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New case studies on the coexistence of GM and non-GM crops in European agriculture

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Foreword

On 2003, the European Commission's Joint Research Centre (JRC) agreed with several Commission services (Directorates-General for Agriculture, Health and Consumer Protection, Environment and Legal Service) to undertake new case studies on the agronomic and economic issues of coexistence between genetically modified (GM) crops and non-GM crops in European agriculture.

The studies were designed and coordinated by Manuel Gómez-Barbero, Karine Lheureux (currently at EFSA, Parma) and Emilio Rodríguez-Cerezo, from the SAFH Unit of the Institute for Prospective Technological Studies (IPTS) of the JRC. A consortium was formed within the European Science and Technology Observatory (ESTO) framework. This report synthesises the results obtained from six working packages carried out by the following institutions and individuals:

- *Coexistence of Genetically Modified and Non Genetically Modified Beet Crops in France and Germany: the Case of Tolerance to a Non-Selective Herbicide*

  Institut National de la Recherche Agronomique (INRA), Eco-innov Unit, Grignon, France
  Mathilde Sester, Frédérique Angevin, Cécile Choimet and Antoine Messéan

- *Coexistence of Genetically Modified and Non Genetically Modified Maize Crops in France*

  Institut National de la Recherche Agronomique (INRA), Eco-innov Unit, Grignon, France
  Arnaud Gauffreteau, Frédérique Angevin, Cécile Choimet and Antoine Messéan

- *Coexistence of Genetically Modified and Non Genetically Modified Cotton Crops in Andalusia (Spain)*

  Empresa Pública de Desarrollo Agrario y Pesquero (DAP) - Foresight Unit, Cordoba, Spain
  Francisco Cáceres Clavero, Encarnación Serrano Jaén, José Carlos Cruz Gómez, Miguel Ángel Méndez Rodriguez, Trinidad Manrique Gordillo and Blanca Lucena Cobos

- *Effect of the Quality of Sown Rape Seed Lots and of the Genotype of GM Varieties on Harvest Adventitious Presence in the case of Coexisting GM, Non-GM and Organic Crops*

  Institut National de la Recherche Agronomique (INRA), Dijon and Grignon, France
  Nathalie Colbach, Frédérique Angevin and Antoine Messéan

- *Economic Assessment of Coexistence Schemes and Measures*

  University of Applied Sciences of Weihenstephan, Science Centre Straubing, Germany
  Klaus Menrad and Daniela Reitmeier

- *Review of Models*

  Institut National de la Recherche Agronomique (INRA), Arche Unit, Toulouse, France
  Vianney Houlès and Daniel Wallach

JRC-IPTS is grateful for the contribution of the AGRIFISH unit of the JRC Institute for Protection and Security of the Citizen (IPSC), that provided digitalised versions of agricultural landscapes for case studies.

Seville, January 2006

Per Sorup
Head of Sustainability in Agriculture,
Food and Health Unit (SAFH Unit)

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Executive summary and conclusions

- This report analyses the need and feasibility of changes in agricultural practices to ensure coexistence between GM and non-GM crop production in the EU. The term coexistence refers to the ability of farmers to choose between conventional, organic or GM-based crop production, in compliance with the relevant EU legislation on labelling and/or purity standards. EU regulations have introduced a 0.9% labelling threshold for the adventitious presence of GM material in non-GM products. Since agriculture does not take place in a closed environment, suitable technical and organisational measures during cultivation, harvest, transport and storage may be necessary to ensure coexistence. Coexistence measures should make it possible for farmers growing non-GM crops to keep the adventitious presence of GM material in their harvest below the labelling thresholds established by Community law.
- A previous set of case studies published by an JRC/IPTS-ESTO consortium[1] concluded in 2002 that the need for coexistence measures in the EU was not general, and depended on the agricultural landscape (size, form and relative positions of GM and non-GM plots), farm typologies and the crops considered (maize, oilseed and potato were studied). This report focused on the feasibility of coexistence measures designed to be taken by non-GM crop farmers if they wished to avoid adventitious GM presence above labelling thresholds, and the possible economic consequences of having to label their crops as GM. In 2002, there were still no coexistence guidelines or decrees issued by Member States, so GM crop farmers were under no obligation to take any measure to avoid adventitious presence in non-GM crops.
- On 23 July 2003, the European Commission adopted Recommendation 2003/556/EC on guidelines for coexistence, reaffirming that measures for coexistence should be developed by the Member States. The guidelines specify that those farmers who introduce the new production type in a region should bear responsibility for implementing the farm management measures necessary to limit gene flow. Following these guidelines, measures currently being discussed by Member States are designed to be taken by GM crop farmers. Furthermore, since seeds may be a source of adventitious GM presence in agriculture, the European Commission initiated discussions on setting specific thresholds for the adventitious presence of GM seeds in conventional seeds, lower than those allowed in the final crops (0.9%). Therefore, seed production might have to operate under different coexistence requirements than crop production. These discussions are still ongoing.

