

RESEARCH

Open Access

Consequences of isolation distances on the allocation of GM maize fields in agricultural landscapes of Germany

Ulrich Stachow^{*}, Claudia Bethwell, Angelika Wurbs and Frieder Graef

Abstract

Background: Coexistence measures such as isolation distances aim at minimizing conflicts between genetically modified (GM) and non-GM agricultural systems. Depending on landscape structure such as field sizes, field distribution and cropping patterns, these measures may spatially restrict GM cropping. Additional restrictions on GM cropping may be caused by environmental concerns, for instance protected sites or habitats of selected species may require isolation distances. To explore possible GM cropping restrictions in German agricultural landscapes, we conducted scenario simulations with 10% and 70% GM maize cropping shares, 1,000-m isolation distances to protected sites, and 150- and 300-m isolation distances to neighboring conventional and organic maize fields, respectively. While previous simulation studies applied smaller isolation distances (40 to 50 m), our research question was whether the conservative nature of isolation distances in Germany constitutes limitations to GM maize cropping. We investigated a variety of landscapes on two spatial scales: 4 federal states and 42 rural counties.

Results: On the state scale, we found that the maximum percentage of fields planted with GM maize compared to all potentially available fields was approximately 30%, indicating no limitation to GM cropping. On the scale of counties, the relevance and variability of landscape metrics was much greater. This resulted in potential limitations to GM cropping, especially for counties with more than 40% maize share. One thousand-meter isolation distances to protected sites had only marginal effects on the area available for GM cropping.

Conclusions: Isolation distances usually disregard landscape specifics. Our results suggest that the average shares of arable areas and 1,000-m distances to protected areas do not limit the allocation of GM maize. Limitations may occur in counties with more than 40% maize.

Keywords: GM crops; Coexistence measures; Isolation distances; Field allocation; Landscape metrics; Protected areas

Background

The cultivation area of genetically modified (GM) crops on the global scale is continuously increasing. In Europe, concerns by farmers and the public, however, make the coexistence of GM and non-GM crops critical in some regions. GM material may be transported into protected sites [1] or cross-pollinate neighboring fields with non-GM varieties [2]. Both pathways may cause unwanted effects, such as contaminate non-GM harvests above tolerance threshold for GM material [3,4], or adversely affect trophic links and/or other

processes within ecological communities [5-7]. For example, the lepidopteran-active Bt-maize events may do potential environmental harm to non-target lepidopteran species of conservation concern that inhabit protected habitats. This exposure can be reduced to a level of no or minimum concern by imposing isolation distances. To minimize cross-pollination and thus secure the freedom of choice for farmers and consumers, as well as to minimize environmental risks, GM cropping in many countries is regulated by coexistence measures [2,8], including pollen barriers, flowering asynchrony and crop rotation. These measures are obligatory for GM crop farmers. The measures include minimum isolation distances between GM fields and non-GM fields [9] and, in some countries, to protected

^{*} Correspondence: ustachow@zalf.de
Leibniz Centre for Agricultural Landscape Research (ZALF), Institute of Land Use Systems, Eberswalder Str. 84, Muencheberg 15374, Germany

sites. Information on pollination distances, cross-fertilization rates, and on potential wild relatives serves as a basis for defining these isolation distances, issued by the individual EU countries. These distances vary considerably between European countries, with a minimum of 15 m to conventional maize in Sweden and a maximum of 800 m to organic maize in Hungary [8,10]. Minimum distances of GM maize fields to protected sites in Germany are regulated by individual federal states and range between 800 and 1,000 m; this is significantly more than the 30 m suggested, for instance, for the Bt-maize 1507 by the EFSA Panel on Genetically Modified Organisms (GMO) [11].

