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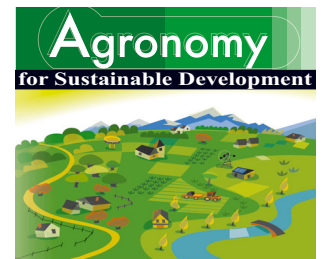
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## Review article

# Agro-environmental effects due to altered cultivation practices with genetically modified herbicide-tolerant oilseed rape and implications for monitoring. A review

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**Abstract** – Genetically modified herbicide-tolerant oilseed rape or canola (*Brassica napus* L.) is at the forefront of being introduced into European agriculture. Concerns have been raised about how genetically modified oilseed rape cultivation and the modified cropping practices might impair the agro-environment. The present review compiles and categorises evidenced and potential agro-environmental effects of cultivating genetically modified oilseed rape and assesses the data quality of published references. Cropping practice changes were identified for (a) the introduction of genetically modified oilseed rape cultivation per se, (b) time, mode and rate of herbicide application, and spraying frequencies, (c) soil tillage and cover crops, (d) crop rotations and (e) coexistence measures to avoid mixing of genetically modified and non-genetically modified cultivation systems. Agro-environmental effects identified are directly linked to the herbicide tolerance technology and may impact ecological processes on various scales. The herbicide-tolerant oilseed rape biology, genotype and co-existence constraints with neighbouring agricultural systems also entail various agro-environmental effects. The potential and especially the well-evidenced adverse effects on the agro-environment, according to European legislation, require a systematic monitoring of genetically modified oilseed rape. The most evidenced adverse effects to be monitored are persistence and/or spread of feral herbicide-tolerant oilseed rape and volunteers, transfer of herbicide tolerance to wild relatives and decline in agrobiodiversity, and development of herbicide tolerance in weeds, as well as adverse effects on field organisms and/or soil bio-geochemical cycles. Other well-evidenced potential adverse effects include reduced crop rotation options, increased late-season herbicide drift and pollution, and implications for microbial and faunal activities due to altered agrochemical profiles, as well as implications of feral herbicide-tolerant oilseed rape on neighbouring habitats.

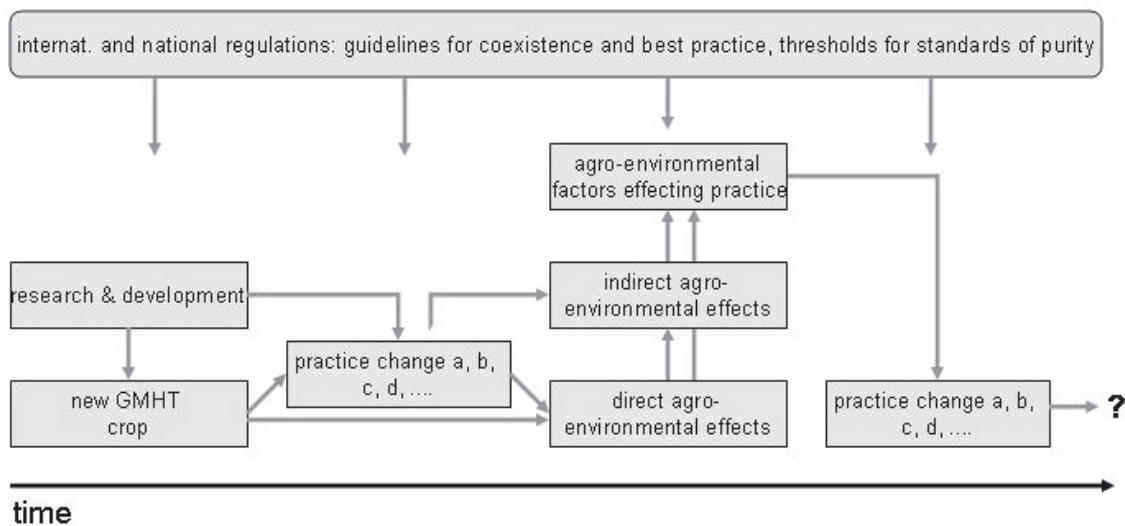
**oilseed rape / canola / genetically modified herbicide tolerance / agricultural practice / agro-environmental effects / monitoring**

## 1. INTRODUCTION

Introducing genetically modified (GM) crops with new traits implies changing farming practices. Among the commercially cultivated GM crops, herbicide tolerance is the dominant trait (68% area), followed by insect resistance (19% area) (James, 2006). Of the GM herbicide-tolerant (GMHT) plant species with tolerance to either glufosinate or glyphosate, oilseed rape and its canola cultivars cover 5% of the global biotech area of 102 million hectares. 18% of the 27 million hectares of cultivated oilseed rape is genetically modified. However, growing interest in biofuels is expected to boost oilseed rape acreage and the proportion of biotechnology involved.

Changes in land use and farming practices (Boutin and Jobin, 1998) over the past few decades have been shown to affect farmland biodiversity (Benton et al., 2002; Krebs et al., 1999; McLaughlin and Mineau, 1995). The new cropping techniques introduced with both GM and also non-GM (conventionally bred) HT plants (Champion et al., 2003; Hayes et al., 2004; Johnson, 2004) may impact farmland biodiversity (Firbank and Forcella, 2000). Companies develop and offer new HT varieties that enable farmers to optimise their practice in weed suppression; for instance, using only one complementary herbicide application, reduction to one application only, thus reducing the active ingredient (ai) rate. Some of their direct effects on the agro-ecosystem such as enhanced weed suppression and consequences thereof on fauna were focused on in the Farm Scale Evaluations (FSE) (Firbank et al., 2003a, b). Others (Devos et al., 2004; Hayes et al., 2004; Légère, 2005)

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**Figure 1.** Conceptual scheme of factors influencing practice changes and subsequent agro-environmental effects when introducing a new GMHT crop (adapted from Graef et al., 2007).

discuss a number of indirect agro-environmental effects of their cultivation; for instance, transfer of HT to volunteers or wild relatives by vertical gene flow through pollination and the subsequent formation of interspecific hybrids. Interpreting those effects as solely due to HT plant cultivation is challenging due to the ongoing change of production factors in agricultural practice (Robinson and Sutherland, 2002), inherently involving many degrees of freedom.

In accordance with the precautionary principle, the Directive 2001/18/EC regulates the release of GM crops into the agro-environment, applying a step-by-step approval process (European Commission, 2001). Environmental GM crop releases thus need to be accompanied by environmental monitoring to detect potential adverse effects, either direct or indirect, immediate or delayed, on human health and the environment. These adverse effects, for instance, are unacceptable levels of gene flow from GM crops to wild relatives, their spread in the environment or adverse effects on single species or species groups, thus reducing biodiversity. With respect to potential adverse environmental effects of GMHT crops at present, there is an overlapping of competencies between the pesticide Directive 91/414/EEC (European Commission, 1991) and the Directive 2001/18/EC on the deliberate release of GMOs. Some of the agro-environmental effects discussed in the following will thus fall into the remit of the pesticide directive.

This review paper systematises and categorises pathways of both direct and indirect potential and evidenced agro-environmental effects of practice changes when introducing GMHT oilseed rape in European agriculture. It does not cite literature where no agro-environmental effects have been recorded, and thus targets issues relevant for GM crop monitoring (European Commission, 2001). The sampled indicators, sampling methods and data quality of the literature are evaluated to indicate the evidence for identified effects, which subsequently can be selected for the obligatory monitoring of GM crops.

The term ‘agro-environment’ for this review is defined as the area cultivated with GMHT oilseed rape along with neighbouring fields and biotopes. The term ‘oilseed rape’ in the following includes the canola cultivars. The term ‘direct effects’ is defined as intended results from practice changes, whereas the term “indirect effects” is defined as unintended consequences of either practice changes or preceding intended direct agroecosystem effects.