Objectives

- Taking into account these developments, a new consortium JRC/IPTS-ESTO was formed in 2003[2] with the task of analysing new case studies on how GM and non-GM production systems can coexist in the same region with the probability of adventitious admixture

1 Scenarios for coexistence of genetically modified, conventional and organic crops in European agriculture. (2002) DG-JRC-IPTS-ESTO Technical Report EUR 20394 EN. Members of this consortium were IPTS, INRA (France); NIAB (UK); CEST (UK); Fraunhofer ISI (Germany); ADAS Consulting Ltd (UK).

2 Members of this consortium were JRC-IPTS, Empresa Pública Desarrollo Agrario y Pesquero-DAP (Spain), University of Applied Sciences of Weihenstephan and Fraunhofer-ISI (Germany), and INRA (France).

minimised by adapting farming practices, if necessary. The specific objectives are to:

- Identify agronomic measures for coexistence that could be implemented by GM crop farmers and study their techno-economic feasibility.
- Introduce the landscape scale for estimating gene flow and levels of adventitious presence of GM crops in non-GM crops. Also, simulate in real agricultural landscapes the efficacy and feasibility of coexistence measures.
- Identify and evaluate specific measures needed to meet the thresholds being discussed for seed production. Also, describe how different levels of initial seed purity affect the final level of adventitious presence in the crops produced.
- Study the effects of long time periods on the level of adventitious presence of GM crops. This is relevant for crops producing seeds with a long life and dormancy period, which can build banks of GM seeds in the soil.

Case studies: scope and methodological approach

- The case studies selected are seed and crop production of maize, sugar beet and cotton (plus oilseed rape for the analysis of coexistence over time) in defined EU regions. Maize is the only major GM crop authorised for cultivation in the EU and is thus a priority for coexistence research. The other crops are among the list of GM varieties in the development/authorisation pipeline[3]. The scope of the studies is agricultural production up to the farm gate.
- The report considers two scenarios for the presence of GM crops in the landscape (10% and 50% share of GM varieties in the respective crop) and different target thresholds for the level of adventitious GM presence: 0.1% and 0.9% for crop production and 0.1%, 0.3% and 0.5% for seed production.
- For each case study, the report (i) identifies key sources of adventitious GM presence in non-GM crops, (ii) estimates the levels of adventitious presence (expressed as the percentage of seeds, grains or roots harvested that are GM) with current and adapted farming practices, (iii) proposes adapted agronomic practices and technical measures to reduce adventitious presence to desired thresholds and (iv) evaluates the techno-economic feasibility of such proposals.
- To estimate the levels of adventitious GM presence and the effect of changes in farming practices, a combination of expert opinion and gene flow models are used. These models can operate at landscape level, and take into account agricultural practices, climate and crop rotations.
- The report describes in specific appendixes the status of validation of these models with field data, a process that is on-going. In addition to the prediction of adventitious presence levels, the ability to simulate, compare and rank specific coexistence measures according to their efficiency is what makes models a unique tool for the purpose of these case studies.

Coexistence in maize crop production

- Maize is a major crop in the EU. Grain maize is grown for its dry seed, which is processed into a range of animal and human foods. France is the leading EU grower of grain maize (nearly 2 million hectares), and GM maize is the only GM crop grown commercially in the EU (mainly in Spain, where 58 000 hectares were grown in 2004). The region of Poitou-Charentes accounts for 12% of maize production in France and is selected as a case study because of the potential adoption of GM maize varieties (for controlling weeds and/or corn borer infestations) and the availability of a digitised dataset on the maize field landscape.