Minimum isolation distances of GM fields to non-GM and protected habitats may influence the distribution pattern of GM crop fields within agricultural landscapes [12,13]. These patterns, however, can be expected to vary between different types of landscapes. They depend on landscape characteristics such as crop species grown and their proportions, field sizes and their distribution, and the distribution patterns of protected sites. Thus, the spatial distribution patterns of GM crops, and also the maximum feasible proportion of GM crops in agricultural landscapes, are expected to be landscape specific. As more GM crops are grown, in some landscapes it may become difficult to allocate GM crop fields following such coexistence measures. Agricultural landscapes may thus exhibit different degrees of conflict potential for GM cropping. According to [3], coexistence measures and particularly minimum distances should be appropriate and consider regional and local constraints. Recent research stresses the importance of agricultural landscape characteristics on possible unwanted effects of GM crops and hence on the definition and flexibility of coexistence measures [8,13]. While large isolation distances of GM fields have been criticized for reducing GM farmers' cropping options and causing additional costs, landscape-specific scenarios regarding their impact on GM cropping potentials remain scarce [14-16]. Methods have been developed to simulate spatial GM cropping patterns and their effects on coexistence options [10,12], but they have not yet been applied to large areas with variable land use structure under simultaneous consideration of environmental concerns. Here, we selected the relatively large isolation distances applied in Germany. Our question was whether those large distances pose limitations to the available area for GM crops under four scenario assumptions (share of GM crops 10% and 70%; consideration of nature reserves or not). We also examined a wide variety of agricultural landscapes.

We explored the impacts of different minimum distances on the GM cropping potential. If the overall impact is small, there would be less need to adapt minimum

distances to regional and local specifics. We also analyzed the present agricultural land use in several German landscapes that differ in structural characteristics. In each, we simulated various GM maize shares as well as differing isolation distances to neighboring crops and protected areas.

Results and discussion

Simulated use of potentially available GM area (SUA) at the level of federal states

At this level, the SUA results of the four scenarios varied considerably but indicated a very limited use of the potentially available area for GM crops (Table 1). Even taking into account protected areas, a 1,000-m distance to protected sites and a 70% GM maize share (Sc4), only 30% of the area available for GM maize was assigned to GM fields. The protected areas (Sc1 versus Sc3, and Sc2 versus Sc4) showed a much smaller increase in the SUA compared to the increase resulting from changing the GM maize share from 10% to 70% (Sc1 versus Sc2, and Sc3 versus Sc4). At the federal state level, this indicates a comparatively low influence of the share and allocation of protected areas on the simulation outcome.

Effect of maize share, field size and share of protected sites at the county level

At this level, we found a much higher variability in maize shares, field sizes and share of protected sites compared to the level of federal states (data not shown). As expected, these three parameters are related to each other, with the most significant correlation ($p < 0.001$) for the maize share with the share of protected areas ($r = -0.25$) and for the maize share with the average size of arable areas ($r = -0.22$). Hence, larger maize areas tend to be associated with the lower shares of protected areas and, interestingly, with smaller arable area sizes.

Simulated use of potentially available GM area at the county level

We expected that larger average sizes of arable areas would lower the SUA, but the two are not correlated ($p > 0.05$). Clearly, a high number of smaller arable areas can compensate the SUA of few large arable areas. Thus, from a methodological point of view and based on our datasets, it was irrelevant whether the geometries of arable fields precisely represent the real cultivation situation of a specific crop or whether the geometries are taken from topographic databases such as ATKIS with coarser geometries. We therefore can apply the ATKIS geometries with sufficient certainty with regard to the SUA results.

As expected [16], present maize cultivation shares are strongly correlated ($p < 0.001$) with the SUA in all

Table 1 Simulated use of potentially available GM area for four GM maize cultivation scenarios in federal states