## 2. METHODOLOGY OF CATEGORISING CHANGES AND AGRO-ENVIRONMENTAL EFFECTS

Practice changes may induce different pathways of agro-environmental effects (Senior and Dale, 2002; Squire et al., 2003). It is therefore necessary to categorise practice changes and respective effects on the agro-environment and indicate their pathways using hierarchies (Hayes et al., 2004) and schemes of influencing factors (Graef et al., 2007). However, there is an inherent abundance and diversity of direct and indirect pathways that may be triggered by a single practice change (Fig. 1). Direct effects are directly connected to a practice change, whereas indirect effects occur as a result of preceding direct effects. For instance, the HT technology enhances weed suppression (Owen, 1999) and may reduce erosion due to denser plant cover (Agronomy guide, 1999/2000), but may increase herbicide drift because spraying height is increased due to later-season spraying along with further developed, higher crops (Johnson, 2001). On the other hand, many different changes in agricultural practice may lead to a single agro-environmental effect only; for instance, a decline in agrobiodiversity (Benton et al., 2002; Firbank and Forcella, 2000).

The present review therefore hierarchically categorises practice changes and agro-environmental effects as strictly as possible. Practice changes and agro-environmental effects may

entail indirect changes and indirect agro-environmental effects, respectively, because many pathways have multiple implications and vice versa. This leads to redundant information. Thus, to avoid inflating information this categorisation was not followed exclusively and fully consistently (Tab. I). Evidence of observed practice changes and agro-environmental effects was approximated from the referenced sources using evaluation scores for different quality aspects (Kraayer von Krauss et al., 2004).

### 3. PRACTICE CHANGES WITH GMHT OILSEED RAPE CULTIVATION

Cultivating GMHT rape instead of conventional rape may lead to direct, indirect, immediate, delayed and/or cumulative practice changes. They can be categorised into the following groups: (a) the introduction of GMHT oilseed rape cultivation, (b) time, mode and rate of herbicide application, and spraying frequencies, (c) soil tillage and cover crops, (d) crop rotations and (e) coexistence measures to avoid mixing of GM and non-GM cultivation systems. Table I presents an overview of practice changes with the implementation of GMHT oilseed rape cultivation and their agro-environmental effects.

#### 3.1. Introduction of GMHT oilseed rape cultivation

GMHT oilseed rape is not yet authorised for commercial cultivation in Europe but has been cropped for 10 years in the USA and Canada (Benbrook, 2004; James, 2006). In European agriculture it will introduce a new weed control technology, altering existing cropping systems (Canola Council of Canada, 2001; van Acker et al., 2003). Together with the increased acreage of HT oilseed rape, the overall cropping frequency of oilseed rape over the years may increase; at the expense of conventional oilseed rape varieties, the summer fallow acreage may also be reduced (Schütte et al., 2004). Due to increased weed suppression, GMHT oilseed rape cultivation can be expanded to areas which were not suitable for oilseed cultivation before (Beckie et al., 2006).

#### 3.2. Time, mode and rate of herbicide application, and spraying frequencies

In HT oilseed rape cultivation, herbicides with a wide spectrum of activity – glyphosate or glufosinate – are often applied at the post-emergence stage until early bolting. Timing is more flexible and the application of only one herbicide simplifies weed control (Champion et al., 2003; Hin et al., 2001). In a few cases, due to the low residual activity of the active ingredients two applications may become necessary (Pallutt and Hommel, 1998; Beckie et al., 2006). In conventional agriculture either glyphosate or glufosinate are applied at the pre-seeding or pre-emergent stage to clear fields before crop emergence, pre-harvest as desiccants and post-harvest for volunteer control.

With HT oilseed rape, the intention is to reduce the number of spraying rounds (Madsen et al., 1999) and the active



**Figure 2.** Oilseed rape volunteers in winter wheat (source: Dr. Sabine Gruber, Universität Hohenheim, [www.biosicherheit.de](http://www.biosicherheit.de)).

ingredient (ai) amount and to rely preferably on one broad-band herbicide only, which reduces work and costs to farmers (Beckie et al., 2006; Canola Council of Canada, 2001). During the first years of cultivating GMHT oilseed rape, most farmers reduce ai rates and application frequencies (Brimner et al., 2005; Champion et al., 2003; Benbrook, 2004). After years of continued cultivation in some areas (a) weeds may become herbicide-tolerant through natural adaptation and selection pressure, especially if different HT crops resistant to the same herbicide are cultivated in the same rotation (Beckie et al., 2006; Devos et al., 2004; Hayes et al., 2004; Service, 2007), (b) HT oilseed rape volunteers may occur in subsequent rotations due to harvest seeds falling to the ground (Beckie et al., 2006; Légère, 2005) (Fig. 2), (c) HT volunteers may evolve in non-HT oilseed rape fields due to pollen-mediated gene flow from neighbouring HT oilseed rape fields and due to neighbouring volunteers resulting from HT oilseed rape seed banks and seed impurities (Damgaard and Kjellsson, 2005; Gruber and Claupein, 2007; Pekrun et al., 2005), (d) HT weedy relatives (Daniels et al., 2005) or interspecific hybrids (Devos et al., 2004) may evolve due to pollen-mediated gene flow, (e) the composition of weed communities can change (Cerqueira and Duke, 2006; Beckie et al., 2006) and (f) multiple HT oilseed rape may develop due to pollen-mediated gene flow from neighbouring HT oilseed rape fields (Hall et al., 2000). Consequently, ai rates, application frequencies and numbers of ai may increase again, particularly in low-disturbance seeding systems (Senior and Dale, 2002).





Table I. Continued.

Practice changes	Chain of potential agro-environmental effects	References <sup>1</sup>	Evaluation of data quality <sup>2</sup>			
			Proxy <sup>3</sup>	Method <sup>4</sup>	Data validation <sup>5</sup> Overall evidence <sup>6</sup>	
→ change in spray schedules of insecticides and fungicides due to modified herbicide spraying	positive or negative implications for microbial and fauna activities	1, 4, 9, 13, 37, 47	2,2,3,2,2,2	2,2,2,2,2,2	1,1,1,2,1,1	6
→ minimum till associated with HT oilseed rape cultivation	increased competitiveness of perennial weeds	1, 14, 32	3,2,2	2,3,1	1,3,1	8
control of HT oilseed rape volunteers in followcrops	less soil compaction, higher soil biodiversity	1, 8, 9, 24, 34, 55	1,1,2,3,3,3	2,2,2,3,3,2	1,1,1,2,3,2	8
	reduced crop rotation options (e.g. wider rotations or crops with other HT traits)	20, 21, 22, 23	3,3,3,3	3,3,3,2	3,3,3,3	9
control of increased HT in weeds	→ various positive or negative implications for field organisms and soil bio-geochemical cycles	1, 2, 3, 16, 32	1,1,1,2,2	1,1,1,2,1	1,1,1,1,1	5
	changes in tillage system → positive or negative implications for soil degradation and erosion	1, 3, 17, 20, 21, 22, 23, 32	1,1,2,2,2,1, 1,2	1,1,2,2,2,2, 2,2	1,1,1,2,2,2, 1,2	6
	increased ai amount, different types of herbicides, higher spraying frequency	1, 2, 3, 12, 13, 18, 47	3,2,3,3,2,2, 3	2,2,2,3,3,2, 2	1,1,1,2,3,2, 2	8
	→ various adverse effects on field organisms and/or soil bio-geochemical cycles	1, 2, 3, 16, 17, 25, 29, 32	3,1,3,2,1,2, 3,2	2,2,1,2,2,2, 3,1	1,2,2,2,1,3, 3,1	9
in case of survival or spread of feral HT oilseed rape or wild relatives	various adverse effects on neighbouring habitats	15, 19, 47	2,3,3	2,2,2	1,1,1	6
in case of decreased summer fallow acreage	less food and flowers for various herbivores, pollinators and for beneficial species (pest antagonists)	3, 28, 29, 37	2,2,2,2	1,3,2,2	1,3,3,2	8
in case of increased yield potential	increased nutrient leaching	1, 8, 30	1,1,3	2,3,2	1,1,2	7
→ increased fertiliser use						
coexistence measures to reduce vertical gene flow	reduced crop rotation options, isolating fields of GM oilseed rape, modified tillage, and sowing and harvesting at a modified crop development stage	2, 13, 21, 23, 50	3,3,3,3,2	2,2,2,2,2	2,2,2,2,1	7
	→ various positive or negative implications for field organisms and/or soil bio-geochemical cycles	32, 45, 47	2,2,2	2,2,2	2,2,2	6