Key sources of adventitious presence and measures to reduce it

- Three key sources of adventitious presence are identified for maize crops: traces of GM seeds in non-GM seed lots, cross-pollination from neighbouring GM fields, and the sharing of harvesting machinery between GM and non-GM fields. For current GM maize varieties, simulations using the MAPOD® model show that the contribution of initial seed impurities to final adventitious GM presence is roughly additive. Different levels of GM traces in seeds (ranging from 0.01% to 0.5%) are considered in the report for quantifying the final adventitious GM presence in the crop. Based on expert opinion and a literature review, it is estimated that the contribution of harvesting machinery ranges from 0% (dedicated harvesters) to 0.4% (shared harvesters and lack of cleaning practices).
- The contribution of cross-pollination and the strategies to reduce it are first tested by performing simulations with MAPOD® in a simple one-field to one-field design. Simulations show that two variables related to the agricultural landscape (the relative position of GM and non-GM fields with respect to dominant winds and the relative sizes of neighbouring GM and non-GM fields) have a major effect. Since these parameters are difficult to change, the impact of three measures targeting GM crop growers in order to reduce gene flow is simulated. The most robust strategy is the introduction of isolation distances between GM and non-GM fields. Sowing a non-GM maize buffer strip around GM fields is also effective. Lastly, using GM varieties with different flowering dates compared with non-GM varieties is highly effective but is too dependent on meteorological conditions and hampered by associated yield losses[4].
- A decision table is provided in the report to determine the isolation distances necessary to keep adventitious GM presence due to gene flow below a desired threshold, for different field sizes and wind orientations. The decision table also shows how isolation distances can be reduced when combined with non-GM buffer strips of different widths and/or with flowering time lags. By adding the contributions from seed impurities and harvester sharing, the table offers a decision tool for selecting coexistence measures in maize.

Feasibility of coexistence at landscape level

- The one-field to one-field simulations show the importance of considering actual agricultural landscapes when estimating gene flow. A digitised version of the 23 000 ha maize landscape[5] of Poitou-Charentes, including the spatial distribution of maize fields, areas, perimeters and owners, is used as the input to the MAPOD® model. Estimations of adventitious presence levels due to cross-pollination are then carried out in actual maize field landscapes. Simulations with MAPOD® are also used to test the regional impact of selected coexistence measures (found to be efficient in the previous section). Adding the contributions due to seed impurity and shared harvesters allows the feasibility of coexistence to be studied at regional level. This is expressed in the report as the share of maize area in the region able to comply with a target coexistence threshold.

3 "Review of GMOs under research and development and in the pipeline in Europe" (2003) DG JRC-IPTS-ESTO Technical Report. European Commission (EUR 20680 EN).

4 A potentially effective measure is the use of different sowing dates for GM and non-GM varieties, which will result in different flowering dates. While this is rather difficult in the region studied, due to the narrow window of suitable weather conditions for sowing, it may be a measure worth considering in other maize regions, particularly further south.

5 The geographic information system (GIS)-based dataset was kindly provided by the Joint Research Centre - Institute for Protection and Security of the Citizen (JRC-IPSC).

- A first analysis of the landscape shows that maize fields are clustered (grouped around water supply points). These clusters vary in area and number of farmers owning one or more fields within a cluster. Farmers may decide to cultivate only one type of maize in each cluster, which reduces the analysis to coexistence between different clusters. However, there will be cases where farmers do not agree and will grow GM and non-GM maize fields in the same cluster, making it necessary to analyse intra-cluster coexistence.
- Coexistence between clusters is fairly easy. Levels of adventitious presence below the 0.9% target can be achieved simply by cleaning shared harvesters, whatever the proportion of GM maize in the landscape (10% or 50%). Coexistence between clusters may be feasible for thresholds lower than 0.9%, but then there is a need to introduce additional measures.
- Intra-cluster coexistence is also possible at regional level. In fact, if shared harvesters are cleaned, the majority of the maize area (85%-90%) would comply with a 0.9% threshold. The remaining area corresponds to fields particularly affected by cross-pollination (e.g. a small non-GM field downwind of GM fields). Achieving 100% compliance of the regional maize area for a 0.9% threshold is possible, but requires additional measures. Simulation results offer numerous solutions, from single measures (isolation distance) to combinations of reduced distances and buffer strips. Ensuring coexistence intra-cluster coexistence at 0.1% would not be technically feasible.
- Reducing the maximum adventitious presence of GM seeds in initial seed lots[6] would allow less strict coexistence measures to be adopted at crop level (e.g. reduction of mandatory isolation distances). However this entails the introduction of new coexistence measures and costs for maize seed production (see seed section below).