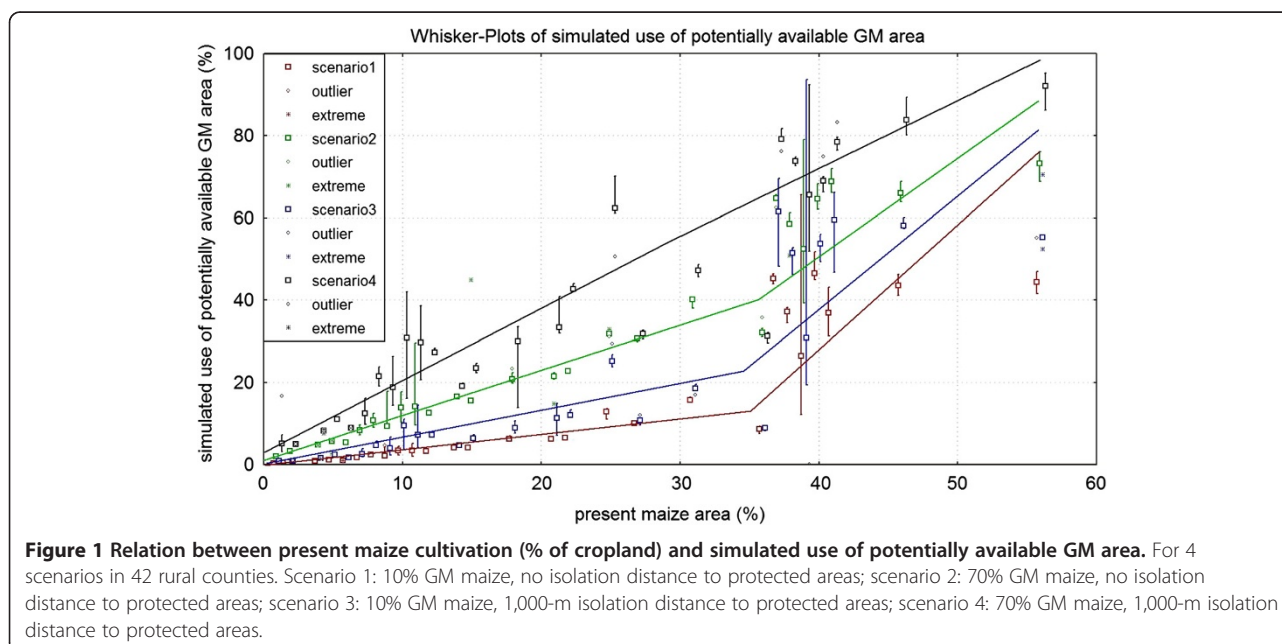
Federal state	Sc1	Sc2	Sc3	Sc4
	(10% GM, no isolation distance to protected areas)	(70% GM, no isolation distance to protected areas)	(10% GM, 1,000 m isolation distance to protected areas)	(70% GM, 1,000 m isolation distance to protected areas)
BY	5.29	19.65	8.52	30.37
NI	5.16	18.41	6.94	29.14
RP	1.01	5.63	1.78	9.64
SN	2.56	11.20	5.89	24.37

BY, Bavaria; NI, Lower Saxony; RP, Rhineland-Palatinate; SN, Saxony.

four scenarios (Sc1 $r = 0.86$; Sc2 $r = 0.95$; Sc3 $r = 0.85$; Sc4 $r = 0.90$). The higher the share of maize, the more difficult it is to allocate GM maize areas without violating the minimum distance rules. This is indicated by the slope of the regression curve, which becomes steeper with higher maize shares (Figure 1). In all scenarios, a relatively linear relation was evident up to a maize share of approximately 40%. Above this value, the variability of the SUA results among single counties clearly increased, and in some cases for Sc4, the SUA was very high (>90%). This indicates, for some counties, significant conflict potential between GM cropping and the requirements for isolation distances. We assume that the increasing variability above 40% maize reflects the higher spatial dispersion of simulated non-GM fields in some counties when excluding GM cropping to fields below 1,000-m distance from protected areas. Here, the area of overlapping buffers becomes crucial for GM maize field allocation. The variation

might be even larger on the local scale. This will be the subject of further analysis in relation to landscape structure. Border effects on the county scale were excluded by including the adjacent areas into the scenario calculations. At the scale of federal states, we consider the border effect to be negligible.

Higher shares of protected sites with 1,000-m isolation distance were expected to increase the SUA. In contrast, we found significant negative correlations for scenario 3 ($r = -0.29$; $p < 0.001$) and scenario 4 ($r = -0.17$; $p < 0.03$). Figure 2 illustrates the large SUA variability in most counties. We explain this unexpected relation and the large variability by (a) the high shares of protected sites associated with low maize cultivation shares ($r = -0.25$, $p < 0.001$), (b) the varying clustering of protected areas [16], and the strong relation between SUA and agricultural area (Figure 1). Hence, in landscapes with variable shares of protected sites and maize acreages, the SUA levels become increasingly