<sup>1</sup>References legend (E: Expert opinions; M: Models; R: Review; O: Original data); 1 (Hayes et al., 2004/E, M); 2 (Devos et al., 2004/R); 3 (Schütte et al., 2004/E, R); 4 (Senior and Dale, 2002/R); 5 (Bohan et al., 2005/O); 6 (Owen, 1999/E); 7 (Krebs et al., 1999/E, R); 8 (Agronomy Guide, 1999/2000/E, O); 9 (Wemer et al., 2000/E, M, R); 10 (Madsen et al., 1999/E, M); 11 (Canola Council of Canada, 2001/E, O); 12 (Benbrook, 2004/R, O); 13 (Champion et al., 2003/O); 14 (Frick and Thomas, 1992/O); 15 (Crawley and Brown, 2004/O); 16 (Orson, 2002/E, O); 17 (van Acker et al., 2003/E, R); 18 (Légère, 2005/E, R); 19 (Wilkinson et al., 2000); 20 (Colbach et al., 2005/M); 21 (Gruber et al., 2004/O); 22 (Lutman et al., 2005/O); 23 (Pekrun et al., 2005/M, O); 24 (Jordan et al., 2004/O); 25 (Strandberg et al., 2005/O); 26 (Funk et al., 2006/O); 27 (Damgaard and Kjellsson, 2005/M); 28 (Denys and Tscharnke, 2002/O); 29 (Robinson and Sutherland, 2002/R, O); 30 (Pacini et al., 2003/O); 31 (Benton et al., 2002/R, O); 32 (McLaughlin and Mineau, 1995); 33 (Halfhill et al., 2004/O); 34 (Thorbek and Bilde, 2004/O); 35 (Owen and Zelaya, 2005/O); 36 (Begg et al., 2006/E, R); 37 (Hole et al., 2005/R); 38 (Firbank et al., 2005/O); 39 (Heard et al., 2003b/O); 40 (Heard et al., 2003a/O); 41 (Heinemann and Traavik, 2004/O); 42 (Nielsen and Townsend, 2004/O); 43 (Rensing et al., 2002/O); 44 (Johnson, 2001/E, O); 45 (Relyea, 2005/O); 46 (Watkinson et al., 2000/M, E); 47 (Züghart and Breckling, 2003/R); 48 (Regal, 1994/E, R); 49 (Firbank and Forcella, 2000/E, R); 50 (Schiemann, 2003/E); 51 (Rieger et al., 2002/O); 52 (Brimmer et al., 2005/R); 53 (Garnier and Lecomte, 2006/M); 54 (Beckie et al., 2006/R, O); 55 (Cerdeira and Duke, 2006/R); 56 (Gruber and Claupein, 2007/M, O); 57 (Yoshimura et al., 2006/O); 58 (Kleter et al., 2007/R).

<sup>2</sup> Evaluation of data quality (adapted from Krayer von Krauss et al. (2004): evaluation scores for different quality aspects of sources.

<sup>3</sup> "Proxy" refers to how closely the measured or observed effects and indicators resemble the actual effects and indicators about which information is desired (1: weakly correlated, 2: well correlated, 3: direct measurement).

<sup>4</sup> "Method" refers to the quality, mode and accuracy of the methodological design and to the degree to which empirical or expert observations have been used to produce the data (3: well-established method and precise experiments, 2: acceptable method, indirect measurements, modelled or expert-based data, 1: preliminary methods, thumb estimates).

<sup>5</sup> "Data validation" describes the statistical design, number of replications, spatio-temporal representativeness (3: well-established statistical design, cross-checks against independent sources, long period, 2: existent statistical approach, few replications, not independent measurements, shorter period, review of case studies, 1: weak and indirect validation).

<sup>6</sup> "Overall evidence" is calculated from the sum of maximum scores per single source.

### 3.3. Tillage and cover crops

Conservation tillage, no-tillage and cover crops help to prevent soil erosion and generate a higher soil bioactivity (Cerqueira and Duke, 2006; Duke, 1999). HT crops facilitate the use of enhanced crop cover and no-tillage or reduced-tillage, minimising weed pressure (Légère, 2005; Pekrun et al., 2005). Because it requires less tractor use, the practice reduces soil compaction. The use of no-tillage or reduced-tillage systems has greatly increased since the introduction of HT crops (Service, 2007). In present European agriculture, glyphosate is sprayed pre-seeding in reduced-till systems and on fallow land; with HT oilseed rape the herbicide is applied after crop emergence. In Canada the recommended integrated weed management is not largely practised (Beckie et al., 2006), but HT oilseed rape is often grown in weedy fields to reduce the weed seed bank in subsequent years. If HT weeds and HT oilseed rape volunteers in the followcrops develop, the necessary control is likely to trigger more intensive tillage (Gruber et al., 2004).

### 3.4. Crop rotations

Crop rotations help control pests, diseases and weeds and can save pesticides and fertilisers. With GMHT oilseed rape, both additional and less crop species can be expected for future rotations (Schütte et al., 2004). Seed dispersal of oilseed rape may lead to HT volunteers in subsequent crops of the rotation (Colbach et al., 2005; Gruber et al., 2004, Sweet et al., 2004), which may require specific measures such as wider rotations or crops with other HT traits. In general, most dispersed oilseed rape seeds germinate rapidly, either during the late season or in the following year. However, in case seeds get into deeper soil layers through deep ploughing secondary dormancy can be induced (Devos et al., 2004; Pekrun et al., 2005). As a result, seeds can persist for years in the soil. After growing GMHT oilseed rape, returning to a conventional oilseed rape in the crop rotation may become difficult due to HT volunteers and their seed admixture in the harvest (Messéan et al., 2007).

### 3.5. Coexistence requirements

A number of practice changes may also become necessary due to coexistence requirements with GMHT oilseed rape cultivation to avoid GM material presence in non-GM crop production (Devos et al., 2005; European Commission, 2003b; Schiemann, 2003). They generally aim at reducing vertical gene flow to avoid contamination of non-GMHT oilseed rape; for instance, by increasing the time span between successive rape varieties, isolating fields of GM oilseed rape and introducing isolation distances, modified tillage, and sowing and harvesting at a modified time schedule using other varieties (Colbach et al., 2005; Gruber et al., 2004; Lutman et al., 2005; Pekrun et al., 2005).

