3 – Soil	0	0	2	0	0.5
4 – Watercourses	0	0	2	1	0.75
Mean biodiversity stressor score	0	0	1.5	0.25	

Table 6. Comparison of mean scores, illustrating potential GM crop impacts of biodiversity stressors (C, I, N, Ma).

	NEGATIVE									**POSITIVE**							
CINMa SCORE	**2**	**1.75**	**1.5**	**1.25**	**1**	**0.75**	**0.5**	**0.25**	**0**	**0.25**	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**1.75**	**2**
OSR – HT																	
OSR – NUE																	
Maize – HT																	
Potato – LBR																	
Potato – NUE																	

Table 7. Comparison of mean scores, indicating the potential impact of GM crops on the four selected landscape zones.

	NEGATIVE									**POSITIVE**							
ZONE SCORE	**2**	**1.75**	**1.5**	**1.25**	**1**	**0.75**	**0.5**	**0.25**	**0**	**0.25**	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**1.75**	**2**
OSR – HT																	
OSR – NUE																	
Maize – HT																	
Potato – LBR																	
Potato – NUE																	

altered management and lower nutrient inputs should have a net beneficial effect on the wider landscape. For GMHT oilseed rape, CINMa shows a modest potential benefit for soil organisms under the newer management regime that novel trait crops necessitate and facilitate. There is some belief that there may be some unrelated "weed" species evolution with lowering of herbicide diversity in farm management regimes, but this has yet to be shown to be a stressor on other species and habitats in rural landscapes. There are no chemical concerns in marginal habitats, soils or watercourses due to the low toxicity of glyphosate; hedgerows, waterways and roadsides in Ireland are not typically managed using herbicides hence for those GM oilseed rape (*B. napus* × *B. rapa*) hybrids that do emerge the absence of a selection pressure will ensure that the opportunity to increase in numbers because of trait introgression does not materialise. Still, using a precautionary approach a negative score was allocated. This scenario will be different for other landscapes where species differ or with more related species in the wild. It will also be different for other novel trait crops. For example, in the case of imidazolinone tolerant oilseed rape the concern would be its potential toxicity to soil and water organisms. It is clear, however, that both oilseed rape crops may have a wide range of impact and this should guide future GS policies.

For GMHT maize, CINMa yields a higher likelihood of this variety positively impacting upon biodiversity. Again it is in the area of management that the benefits accrue as well as in-field weed diversity due to altered timing of spray application. As with GMHT oilseed rape, there may be a similar issue with herbicide diversity loss and the potential for forced "weed" evolution. For GMLBR potatoes, CINMa reports a positive benefit from management regime change, though again there are no data on potential impacts on the typical semi-natural habitats such as hedgerows that may be found in heterogeneous landscapes. The practical reduction or elimination of farm traffic, tanker washing, chemical mixing, and soil compaction have a high likelihood of reducing biodiversity stress. However, the use of GMLBR potatoes will impose an evolutionary pressure on *Phytopthora infestans* to mutate, but this cannot be counted as a negative impact as it is known that *P. infestans* spontaneously mutates in response to

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conventional potato breeding strategies[1]. Nevertheless, GMLBR is in the advanced stages of trials and can be expected to be released in the near future. For GMNUE potatoes, CINMa shows a similar result and it is the only case where there may be a demonstrable benefit to semi-natural habitats. As with all of the novel traits, there is a potential benefit to the biodiversity of the soil. This can be seen as being a positive step, because the biodiversity of soils, especially agricultural soils, has significant economic consequences locally and globally (Brussaard et al., 2007; FAO, 2002; Kuhlman et al., 2010).

From a standpoint of ecological complexity, this index does not differentiate between landscape elements and interactions. Nor does it discriminate between individual elements of landscape biodiversity. However, it does permit the formation of a baseline for the analysis of any novel traits in the agricultural landscape and under all agricultural management regimes, regardless of their regulation. This index also contributes to landscape planning (under the European Landscape Convention (Council of Europe, 2000)) as well as policy evaluations. Critically, the CINMa index will provide guidance when carrying out GS in order to target specific areas (zones) for more intensive surveillance across landscapes. We expect that scores will need to be adjusted over time as new data become available and that discussions on the validity or otherwise of the CINMa scores presented here will stimulate such investigations and/or highlight specific areas where the CINMa approach can be improved upon. One such area for exploration may be to examine the difference in CINMa scores within non-GM farming systems in order to contribute to the sometimes divisive debate on the ecological impacts of different farming systems.

As an indicator model, CINMa may be used to highlight gaps in impact awareness of all crops and reveal areas of contention and possible conflict in agri-environmental systems. However, the index is reliant on the accuracy and validity of existing data, adequacy of research parameters and similarity of landscapes, and thus it indicates likely trends rather than specific measures. Therefore the index ought to be used as a scoping tool at the preliminary stage of biodiversity impact assessments as well as an *ex post* tool for testing predictions or GS. The CINMa index is not intended to be used to illustrate that GM crops can bring about a reversal of habitat and species decline in agricultural landscapes. It shows, however, that the GM crop management regimes have the potential for redressing some of the previous impacts on farm biodiversity, and this ought to be considered when planning and reviewing the policies governing the release of new crops.

[1] See: www.eucablight.org (accessed, February, 2011).

CONCLUSIONS

The authorisation process for GM crops in the EU has highlighted the importance and significance of impact assessments. However, an "impact" is challenging to quantify in its entirety and so it is necessary to adopt a wider viewpoint on the issue in order to make evidence-based assumptions that withstand scientific critique. A synthesis of research can be highly valuable when devising strategies for landscape conservation and some studies have extrapolated for data in similar landscapes (Reuter et al., 2011), or use landscape scale predictive modelling (Breckling et al., 2011). Much of the GM impact assessments rightly focus on vertical gene transfer, but there has been a deficit of attention to the potential impact on biodiversity at a landscape level. Though novel trait crops may not differ from similar varieties in their ecological impact no crop release can be impact free. Yet, as GM crops are "designed" to make farming more efficient it is logical to look for the impacts of altered management regimes when seeking to establish the potential impact on biodiversity. This has not been the case so far and thus there is a necessity to draw on as many discussions of the topic in order to provide research and management guidance to policy-makers, farmers and researchers.

The CINMa index presents a novel approach to gain an *ex ante* insight into the possible impacts of novel traits (GM or non-GM derived) on farm habitats, and as such provides a tool to regulators and researchers. While there are no data available on the actual impact, if any, of novel trait crops to on-farm habitats in Irish heterogeneous landscapes, the CINMa index addresses the absence of research specific to tillage landscapes. The index indicates that the potential impacts on biodiversity could largely be positive in tillage landscapes and that this can be attributed to the movement towards stricter and co-ordinated farm management regimes. With some case-specific modifications the index may be used to capture the potential impact of diverse crops, such as the afforestation of agricultural lands by novel trait tree crops. Compounding much of this discussion is the fact that agri-environmental impact research in tillage landscapes is minimal. We therefore propose that the CINMa index be considered as a predictive tool to direct future research endeavours or monitoring as novel trait crops become a more prevalent feature across European heterogeneous landscapes.

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