Economic consequences of coexistence measures

- A particular feature of mandatory isolation distances is that they do not affect all farmers equally, because the distribution of maize fields is not random. Farmers whose neighbouring fields lie beyond the isolation distance will not face economic constraints in deciding whether or not to plant GM varieties and will experience no economic impact at farm level. Using an actual maize landscape, the report studies what proportion of fields and farms would be affected in Poitou-Charentes by different isolation distances. It therefore offers a tool for reducing isolation distances to values that are effective but minimally disruptive (for example in combination with other measures).
- Farmers intending to use GM varieties but with neighbouring non-GM maize fields within the isolation distance will be constrained in their choice. Consensus expert opinion is that farmers will manage these fields by sowing non-GM maize. The economic consequences would then be related to the opportunity cost of not growing GM maize. At farm level, this cost amounts to the difference in economic performance between the GM and non-GM maize varieties[7]. At regional level, the economic effects will depend on the landscape area affected. Other aggregated economic consequences of a reduced use of GM crop varieties at regional level would need further study.

6 In the simulations, seed impurities ranged from 0% to a maximum of 0.5%.

7 No data on economic performance is available for the region studied since GM maize is not yet grown, and no ex-ante studies have been performed. Ongoing JRC studies are assessing the economic performance of GM and non-GM maize in Spain, the only EU country where there is significant cultivation.

- The economic consequences for GM farmers of introducing mandatory non-GM buffer strips again are related to the opportunity cost of not growing GM maize. At farm level, the impact on gross margins will depend on several factors, including the width of the strip and the size of the field (impacts will be higher for farmers with smaller fields, who will be more likely to opt out GM varieties if buffers strips are mandatory).
- The effectiveness of cleaning harvesters between GM and non-GM fields for coexistence is clear. A cost of €50-60 per cleaning operation is estimated. This can be reduced by organising the harvest of GM and non-GM varieties in different periods to reduce cleaning operations.

Coexistence in maize seed production

- France is the leading maize seed producer in Europe and 50% of seed production is concentrated in the South-West (used as a case study). Maize varieties are hybrids and therefore seed production plots are set up with separate rows of male lines and female lines. Such a production scheme is much more sensitive to cross-pollination from neighbouring fields than maize crop production. Seed production is carried out through contracts between seed companies and farmers under strict statutory measures (including isolation distances) to ensure purity and quality. This often includes organising groups of fields dedicated to seed production in clusters.
- Different thresholds for the presence of GM seeds in maize seeds are being discussed. The current production regime requires the complete absence of seeds other than maize, but has no specific thresholds for varietal purity (the presence of other maize varieties). However, seed operators have for years visually recorded impurities due to cross-pollination. In seeds produced in recent years, visually recorded outcrosses have fallen to an average ~0.3%, although a significant proportion of lots (30-40%) still exceeds this level.
- For maize seed production, cross-pollination is considered the only source of adventitious GM presence. The contribution of basic seeds and machinery use is considered nil in current production regimes. Since maize seed fields and crop fields are quite different in their pollen production and sensitivity to cross-pollination, two situations must be considered: coexistence between GM and non-GM seed fields (seed-seed coexistence) and coexistence between non-GM seed production and neighbouring GM crop production (seed-crop coexistence).

Seed-seed coexistence

- Seed production is organised in clusters of plots. Ensuring coexistence between GM and non-GM maize seed production plots would not require significant changes in current production techniques for a threshold of 0.5%, other than having GM and non-GM plots of similar sizes. For a 0.3% threshold, additional measures need to be taken. A decision table based on MAPOD® simulations is included to present the efficiency of different strategies. For example, arranging GM and non-GM seed plots to ensure optimum orientation with respect to the dominant wind direction or, if not feasible, increasing the current isolation distance are efficient measures. This is technically feasible since such arrangements could be specified in the contracts between the farmers involved in the same seed production cluster and the seed companies. A 0.1% threshold is not obtainable in practice under these conditions.
- The economic consequences of additional measures for GM seed farmers are variable (depending on relative field sizes and the precise combination of measures), but may exceed 20% of the gross margin, assuming

companies pay to farmers the same prices for GM and non-GM seeds. It would then be unattractive to produce GM maize seed, unless isolated clusters of suitable fields are found.