## 4. EFFECTS OF PRACTICE CHANGES ON THE AGRO-ENVIRONMENT AND IMPLICATIONS FOR COEXISTENCE

Analogously to the practice changes with the introduction of GMHT oilseed rape, potential direct, indirect, immediate, delayed and/or cumulative agro-environmental effects may occur. We followed a hierarchical categorisation (Tab. I), although in some cases it is difficult to distinguish between practice changes and agro-environmental effects because the latter may also be perceived as indirect practice changes (Graef et al., 2007) triggered by GMHT oilseed rape cultivation. One example is potential changes in tillage systems and crop rotations to control volunteers. Some effects on the agro-environment may be induced by several different direct or indirect mechanisms that may work singly or cumulatively. For instance, the potential decline in agrobiodiversity inter alia may result from increased weed suppression, decreased crop species diversity or change in the agrochemical profile (Champion et al., 2003; Owen and Zelaya, 2005; Squire et al., 2003). A number of agro-environmental effects are restricted to the cultivated fields and field margins (Denys and Tschardtke, 2002). Others may extend to neighbouring fields and/or habitats (Colbach et al., 2005) and to the wider environment (Züghart and Breckling, 2003; Crawley and Brown, 2004). Whether effects of GMHT oilseed rape cultivation are considered as being positive, not relevant, relevant for monitoring or even meriting withdrawal of further approval is discussed further below. We grouped the potential agro-environmental effects into three categories.

### 4.1. Introduction of GMHT oilseed rape to the farming system and agro-environmental effects directly linked to the HT technology

A number of agro-environmental effects of the new technology have a predominantly agronomic relevance. More efficient weed suppression, for instance, is the most prominent aim and effect of the HT technology (Beckie et al., 2006; Bohan et al., 2005; Owen, 1999). However, after applying this technology for several years, the potential challenges include, for instance, development of HT in weeds (Benbrook, 2004; Owen and Zelaya, 2005; Service, 2007), a shift of weedy species and the weed seed bank (Heard et al., 2003a; Firbank et al., 2005; Cerqueira and Duke, 2006), and the persistence of HT oilseed rape volunteers in subsequent rotations (Sweet et al., 2004; Gruber et al., 2004; Légère, 2005). To control HT oilseed rape volunteers in followcrops, crop rotations have to avoid oilseed rape and the HT traits for longer periods and may have to change the tillage system (Colbach et al., 2005; Gruber et al., 2004). This may affect field organisms and soil bio-geochemical cycles (McLaughlin and Mineau, 1995; Orson, 2002). Increased ai amount, different types of herbicides or higher spraying frequency to control HT in weeds (Hayes et al., 2004; Schütte et al., 2004) may have various adverse side effects on agrobiodiversity. Post-emergent spraying enables the buildup of more biomass



for feeding organisms until spraying (Werner et al., 2000; Strandberg et al., 2005) and reduces erosion due to more weed biomass and residues (Agronomy guide, 1999/2000). However, post-emergent spraying may also increase herbicide drift into the agro-environment, for instance, due to increased spraying height (Johnson, 2001). Post-emergent spraying also often entails a change in spray schedules of insecticides and fungicides, with potential implications for microbial and faunal activity (Champion et al., 2003; Thorbek and Bilde, 2004). The HT technology supports minimum till, which reduces soil erosion and compaction, and enhances soil biodiversity, but may increase the competitiveness of perennial weeds (Frick and Thomas, 1992; McLaughlin and Mineau, 1995).

If the HT technology is widely adopted, herbicide and other pesticide applications in formerly uncultivated areas can be expected, for instance, where weed pressure has not yet allowed cultivation. This may have various potential effects on field organisms and soil bio-geochemical cycles even on a large scale (Benton et al., 2002; Cerdeira and Duke, 2006; Robinson and Sutherland, 2002).

#### 4.2. Impact on ecological processes on different scales

Direct agro-environmental effects of applying glyphosate and/or glyphosate compared with other herbicides have been controversially discussed. Increased mortality of amphibians has been observed by Relyea (2005) and may be possible for other non-target organisms too (Richard et al., 2005; Züghart and Breckling, 2003). Some studies, however, indicate less herbicide toxicity and persistency than other herbicides (Agronomy guide, 1999/2000; Squire et al., 2003).

While the persistence of non-HT or HT oilseed rape has been evidenced in several habitats (Crawley and Brown, 2004), its invasiveness has not yet been proved. Populations that have established outside the agricultural fields often become extinct after two to four years (Crawley and Brown, 2004). Other studies suggest that feral oilseed rape populations can persist far longer (8–10 years) (Pessel et al., 2001). Unless the habitats are disturbed on a regular basis (e.g. herbicide application, soil disturbance) or replenished with seed from seed spillage from passing traffic, feral oilseed rape populations will eventually be displaced. Feral oilseed rape populations thus have been reported along transport routes due to seed spillage (Garnier and Lecomte, 2006; Yoshimura et al., 2006) (Fig. 3). Depending on the road management practices and herbicides used, the HT populations may persist longer than their non-GM counterparts may.

Oilseed rape has many cross-compatible wild relatives (Daniels et al., 2005). However, viable hybrids that germinate, flower and develop viable seeds are only formed in a few cases; for instance, with *Brassica rapa*. Nonetheless, cross-compatibility remains a major concern (Hayes et al., 2004). Furthermore, HT oilseed rape, if it becomes invasive, may have various adverse effects on neighbouring habitats (Légère, 2005; Züghart and Breckling, 2003).

A number of studies have detected changes in the agrobiodiversity as one of the most prominent effects with GMHT



**Figure 3.** Ruderal oilseed rape on a grass verge next to a country road (source: Barbara Elling, Universität Osnabrück, [www.biosicherheit.de](http://www.biosicherheit.de)).

oilseed rape cropping (Bohan et al., 2005; Heard et al., 2003a,b; Watkinson et al., 2000): HT allows more efficient weed control, leading to fewer surviving flowering plants to provide food for various feeding organisms. Overall, countryside biodiversity may also be affected over the long term, for instance, due to altering current herbicide management regimes or decreasing the number of cultivated crop species (Werner et al., 2000; Hails, 2002).

Some effects, which are less specific for the HT trait but more of general ecological concern, were identified. But their long-term negative impact remains to be definitively proved; for instance, the pleiotropic and epigenetic genome effects of the GM plant (Regal, 1994) or the horizontal gene transfer of HT to microorganisms (Heinemann and Traavik, 2004). Adverse effects may occur on decomposers and soil organisms (Heuer et al., 2002), thus hampering soil functions or bio-geochemical cycles (Züghart and Breckling, 2003). Squire et al. (2003) mention potential effects on sedentary invertebrate species, migratory and wide-ranging species, changed quality of leaf litter, altered crop competitiveness, and changed insect resistance.

#### 4.3. HT oilseed rape biology, genotype and effects on co-existence with neighbouring agricultural systems

The specific oilseed rape biology, i.e. volunteer growth, the high rate of pollen spread and cross-pollination (Begg et al., 2006; Damgaard and Kjellsson, 2005) combined with



the modified HT genotype, is likely to impair co-existence with neighbouring non-GM agricultural systems (European Commission, 2003b; Schiemann, 2003). The transfer of HT to neighbouring oilseed rape fields is well evidenced (Colbach et al., 2005; Daniels et al., 2005; Rieger et al., 2002). Genes can be transferred by outcrossing and hybridisation with non-GM oilseed rape crop and wild relatives, and might increase crop and weed management efforts (Crawley and Brown, 2004; Wolfenbarger and Phifer, 2000). Fitness parameters of GMHT oilseed rape and relative hybrids may be enhanced, especially if selection pressure through herbicide applications is applied, leading to invasiveness into both neighbouring fields and natural habitats (Wilkinson et al., 2000; Snow, 2003). HT can also be transferred to volunteers and feral oilseed rape, which can backcross into non-GM oilseed rape (Züghart and Breckling, 2003). Different HT cultivars grown nearby can develop stacked genes and lead to volunteer hybrids with multiple tolerances (Hall et al., 2000; Simard et al., 2005). To avoid contamination of non-GMHT oilseed rape or to reduce it below a specified level of purity, a number of practice measures are being discussed (Devos et al., 2004; Gruber et al., 2004).