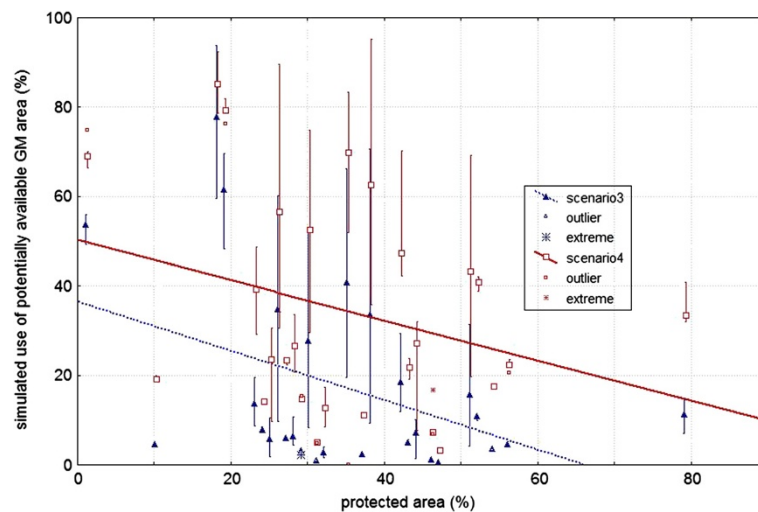


Figure 2 Relation between protected sites (% land coverage) and simulated use of potentially available GM area. For two scenarios (3 and 4) in 42 rural counties. Scenario 3: 10% GM maize, 1,000-m isolation distance to protected areas; scenario 4: 70% GM maize, 1,000-m isolation distance to protected areas.

unpredictable but can be simulated using our approach. Although the p values are statistically significant, some are quite low. We suggest exploring and integrating additional landscape metrics into the coexistence simulation studies. As expected based on Table 1, both the average and SD of SUA results at the county level varied largely between federal states (data not shown). Under the given scenarios, these differences are hardly relevant as long as the SUA remains below 100%, because this indicates that minimum isolation distance rules can be obeyed. Nonetheless, if counties or federal states strongly increase their GM maize area shares, and possibly in the case of more than one cultivated GM crop, the conflict potential is expected to increase. This would require a more differentiated examination of the respective agricultural landscapes.

Are region-specific minimum isolation distances necessary?

While too short distances may not guarantee safe coexistence, too large distances may inappropriately restrict GM cropping. Minimum distances can be adapted to specific landscapes and characteristics such as crop distribution patterns, field size distributions and microclimate [8]. Nonetheless, this is possibly irrelevant, for instance, if too large distances do not limit the GM crop share. A study [2] has shown that the spatial distribution of GM crop fields is important in order to comply with minimum distance rules: a clumped distribution of GM crop fields appeared helpful in this regard, whereas random distributions increasingly entailed coexistence

violations as the share of GM crops increased. We assume our approach to be more realistic because it enables the farmers to choose the scale of individual farms aiming to grow GM crops. This choice refers to the potential allocation of additional GM crop fields in respect to the distribution of present non-GM crop fields in the area. Based on this precondition, the minimum distances between GM fields and non-GM fields (150, 300 m), and even 1,000 m to protected sites, did not restrict the allocation of the targeted share of GM crops in the 42 counties and GM-share scenarios analyzed.

Conclusions

Coexistence rules, especially in minimum isolation distances, are designed to minimize conflicts due to transport of GM crop material into neighboring habitats, non-GMO fields and/or protected areas. Appropriate minimum distances should consider regional conditions. Nonetheless, although the states and counties of Germany vary in the average size of arable areas, the share of protected sites and the share of maize, we found only a marginal effect of the minimum distance to protected sites (1,000 m) on the GM area available for cultivation. Hence, the available area for GM maize cultivation is not limited by minimum distances even if 70% of the maize grown is GM. Some regions with higher shares of maize, however, exhibit increased conflict potential because the available areas for GM maize are almost completely needed for the shares of GM maize. Although large and fixed isolation distances usually disregard landscape specifics, our results for

Table 2 Key characteristics of selected federal states and counties

Federal state/county	Size (in 1,000 km ²)	Percentage of arable land (%)	Share of maize (%)	Average size of arable areas (ha) ^b	Protected areas with 1,000-m isolation buffer (% of total area)
Bavaria (BY)	70.6	33	20.5	12.1 ± 13.3	37.3
Lower Saxony (NI)	47.6	40	22.5	7.8 ± 8.6	35.5
Rhineland-Palatinate (RP)	19.8	22	7.3	3.8 ± 3.6	51.5
Saxony (SN)	18.4	40	10.6	14.2 ± 20.3	51.1
Forty-two counties average ^a	1.0 ± 0.5	40 ± 15	20.6 ± 14.3	11.7 ± 5.3	39.8 ± 13.9

^aBY: 16 counties; NI: 12; RP: 5 and SN: 9; ^bATKIS units.