Seed-crop coexistence

- Ensuring coexistence between GM maize crop fields and non-GM seed production is difficult to achieve even for a 0.5% threshold. Among the potential measures targeting GM crop growers, increasing isolation distances is technically the most efficient. Implementing these distances (in the range of 400-600 m) would lead in practice to the exclusion of GM crop maize production from the vicinity of areas with significant seed production. The most likely alternative for farmers would be to grow non-GM crop maize, where the analysis of economic consequences is then similar to that developed above for crop coexistence and isolation distances.

Coexistence in sugar beet production

- Sugar beet is cultivated for its root and harvested before flowering. Bolting (premature flowering) and cross-pollination in sugar beet production could result in the presence of GM weed beets in non-GM fields, but not in the admixture of GM and non-GM sugar beet roots in the harvest. The only significant source of adventitious presence of GM sugar beet roots in the harvest of non-GM fields is the initial presence of GM seeds in seed lots. Where the adventitious GM presence in non-GM seeds remains below the set threshold, there is no need for specific coexistence measures for sugar beet crop production.
- Sugar beet seed production is strictly regulated and carried out under contracts with seed companies. Farmers must comply with measures to minimise gene flow between beet forms. Under the current "inter-professional agreement" in France, an overall varietal impurity of 0.2% is acceptable, with a maximum of 0.1% annual beet and 0.1% red and fodder beet. For lots with a higher varietal impurity, acceptance depends on case-by-case negotiation. Compliance with these existing rules should be sufficient to limit adventitious GM presence in non-GM seed production to a 0.5% threshold.
- Additional measures have been recommended to ensure that such levels are maintained in the long term and even reduced. Depending on the target threshold (0.1%, 0.3% or 0.5%), additional costs would range from 6-14% of the gross margin.
- For the case of herbicide-tolerant sugar beets, the report evaluates the efficacy of measures designed to successfully manage the appearance of herbicide tolerant GM weed beet. The appearance of GM weed beet in neighbouring fields does not translate in adventitious presence of GM in the final crop (roots), and therefore is not a coexistence issue *sensu stricto*, but an agronomic problem that can cause conflict between farmers.

Coexistence in cotton production

- Cotton is the most important non-food crop world-wide and cultivation of GM varieties is widespread. No GM variety is yet authorised for cultivation in the EU but several are in the regulatory pipeline. The agricultural area devoted to cotton in the EU is small but the crop is economically very important for some regions. The case study looks at Andalusia (southern Spain), with over 80 000 ha of cotton fields. Cotton is mostly autogamous and cross-pollination is negligible.
- Provided the adventitious GM seed presence in non-GM seeds remains below 0.5%, practices based on cleaning machinery are

enough to keep the adventitious GM presence below 0.9% for cotton crop production.

- To comply with a threshold of 0.5% adventitious GM presence in cotton seed production, no additional measures are required beyond those already in place for certified cotton seed production, so no extra costs have to be calculated. The report presents a set of stricter practices for achieving lower thresholds in seed and crop production and estimates the additional costs involved.

Effect of seed purity and long time periods on adventitious GM presence in oilseed rape

- Coexistence measures for oilseed rape crops were addressed in a previous study. Two issues are covered in this report: 1) the impact of different initial seed purity levels on final adventitious presence and 2) the effect of long time periods (over 50 years) on adventitious GM presence. This is relevant because oilseed rape has seeds that persist in the soil for long periods.
- The GeneSys-rape model is used for simulating adventitious presence in a number of farm types. The contribution of initial seed impurities to final adventitious GM presence is roughly additive for all types of farm. Cross-pollination and seed persistence in the soil remain the main source of adventitious GM presence. Only for very large fields (where the effect of cross-pollination is diluted) is seed impurity the main source of adventitious presence. Assuring seed purity is therefore not enough to achieve coexistence in oilseed rape and specific measures need to be evaluated.
- GeneSys-rape simulations show that, after the introduction of GM varieties in a region, the rates of adventitious presence will not increase significantly after the second rotation of oilseed rape (simulations up to 50 years). A significant exception is that of farms not buying certified seed but using farm-saved seeds, which led to a continuous increase in adventitious presence over time.