These practice measures – for instance, increasing the time span within a crop rotation between successive rape varieties, isolation distances between GM and non-GM fields, pollen barriers, modified tillage, and sowing and harvesting at a modified crop development stage – can also trigger various agro-environmental effects as mentioned above, depending on the type of measure (Werner et al., 2000; Champion et al., 2003; Squire et al., 2003).

## 5. MONITORING REQUIREMENTS AND REFERENCE BASIS

According to the Directive 2001/18 /EC on the deliberate release of GMOs, monitoring of adverse effects of GMO cultivation must be based on good scientific practice (European Commission, 2001). Whether adverse effects are considered relevant to be monitored is determined by an environmental risk assessment (e.r.a.) and by a decision-making process based on scientific evidence (Andow and Hilbeck, 2004; Damgaard and Lükke, 2001) and/or expert judgements (Kramer von Krauss et al., 2004; Hayes et al., 2004). As experienced in the GMO debate so far, decisions will also largely depend on political and societal assessments such as defined standards for purity of seed (Devos et al., 2007; European Commission, 2003a). Such decisions should also be made based on predefined thresholds of observed agro-environmental effects. In some cases, the e.r.a. may also identify a need and methods for risk mitigation. Potential effects of large-scale cultivation to a small extent can be drawn from the limited-scale studies required prior to market releases (Mellon and Rissler, 1995; Lang, 2004; Faivre et al., 2004; Prasifka et al., 2005).

It is important to note that some agro-environmental effects identified fall beyond the monitoring remit of the Directive 2001/18/EC of the deliberate release of GMOs. For instance, coexistence restraints such as outcrossing to neighbouring

non-GM fields is considered as a socio-economic issue, and monitoring herbicide resistance in weeds should be monitored under the pesticide Directive 91/414/EEC.

Agro-environmental effects of GMHT oilseed rape cultivation compared with conventional oilseed rape or other crops are diverse and manifold. They are difficult to monitor because of constantly changing land use and cultivation systems and production factors (Gafsi, 1999; Senior and Dale, 2002) and shifting political frameworks (European Commission, 2003b; Gaskell and Tanner, 1991). Coming new trait generations of GM crops will also have implications for crop management changes (Hails, 2002; Lheureux and Menrad, 2004) and subsequent monitoring activities. Cultivation systems may also differ depending on the ecoregion (Kropff et al., 2001), requiring the inclusion of different types of spatial agro-ecological reference data (Graef et al., 2005a). Changing crop management factors must be included as covariables in an adaptive GMO monitoring design (Stein and Ettema, 2003) using different spatial and temporal scales. Structured information from different agricultural systems is required as a covariable too, if possible using a typology (Orians and Lack, 1992; Landais, 1998). The monitoring design also implies selecting different indicators depending on the respective scale level, for instance, the enterprise, the landscape or the state level (Osinski et al., 2003). For the biometric analysis of monitoring data, this implies predefining a sufficient number of sites and replications, their spatial distribution, the indicator parameters measured, and their standard deviation. Here, power analysis can be used beforehand to achieve monitoring results with a tolerable error probability (Perry et al., 2003; McDonald, 2003; Lang, 2004).

## 6. ASSESSMENT ON EFFECT OF PRACTICE CHANGES AND IMPLICATIONS FOR MONITORING

As shown above, both adverse and positive agro-environmental effects can be triggered by practice changes due to HT oilseed rape cultivation (Tab. I), whereby GMO monitoring will focus on detecting the adverse effects. Not every potential adverse effect related to GM cropping can be monitored.

Therefore, prioritising and selecting potential adverse effects and related responsive indicators thereof are required. The prioritisation in this review is done by applying the criteria (a) agro-environmental damage (type of effect, magnitude of negative consequences) (European Commission, 2001) and (b) scientific evidence of an adverse effect. The prioritisation of scientific evidence was carried out based on an expert assessment of the data quality of available literature (Tab. I). Applying the evaluation methodology and criteria of Kramer von Krauss et al. (2004) scores of three (very good quality), two (acceptable quality) and one (weak quality) were given for three quality aspects of sources: (a) proximity of the measured effects and indicators to real effects and indicators about which information is desired; (b) methodological design, mode, accuracy and degree to which empirical or expert observations were used to produce the data; and (c)

data validation, statistical design, number of replications and spatio-temporal representativeness. The maximum scores per single source and quality aspects were summed up to achieve an overall rating that shows the present evidence of an observed agro-environmental effect.

Hence, based on the overall evidence of agro-environmental effects resulting from practice changes (Tab. I), among all identified effects the most-evidenced adverse agro-environmental effects that need to be monitored (evaluation scores 8–9) might be persistence and/or spread of feral HT oilseed rape and volunteers, transfer of HT to wild relatives and decline in agrobiodiversity, and development of herbicide tolerance in weeds, as well as adverse effects on field organisms and/or soil bio-geochemical cycles. Other well-evidenced adverse agro-environmental effects (evaluation scores 6–7) include increased late-season herbicide drift and pollution, and implications for microbial and faunal activities due to altered agrochemical profiles, as well as implications of feral HT oilseed rape on neighbouring habitats. For a number of adverse agro-environmental effects, only little evidence is available (evaluation scores 3–5). These include impact on migratory species, changed quality of leaf litter, pleiotropic and epigenetic genome effects, horizontal gene transfer of HT to microorganisms, and implications for soil bio-geochemical cycles.

Priorities for monitoring adverse effects may vary regionally due to differing ecoregions in the EC (Kropff et al., 2001) and they will also depend on regionally differing value judgements of environmental damage (Devos et al., 2006). Other criteria, all of which may differ regionally, could also be applied to prioritise monitoring requirements. These are, for instance, (a) the probability and/or uncertainty of the occurrence of an adverse effect (Kramer von Kraus et al., 2004), (b) the convenience of including monitoring networks already established (Graef et al., 2005b), and (c) the practicability of monitoring and measuring specified indicators (McDonald, 2003; Stein and Ettema, 2003). These, however, have not been included due to the aggregated level of this review. Note that, legally, poorly evidenced or uncertain adverse effects must also be included in the GMO monitoring (European Commission, 2001). Examples include those adverse effects which (a) occur in a delayed fashion, for instance, transgene spread into the wild (Crawley and Brown, 2004; Wilkinson et al., 2000); (b) happen rarely, for instance, horizontal gene transfer to soil organisms (Nielsen and Townsend, 2004); (c) occur indirectly, for instance, tri-trophic interactions (Schuler, 2004) and reduction of farmland birds (Benton et al., 2002), and (d) have not yet been foreseen (Hails, 2002; Wolfenbarger and Phifer, 2000).

Conservational aspects and obligations may also drive monitoring priorities. For instance, adverse GMO effects on the European Natura 2000 network areas protected under the Council Directive 92/43/EEC (European Commission, 1992) or on other ecologically sensitive regions may be judged as more important than those on intensively cultivated land.

Knowledge about adverse effects of HT oilseed rape cultivation can be conferred to other HT crops if practice changes coincide. The monitoring requirements, however, by all means

must be determined on a case-by-case basis (European Commission, 2001).