Germany suggest that the average shares of arable areas are not relevant and that buffering of protected areas (1,000 m) does not limit the allocation of GM maize. Only above an overall 40% maize share can the available area for GM not suffice if 70% of the maize is GM.

Methods

We selected 4 federal states and 42 counties, all located within these states, to represent German landscapes varying in key structural characteristics (Table 2), namely maize cultivation share (3% to 58%) and average arable area sizes (3.5 to 23.0 ha). The four federal states (Bavaria, Lower Saxony, Rhineland Palatinate, Saxony) represent about 44% of the total area of Germany. We used statistical information on maize cultivation shares and organic farming [17]. We extracted the geometries of arable fields from the digital national topographic-cartographic information system [18], and included all sites protected by the Habitats Directive 92/43/EEC and all national nature conservation areas [19-22]. Based on the German regulations, we provided all these protected sites and nature conservation areas with a buffer of 1,000 m. This led to area shares among counties ranging from 6.5% to 84.8%.

We used the minimum isolation distances of 150 m to non-GM maize fields and 300 m to organic maize fields, as valid throughout Germany, and varied (a) scenarios of different GM maize shares (10% and 70% of the total maize area of each county) and (b) scenarios without versus with a 1,000-m buffer distance between protected areas and GM maize fields. This yielded four scenarios (Table 1). We selected the 10% and 70% GM maize shares based on our own pre-analysis and on the findings of [8], which revealed a nearly linear relationship between the share of GM crops and the likelihood of a randomly selected field to lie within the isolation perimeters. We applied these scenarios by simulating the maize field distribution using ArcGIS 9.2. The following analytical steps were taken: from the cropping statistics of every municipality (the smallest administrative unit

in Germany; average size 18.56 km²), the maize acreage was taken, and the assumed proportion of non-GM maize (90% and 30%) was randomly distributed to the arable fields (tolerance level 5%) in each scenario run. These non-GM maize fields were buffered, yielding the arable land available for GM maize. In scenarios 3 and 4 (Table 1), protected areas were additionally provided with a 1,000-m isolation buffer. The total available area for GM maize was then related to the area required for GM-maize cultivation, corresponding to 10% and 70% of the total maize acreage of the municipality. Each scenario was repeated five times. The relation between the area actually used by GM maize and the area available for GM maize for each scenario was termed 'SUA', the 'simulated use of potentially available GM area'. It is a landscape-specific indicator of conflict potential for co-existence and environmental concerns related to GM material transport across the landscape: as SUA approaches 100%, the allocation of GM maize becomes difficult or impossible. A SUA well below 100% indicates a multitude of options for distributing GM maize fields across the landscape.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

US and FG drafted and wrote the manuscript, CB conducted the GIS analyses and scenario calculations, AW helped to design the scenarios. All authors read and approved the final manuscript.

Acknowledgements

Sigrid Ehler assisted the GIS analyses, Michael Stachowitsch helped to improve the English language. We also like to thank two anonymous reviewers who helped significantly to improve the manuscript. This project was funded by the German Federal Ministry of Education and Research (FKZ 07VPS14A). US and AW were additionally funded by the German Federal Ministry of Consumer Protection, Food and Agriculture and the Ministry of Agriculture, Environmental Protection and Regional Planning of the Federal State of Brandenburg (Germany).