General conclusions

- On the basis of the model simulations and expert opinions gathered in this report, for the case studies covered (maize, sugar beet, cotton), coexistence in seed production is technically feasible for a threshold of 0.5%, with few or no changes in current practices. For maize, this holds true for coexistence between non-GM and GM seed production. However, coexistence of non-GM maize seed production with GM maize crops would need changes in current practices, namely introduction of larger isolation distances (from the current 200-300 m distances to 400-600 m).
- If GM presence in seeds does not exceed 0.5%, coexistence in crop production is technically feasible for the target threshold of 0.9%. For maize, additional measures are needed for some specific situations defined by climatic, landscape and agronomic parameters. The report evaluates measures found to be technically simple and effective. These measures, targeting GM maize growers, have variable farm-level economic consequences that will affect the farmer's decision whether or not to grow GM maize varieties.
- The report illustrates the power of novel gene flow models that actually take into account the spatial patterns of landscapes and agricultural practices. It is now possible to estimate levels of adventitious GM presence in non-GM production resulting from multiple fields and sources, over extended time periods, propose numerous coexistence measures and quickly test their feasibility and consequences at regional level. The information obtained from model

simulations, such as the decision tables presented in this report, is valuable for helping decision-makers set up coexistence strategies. Models simulations are not a substitute for field experiments, but a way of overcoming the limitations (time scale, spatial coverage, costs) inherent to field work.

Introduction

The new European Union legal framework aims at tightening up the assessment of genetically modified organisms (GMOs), ensuring the traceability of products and clearly informing consumers through labelling (Regulations (EC) No. 1829/2003[8] and No. 1830/2003[9]). It also aims at allowing the coexistence of various kinds of production and supply chains by ensuring that "farmers should be able to cultivate freely the agricultural crops they choose, be it GM crops, conventional or organic crops" (Recommendation 2003/556/EC). From an overall perspective, coexistence entails the ability of farmers to make practical choices between production systems, in compliance with legal obligations for labelling and/or purity standards.

Since April 2004, the EU system to trace and label GMOs and to label products derived from GMOs has been put in place. The regulations set a threshold no higher than 0.9% for the adventitious presence of GM material in non-GM food-feed products (Regulation (EC) 1829/2003). In July 2003 the European Commission adopted Commission Recommendation 2003/556/EC on general coexistence guidelines and in order to assist Member States to set up national strategies and best practices to ensure the coexistence of GM crops with conventional and organic farming.

In the specific case of seed production, the regulation of adventitious presence of GM seeds in conventional seed lots is done in the context of Directive 2001/18/EC as well as under the crop specific Directives on the marketing of seeds. However, thresholds for the adventitious presence of GM seeds in conventional seeds have not yet been set and are still under discussion.

Rationale for this coexistence study

In 2000, the Institute for Prospective Technological Studies (IPTS) of the European Commission's Joint Research Centre (JRC) initiated a prospective study requested by the Directorate General Agriculture on the agronomic and economic aspects of coexistence of GM and non-GM crops at European level (Bock *et al*, 2002), focusing on three case studies: oilseed rape for seed production (including one case of crop production), grain maize for feed production, and potato for food production. This first study concluded that the problem of coexistence must be addressed on a farm-crop-specific basis.

The rationale for a follow-up to this first DG JRC/IPTS Coexistence study was as follows.

- The Coexistence study, completed in 2002, assumed that all costs were borne by non-GM farmers. However, the guidelines on coexistence published by the Commission in July 2003 (Recommendation 2003/556/EC) propose that the farmers who introduce the new production type should bear responsibility for implementing the farm management measures necessary to limit gene flow. Therefore, in this study, any additional measures needed and the estimated costs are allocated to GM crop growers. This assumption is in line with the practice in those Member States which have adopted or proposed coexistence legislation so far.
- A detailed analysis of coexistence for seed production, in particular for maize, was needed to supplement the 2002 JRC/IPTS Coexistence study which focused on maize grain for feed production.

8 REGULATION (EC) No 1829/2003 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 September 2003 on genetically modified food and feed.