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## REFERENCES

- Agronomy Guide (1999/2000) PennState University Agricultural Sciences. <http://AgGuide.agronomy.psu.edu/sect6/tab6-22.htm> and <http://AgGuide.agronomy.psu.edu/sect6/tab4-24.htm>.
- Andow D.A., Hilbeck A. (2004) Science-based risk assessment for non-target effects of transgenic crops, *Bio-Science* 54, 637–649.
- Beckie H.J., Harker K.N., Hall S.I., Légère A., Sikkema P.H., Clayton G.W., Thomas A.G., Leeson J.Y., Ségiun-Swartz G., Simard M.J. (2006) A decade of herbicide-resistant crops in Canada, *Can. J. Plant Sci.* 86, 1243–1264.
- Begg G.S., Young M.W., Hawes C., Squire G.R. (2006) Persistence and potential impact of a GMHT trait in oilseed rape, in: *Association of Applied Biologists (Ed.), GM crops – ecological dimensions*, Warwick Wellesbourne, pp. 211–217.
- Benbrook C.M. (2004) Genetically engineered crops and pesticide use in the United States: The first nine years, *BioTech InfoNet Technical Paper 7*, Idaho, USA.
- Benton T.G., Bryant D.M., Cole L., Crick H.Q.P. (2002) Linking agricultural practice to insect and bird populations: a historical study over three decades, *J. Appl. Ecol.* 39, 673–687.
- Bohan D.A., Boffey W.H., Brooks D.R., Clark S.J., Dewar A.M., Firbank L., Haughton A.J., Hawes C., Heard M.S., May M.J., Osborne J.L., Perry J.N., Rothery P., Roy D.B., Scott R.J., Squire G.R., Woivod I.P., Champion G.T. (2005) Effects on weed and invertebrate abundance and diversity of herbicide-tolerant winter-sown oilseed rape, *Proc. R. Soc. Lond. B* 272 / 1562, 463–474.
- Boutin C., Jobin B. (1998) Intensity of agricultural practices and effects on adjacent habitats, *Ecol. Appl.* 8, 544–557.
- Brimner T.A., Gallivan G.J., Stephenson G.R. (2005) Influence of herbicide-resistant canola on the environmental impact of weed management, *Pest Manag. Sci.* 61, 47–52.
- Canola Council of Canada (2001) An agronomic and economic assessment of transgenic canola, *The Growers Manual*, 26 p., <http://www.canola-council.org/production/gmo2.html>.
- Cerdeira A.L., Duke S.O. (2006) The current status and environmental impact of glyphosate-resistant crops: a review, *J. Environ. Qual.* 35, 1633–1658.
- Champion G.T., May M.J., Bennett S., Brooks D.R., Clark S.J., Daniels R.E., Firbank L.G., Haughton A.J., Hawes C., Heard M.S., Perry J.N., Randle Z., Rossall M.J., Rothery P., Skellern M.P., Scott R.J., Squire G.R., Thomas M.R. (2003) Crop management and agronomic context of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops, *Philos. T. Roy Soc. B* 358, 1801–1818.
- Colbach N., Molinari N., Meynard J.M., Messean A. (2005) Spatial aspects of gene flow between rapeseed varieties and volunteers, *Agron. Sustain. Dev.* 25, 355–368.
- Crawley M.J., Brown S.L. (2004) Spatially structured population dynamics in feral oilseed rape, *Proc. R. Soc. Lond. B* 271, 1909–1919.

- Damgaard C., Kjellsson G. (2005) Gene flow of oilseed rape (*Brassica napus*) according to isolation distance and buffer zone, *Agr. Ecosyst. Environ.* 108, 291–301.
- Damgaard C., Lükke H. (2001) A critique of the "concept" of familiarity" as used in ecological risk assessments of genetically modified plants, *BioSafety J.* [online] 6 (p. 18).
- Daniels R., Boffey C., Mogg R., Bond J., Clarke R. (2005) The potential for dispersal of herbicide tolerance genes from genetically-modified, herbicide-tolerant oilseed rape crops to wild relatives, Final report to DEFRA. [http://www.defra.gov.uk/environment/gm/research/pdf/epg\[\\_\]11-5-151.pdf](http://www.defra.gov.uk/environment/gm/research/pdf/epg[_]11-5-151.pdf).
- Denys C., Tscharntke T. (2002) Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows, *Oecologia* 130, 315–324.
- Devos Y., Reheul D., De Schrijver A., Cors F., Moens W. (2004) Management of herbicide-tolerant oilseed rape in Europe: A case study on minimizing vertical gene flow, *Environ. Biosafety Res.* 3, 135–148.
- Devos Y., Reheul D., De Schrijver A. (2005) The co-existence between transgenic and non-transgenic maize in the European Union: a focus on pollen flow and cross-fertilization, *Environ. Biosafety Res.* 4, 71–87.
- Devos Y., Reheul D., De Waele D., Van Speybroeck L. (2006) The interplay between societal concerns and the regulatory frame on GM crops in the European Union, *Environ. Biosafety Res.* 5, 127–149.
- Devos Y., Reheul D., Thas O., De Clercq E., Cougnon M., Cordemans K. (2007) Implementing isolation perimeters around genetically modified maize fields, *Agron. Sustain. Dev.* 27, 155–165.
- Duke S.O. (1999) Weed management: Implications of herbicide resistant crops, <http://www.isb.vt.edu/proceedings99/proceed-ings.duke.html>.
- European Commission (1991) Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market.
- European Commission (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.
- European Commission (2001) Directive 2001/18/EC of the European Parliament and of the Council, *Off. J. Eur. Communities* 2001/18/EC, 1–64.
- European Commission (2003a) Directive 1830/2003 concerning the traceability and labelling of genetically modified organisms.
- European Commission (2003b) Guidelines for the development of national strategies and best practices to ensure the co-existence of genetically modified crops with conventional and organic farming.
- Faivre R., Leenhardt D., Voltz M., Benoit M., Papy F., Dedieu G., Wallach D. (2004) Spatialising crop models, *Agronomie* 24, 205–217.
- Firbank L.G., Forcella F. (2000) Genetically Modified Crops and Farmland Biodiversity, *Science* 289, 1481–1482.
- Firbank L.G., Heard M.S., Woiwod I.P., Hawes C., Haughton A.J., Champion G.T., Scott R.J., Hill M.O., Dewar A.M., Squire G.R., May M.J., Brooks D.R., Bohan D.A., Daniels R.E., Osborne J.L., Roy D.B., Black H.I.J., Rothery P., Perry J.N. (2003a) An introduction to the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops, *J. Appl. Ecol.* 40, 2–16.
- Firbank L.G., Perry J.N., Squire G.R., Bohan D.A., Brooks D.R., Champion G.T., Clark S.J., Daniels R.E., Dewar A.M., Haughton A.J., Hawes C., Heard M.S., Hill M.O., May M.J., Osborne J.L., Rothery P., Roy B.A., Scott R.J., Woiwod I.P. (2003b) The implications of spring-sown genetically modified herbicide-tolerant crops for farmland biodiversity: A commentary on the Farm Scale Evaluations of spring sown crops, <http://www.defra.gov.uk/environment/gm/fse/results/fse-commentary.pdf>.
- Firbank L.G., Rothery P., May M.J., Clark S.J., Scott R.J., Stuart R.C., Boffey C.W.H., Brooks D.R., Champion G.T., Haughton A.J., Hawes C., Heard M.S., Dewar A.M., Perry J.N., Squire G.R. (2005) Effects of genetically modified herbicide-tolerant cropping systems on weed seedbanks in two years of following crops, *Biol. Lett.* [online] 2005, doi: 10.1098/rsbl.2005.0390.
- Frick B., Thomas A.G. (1992) Weed surveys in different tillage systems in south-western Ontario field crops, *Can. J. Plant Sci.* 72, 1337–1347.
- Funk T., Wenzel G., Schwarz G. (2006) Outcrossing frequencies and distribution of oilseed rape (*Brassica napus* L.) in the nearest neighbourhood, *Eur. J. Agron.* [online] 24, 26–34.
- Gafsi M. (1999) A management approach to change on farms, *Agr. Syst.* 61, 179–189.
- Garnier A., Lecomte J. (2006) Using a spatial and stage-structured invasion model to assess the spread of feral populations of transgenic oilseed rape, *Ecol. Model.* 194, 141–149.
- Gaskell P.T., Tanner M.F. (1991) Agricultural Change and Environmentally Sensitive Areas, *Geoforum* 22, 81–90.
- Graef F., Schmidt G., Schröder W., Stachow U. (2005a) Determining ecoregions for environmental and GMO monitoring networks, *Environ. Monit. Assess.* 108, 189–203.
- Graef F., Züghart W., Hommel B., Heinrich U., Stachow U., Werner A. (2005b) Methodological scheme for designing the monitoring of genetically modified crops at the regional scale, *Environ. Monit. Assess.* 111, 1–26.
- Graef F., Stachow U., Werner A., Schütte G. (2007) Review: Agricultural practice changes with cultivating genetically modified herbicide-tolerant oilseed rape, *Agr. Syst.* 94, 111–118.
- Gruber S., Claupein W. (2007) Fecundity of volunteer oilseed rape and estimation of potential gene dispersal by a practice-related model, *Agr. Ecosyst. Environ.* 119, 401–408.
- Gruber S., Pekrun C., Claupein W. (2004) Life cycle and potential gene flow of volunteer oilseed rape in different tillage systems, *Weed Res.* 45, 83–93.
- Hails R.S. (2002) Assessing the risks associated with new agricultural practices, *Nature* 418, 685–688.
- Halfhill M.D., Zhu B., Warwick S., Raymer P.L., Millwood R.J., Weissinger A.K., Stewart J. (2004) Hybridization and backcrossing between transgenic oilseed rape and two related weed species under field conditions, *Environ. Biosafety Res.* 3, 73–81.
- Hall L., Topinka K., Huffman J., Davis L., Good A. (2000) Pollen flow between herbicide-resistant *Brassica napus* is the cause of multiple-resistant B. napus volunteers, *Weed Sci.* 48, 688–694.
- Hayes K.R., Gregg P.C., Gupta V.V.S.R., Jessop R., Lonsdale W.M., Sindel B., Stanley J., Williams C.K. (2004) Identifying hazards in complex ecological systems. Part 3: Hierarchical holographic model for herbicide tolerant oilseed rape, *Environ. Biosafety Res.* 3, 109–128.
- Heard M.S., Hawes C., Champion G.T., Clark S.J., Firbank L.G., Haughton A.J., Parish A.M., Perry J.N., Rothery P., Roy B.A., Scott R.J., Skellern M.P., Squire G.R., Hill M.O. (2003a) Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. II. Effects on individual species, *Philos. Roy. Soc. Lond. B* 358, 1833–1846.
- Heard M.S., Hawes C., Champion G.T., Clark S.J., Firbank L.G., Haughton A.J., Parish A.M., Perry J.N., Rothery P., Scott R.J., Skellern M.P., Squire G.R., Hill M.O. (2003b) Weeds in fields