Received: 19 September 2012 Accepted: 1 August 2013
 Published: 16 August 2013

References

1. Commission E: **Directive 2001/18/EC of the European Parliament and of the Council.** *Official J European Comm* 2001, **L106**:1–38.
2. Devos Y, Reheul D, De Schrijver A: **The co-existence between transgenic and non-transgenic maize in the European Union: a focus on pollen flow and cross-fertilization.** *Environ Biosafety Res* 2005, **4**:71–87.
3. Commission E: **Commission Recommendation of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming.** *Official J European Comm* 2003, **L189**:36–47.
4. Messéan A, Saussee C, Gasquez J, Darmency H: **Occurrence of genetically modified oilseed rape seeds in the harvest of subsequent oilseed rape over time.** *Europ J Agronomy* 2005, **27**:115–122.
5. Heard MS, Hawes C, Champion GT, Clark SJ, Firbank LG, Haughton AJ, Parish AM, Perry JN, Rothery P, Roy BA, Scott RJ, Skellern MP, Squire GR, Hill MO: **Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops. II. Effects on individual species.** *Phil Trans R Soc B* 2003, **358**:1833–1846.
6. Wilkinson MJ, Davenport IJ, Charters YM, Jones AE, Allainguillaume J, Butler HT, Mason DC, Raybould AF: **A direct regional scale estimate of transgene movement from genetically modified oil-seed rape to its wild progenitors.** *Mol Ecol* 2000, **9**:983–991.
7. Bartsch D, Cuguen J, Biancardi E, Sweet J: **Environmental implications of gene flow from sugar beet to wild beet - current status and future research needs.** *Environ Biosafety Res* 2003, **2**:105–115.
8. Devos Y, Demont M, Dillen K, Reheul D, Kaiser M, Sanvido O: **Coexistence of genetically modified (GM) and non-GM crops in the European Union. A review.** *Agron Sustain Dev* 2009, **29**:11–30.
9. Sanvido O, Widmer F, Winzeler M, Streit B, Szerencsits E, Bigler F: **Definition and feasibility of isolation distances for transgenic maize.** *Transgenic Res* 2008, **17**:317–355.
10. Devos Y, Cougnon M, Thas O, Reheul D: **A method to search for optimal field allocations of transgenic maize in the context of co-existence.** *Environ Biosafety Res* 2008, **7**:97–104.
11. EFSA: **Scientific opinion supplementing the conclusions of the environmental risk assessment and risk management recommendations on the genetically modified insect resistant maize 1507 for cultivation.** *EFSA Journal* 2012, **10**(11):2934.
12. Wurbs A, Bethwell C, Stachow U: **Assessment of regional capabilities for agricultural coexistence with genetically modified maize.** *Environ Sci Eur* 2012, **24**(Art. 17):1–14.
13. Graef F, Schütte G, Winkel B, Teichmann H, Mertens M: **Scale implications for environmental risk assessment and monitoring of the cultivation of genetically modified herbicide-resistant sugar beet: a review.** *Living Rev Landscape Res* 2010, **4**. <http://landscaperesearch.livingreviews.org/Articles/lrlr-2010-3/>.
14. Devos Y, Reheul D, Thas O, De Clercq EM, Cougnon M, Cordemans K: **Implementing isolation perimeters around genetically modified maize fields.** *Agron Sustain Dev* 2007, **27**:155–165.
15. Devos Y, Thas O, De Clercq EM, Cougnon M, Cordemans K, Reheul D: **Feasibility of isolation perimeters for genetically modified maize.** *Agron Sustain Dev* 2008, **28**:195–206.
16. Perry JN: **Sensitive dependencies and separation distances for genetically modified herbicide-tolerant crops.** *Proc R Soc Lond B* 2002, **269**:1173–1176.
17. Statistische Ämter des Bundes und der Länder: **Regionaldatenbank Deutschland, Genesis.** 2009 [<https://www.regionalstatistik.de/genesis/online/logon>]
18. Vermessungsverwaltungen der Länder und das Bundesamt für Kartographie und Geodäsie: **ATKIS, Basis-DLM (Digitales Landschaftsmodell).** Frankfurt am Main; 2008.
19. Bayerisches Landesamt für Umwelt: **Schutzgebietsdaten/Ökoflächen aus dem Bayerischen Fachinformationssystem Naturschutz (FIS-Natur).** 2009 [<http://www.lfu.bayern.de>]
20. Ministerium für Umwelt, Forsten und Verbraucherschutz Rheinland-Pfalz: **LANIS (Landschaftsinformationssystem der Naturschutzverwaltung Rheinland-Pfalz).** 2010 [<http://www.naturschutz.rlp.de>]
21. Niedersächsisches Ministerium für Umwelt und Klimaschutz: ; 2009 [<http://www.umwelt.niedersachsen.de>]
22. Sächsisches Landesamt für Umwelt und Geologie: 2009 [<http://www.umwelt.sachsen.de>]

doi:10.1186/2190-4715-25-24

Cite this article as: Stachow et al.: Consequences of isolation distances on the allocation of GM maize fields in agricultural landscapes of Germany. *Environmental Sciences Europe* 2013 **25**:24.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Immediate publication on acceptance
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com