- with contrasting conventional and genetically modified herbicide-tolerant crops. I. Effects on abundance and diversity, *Philos. T. Roy. Soc. B* 358, 1819–1832.
- Heinemann J.A., Traavik T. (2004) Problems in monitoring horizontal gene transfer in field trials of transgenic plants, *Nat. Biotechnol.* [online] 22, 1105–1109.
- Heuer H., Kroppenstedt R.M., Lottmann J., Berg G., Smalla K. (2002) Effects of T4 lysozyme release from transgenic potato roots on bacterial rhizosphere communities are negligible relative to natural factors, *Appl. Environ. Microb.* 68, 1325–1335.
- Hin C.J.A., Schenkelaars P., Pak G.A. (2001) Agronomic and environmental impacts of the commercial cultivation of glyphosate tolerant soybean in the USA. Centre for Agriculture and Environment, Utrecht, Centrum voor Landbouw en Milieu (CLM), 496–2001. <http://www.clm.nl>.
- Hole D.G., Abdel-Baky N.F., Perkins A.J., Wilson J.D., Alexander I.H., Grice P.V., Evans A.D. (2005) Does organic farming benefit biodiversity? *Biol. Conserv.* 122, 113–130.
- James C. (2006) Global Status of Commercialized Biotech/GM Crops: 2006, ISAAA Brief No. 35, ISAAA, Ithaca, NY, <http://www.isaaa.org/resources/publications/briefs/35>.
- Johnson B. (2001) A critical analysis of the field scale trials of herbicide tolerant oilseed rape in the UK, in: Miklau M., Gaugitsch H., Heissenberger A. (Eds.), EU-workshop: Monitoring of environmental impacts of genetically modified plants, 9–10 November 2000, Berlin, UBA-Texte, 45/01, Umweltbundesamt, Berlin, pp. 142–148.
- Johnson B. (2004) Changing cropping systems is an important issue for GM crops, *Naturschutz und Biologische Vielfalt* 1, 229–239.
- Jordan D., Miles R.J., Hubbard V.C., Lorenz T. (2004) Effect of management practices and cropping systems on earthworm abundance and microbial activity in Sanborn Field: a 115-year-old agricultural field, *Pedobiologia* 48, 99–110.
- Kleter G.A., Bhula R., Bodnaruk K., Carazo E., Felsot A.S., Harris C.A., Katayama A., Kuiper H.A., Racke K.D., Rubin B., Shevah Y., Stephenson G.R., Tanaka K., Unsworth J., Wauchope R.D., Wong S. (2007) Altered pesticide use on transgenic crops and the associated general impact from an environmental perspective, *Pest Manag. Sci.* 63, 1107–1115.
- Krayer von Krauss M.P.K., Casman E.A., Small M.J. (2004) Elicitation of expert judgements of uncertainty in the risk assessment of herbicide-tolerant oilseed crops, *Risk Analysis* 24/6, 1515–1527.
- Krebs J.R., Wilson J.D., Bradbury R.B., Siriwardena G.M. (1999) The second silent spring? *Nature* 400, 611–612.
- Kropff M.J., Bouma J., Jones J.W. (2001) Systems approaches for the design of sustainable agro-ecosystems, *Agr. Syst.* 70, 369–393.
- Landais E. (1998) Modelling farm diversity new approaches to typology building in France, *Agr. Syst.* 5, 505–527.
- Lang A. (2004) Monitoring the impact of Bt maize on butterflies in the field: estimation of required sample sizes, *Environ. Biosafety Res.* 3, 55–66.
- Légère A. (2005) Risks and consequences of gene flow from herbicide-resistant crops: canola (*Brassica napus* L.) as a case study, *Pest Manag. Sci.* 61, 292–300.
- Lheureux K., Menrad K. (2004) A decade of European field trials with genetically modified plants, *Environ. Biosafety Res.* 3, 99–107.
- Lutman P.J.W., Berry K.J., Payne R.W., Simpson E.C., Sweet J., Champion G.T., May M.J., Wightman P.S., Walker K., Lainsbury M. (2005) Persistence of seeds from crops of conventional and herbicide tolerant oil-seed rape (*Brassica napus*), *Proc. R. Soc. Lond. B* 272, 1909–1915.
- Madsen K.H., Blacklow W.M., Jensen J.E., Streibig J.C. (1999) Simulation of herbicide use in a crop rotation with transgenic herbicide-tolerant oilseed rape, *Weed Res.* 39, 95–106.
- McDonald T.L. (2003) Review of environmental monitoring methods: Survey designs, *Environ. Monit. Assess.* 85, 277–292.
- McLaughlin A., Mineau P. (1995) The impact of agricultural practices on biodiversity, *Agr. Ecosyst. Environ.* 55, 201–212.
- Mellon M., Rissler J. (1995) Transgenic crops: USDA data on small-scale tests contribute little to commercial risk assessment, *Bio/Technology* 13, (96 p.).
- Messéan A., Sausse C., Gasquez J., Darmency H. (2007) Occurrence of genetically modified oilseed rape seeds in the harvests of subsequent conventional oilseed rape over time, *Eur. J. Agron.* 27, 115–122.
- Nielsen K.M., Townsend J.P. (2004) Monitoring and modelling horizontal gene transfer, *Nat. Biotechnol.* 22, 1110–1114.
- Orians G.H., Lack P. (1992) Arable Lands, *Agr. Ecosyst. Environ.* 42, 101–124.
- Orson J. (2002) Gene stacking in herbicide tolerant oilseed rape: lessons from the North American experience, English Nature Research Reports, No. 443, English Nature, Norfolk, UK.
- Osinski E., Meier U., Büchs W., Weickel J., Matzdorf B. (2003) Application of biotic indicators for evaluation of sustainable land use-current procedures and future developments, *Agr. Ecosyst. Environ.* 98, 407–421.
- Owen M. (1999) Weed management update for the next millennium, <http://www.weeds.iastate.edu/mgmt/qtr99-1/weedupdate.htm>.
- Owen M.D.K., Zelaya I.A. (2005) Herbicide-resistant crops and weed resistance to herbicides, *Pest Manag. Sci.* 61, 301–311.
- Pacini C., Wossink A., Giesen G., Vazzana C., Huirne R. (2003) Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis, *Agr. Ecosyst. Environ.* 95, 273–288.
- Pallutt B., Hommel B. (1998) Konzept und erste Ergebnisse zur Bewertung von Glufosinat-tolerantem Raps und Mais im Rahmen einer 4-feldrigen Fruchtfolge, *Z. Pflanzenk. Pflanzen, Sonderheft* 16, 427–433.
- Pekrun C., Lane P.W., Lutman P.J.W. (2005) Modelling seedbank dynamics of volunteer oilseed rape (*Brassica napus*), *Agr. Syst.* 84, 1–20.
- Perry J.N., Rothery P., Clark S.J., Heard M.S., Hawes C. (2003) Design, analysis and statistical power of the Farm-Scale Evaluations of genetically modified herbicide-tolerant, *J. Appl. Ecol.* 40, 17–31.
- Pessel D., Lecomte J., Emeriau V., Krouti M., Messéan A., Gouyon H. (2001) Persistence of oilseed rape (*Brassica napus* L.) outside of cultivated fields, *Theor. Appl. Genet.* 102, 841–846.
- Prasifka J.R., Hellmich R.L., Dively G.P., Lewis L.C. (2005) Assessing the effects of pest management on nontarget arthropods: The influence of plot size and isolation, *Environ. Entomol.* 34, 1181–1192.
- Regal P.J. (1994) Scientific principles for ecologically based risk assessment of transgenic organisms, *Mol. Ecol.* 3, 5–13.
- Relyea R.A. (2005) The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities, *Ecol. Appl.* 15, 618–627.
- Rensing C., Newby D.T., Pepper I.L. (2002) The role of selective pressure and selfish DNA in horizontal gene transfer and soil microbial community adaptation, *Soil Biol. Biochem.* 34, 285–296.
- Richard S., Moslemi S., Sipahutar H., Benachour N., Gseralini G.-E. (2005) Differential effects of glyphosate and Roundup on human placental cells and aromatase, *Environ. Health Persp.* 113, 716–720.
- Rieger M.A., Lamond M., Preston C., Powles S.B., Roush R.T. (2002) Pollen-mediated movement of herbicide resistance between commercial canola fields, *Science* 296, 2386–2388.
- Robinson R.A., Sutherland W.J. (2002) Post-war changes in arable farming and biodiversity in Great Britain, *J. Appl. Ecol.* 39, 157–176.



- Schiemann J. (2003) Co-existence of genetically modified crops with conventional and organic farming, *Environ. Biosafety Res.* 2, 213–217.
- Schuler T.H. (2004) GM crops: Good or bad for natural enemies? in: Association of Applied Biologists (Ed.), *GM crops – ecological dimensions* 74, Wellesbourne, Warwick, pp. 81–90.
- Schütte G., Stachow U., Werner A. (2004) Agronomic and environmental aspects of the cultivation of transgenic herbicide resistant plants, UBA-Texte 11/04, Umweltbundesamt, Berlin.
- Senior I.J., Dale P.J. (2002) Herbicide-tolerant crops in agriculture: oilseed rape as a case study, *Plant Breeding* 121, 97–107.
- Service R.F. (2007) A growing threat down on the farm, *Science* 316, 1114–1117.
- Simard M.-J., Légère A., Séguin-Schwartz G., Nair H., Warwick S. (2005) Fitness of double vs. single herbicide-resistant canola, *Weed Sci.* 53, 489–498.
- Snow A.A. (2003) Consequences of gene flow, *Environ. Biosafety Res.* 2, 43–46.
- Squire G.R., Brooks D.R., Bohan D.A., Champion G.T., Daniels R.E., Houghton A.J., Hawes C., Heard M.S., Hill M.O., May M.J., Osborne J.L., Perry J.N., Roy D.B., Woiwod I.P., Firbank L.G. (2003) On the rationale and interpretation of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops, *Philos. T. Roy. Soc. B* 358, 1779–1799.
- Stein A., Ettema C. (2003) An overview of spatial sampling procedures and experimental design of spatial studies for ecosystem comparisons, *Agr. Ecosyst. Environ.* 94, 31–47.
- Strandberg B., Bruus Pedersen M., Elmegaard N. (2005) Weed and arthropod populations in conventional and genetically modified herbicide tolerant fodder beet fields, *Agr. Ecosyst. Environ.* 105, 243–253.
- Sweet J., Simpson E.C., Law J.R., Horstman A., Lutman P.J.W., Berry K.J., Payne R.W., May M.J., Champion G.T., Walker J.H., Wightman P.S., Lainsbury M.A. (2004) Bright: Botanical and rotational implications of genetically modified herbicide tolerance, in: *GM crops – ecological dimensions*, Association of Applied Biologists 74, Wellesbourne, Warwick, pp. 207–210.
- Thorbek P., Bilde T. (2004) Reduced numbers of generalist arthropod predators after crop management, *J. Appl. Ecol.* 41, 526–538.
- Van Acker R.C., Brûlé-Babel A.L., Friesen L.F. (2003) An environmental safety assessment of Roundup Ready wheat: Risks for direct seeding systems in Western Canada, <http://www.cwb.ca/en/topics/biotechnology/report/pdf/070803.pdf>.
- Watkinson A.R., Freckleton R.P., Robinson R.A., Sutherland W.J. (2000) Predictions of biodiversity response to genetically modified herbicide-tolerant crops, *Science* 289, 1554–1557.
- Werner A., Berger G., Stachow U., Glemnitz M. (2000) Abschätzung der Auswirkungen transgener Sorten auf Umweltqualitätsziele, TA project report, BATS, Basel.
- Wilkinson M.J., Davenport I.J., Charters Y.M., Jones A.E., Allainguillaume J., Butler H.T., Mason D.C., Raybould A.F. (2000) A direct regional scale estimate of transgene movement from genetically modified oil-seed rape to its wild progenitors, *Mol. Ecol.* 9, 983–991.
- Wolfenbarger L.L., Phifer P.R. (2000) The ecological risks and benefits of genetically engineered plants, *Science* 290, 2088–2093.
- Yoshimura Y., Beckie H.J., Matsuo K. (2006) Transgenic oilseed rape along transportation routes and port of Vancouver in western Canada, *Environ. Biosafety Res.* 5, 67–75.
- Züghart W., Breckling B. (2003) Konzeptionelle Entwicklung eines Monitoring von Umweltwirkungen transgener Kulturpflanzen, UBA –Texte 50/03, Umweltbundesamt, Berlin.