9 REGULATION (EC) No 1830/2003 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 September 2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC.

- For maize grain production, the previous Coexistence Study was based on a 0.3% threshold for adventitious presence. Alternative initial levels of seed impurities had to be considered as well.
- The JRC/IPTS prospective study "Review of GMOs under research and development and in the pipeline in Europe" (Lheureux *et al*, 2003) gives a list of GM products in the pipeline which could potentially come onto the market over the next five years after. New case studies were needed on coexistence for upcoming GM crops, such as cotton and sugar beet.
- The JRC/IPTS Coexistence study was based on both models and expert opinions. More information on the validation of models was required.

Objectives

The objective of this project was to analyse new case studies on how different production systems (GMO, conventional and organic) can coexist in the same region through decreasing the potential level of adventitious presence by adapting farming practices. Seed and crop production of maize, sugar beet and cotton were considered.

The project analysed (i) the sources of adventitious GM presence in conventional crops, (ii) the levels of admixture estimated with current and additional farming practices and (iii) the economic costs of adapting farming practices.

Different levels of initial seed purity were considered in order to estimate their effect on the final level of adventitious presence in the crops produced.

The project reviewed the existing models of gene flow and provided information on the level of validation of these models, in particular for the two models used in the DG JRC/IPTS Coexistence Study, namely MAPOD® and GeneSys® (Appendix 6).

Scope

The project considered two scenarios for the presence of GMOs in the landscape (10% and 50% share of GMOs in the relevant crop), three agricultural production systems (GMO-based, conventional and organic) as well as different levels for adventitious GM presence: 0.1% and 0.9% for crop production and 0.1%, 0.3% and 0.5% for seed production.

However, the results can also be interpreted with other thresholds (whether lower or higher than those mentioned here).

Throughout this report adventitious presence is expressed as the percentage of GM seeds, GM grains or GM roots in non-GM production. Comparison of these results with those obtained with DNA-based methods should be interpreted case by case (see section I. 4 for more details on maize).

The "Review of GMOs under research and development and in the pipeline in Europe" (Lheureux *et al*, 2003) showed that GM maize, GM sugar beet and GM cotton are among the potential candidates for cultivation in the EU.

The most probable traits to be used are herbicide tolerance and insect resistance for maize and cotton and herbicide tolerance in the case of sugar beet.

General methodology

The general objective of this project is to analyse how the different farming systems can coexist in the EU while reducing the possible risk of admixture by adapting current agricultural practices and to assess the economic implications of such changes. For each of the three crops considered, the following steps were carried out:

1. Description of crop and seed production, farming systems, and rules and regulations in major production regions;
2. Identification of sources and estimation of levels of adventitious GM presence in non-GM crops with current practices;

3. Proposals for adapting agricultural practices to coexistence scenarios and estimation of the levels of adventitious admixture with these adapted agricultural practices;

For steps 2 and 3, the same approach as in the previous JRC/IPTS Coexistence study (Bock *et al*, 2002) was followed to estimate the levels of adventitious GM presence in non-GM crops:

- for cotton (seed and fibre) and for beet seed production, an expert approach was used,
- for maize (seed and grain) and root beet production, gene flow models designed at landscape level were used: MAPOD®-maize (Angevin *et al*., 2001) and GeneSys®-beet (Sester, 2004) are spatially explicit and take into account crop rotations as well as agricultural practices.

In the latter case, numerous simulations were carried out to assess the variability of real situations in response to climate, cropping systems and rate of adoption of GM varieties. Several adjustments to agricultural techniques were evaluated in order to establish a panel of practices (or combinations of practices) bringing about a reduction in the adventitious GM presence in harvests.

Simulation results were analysed taking into account results of validation processes (Colbach *et al*, 2005; Angevin & Gauffreteau, 2005).

4. Estimation of the economic effects of changing practices.

With respect to the economic effects of changing practices, the economic performance of the different crops was investigated by reviewing literature, collecting publicly available statistical information and searching databases, as well as contacting and interviewing experts. The costs of coexistence measures for the different crops, farm types and regions were calculated using publicly available data sources of costs of agronomic practices. When calculating the costs of coexistence measures, labour costs as well as opportunity costs of an alternative land use have been taken into account. If necessary, available data were modified according to the situation of the particular farm type and region. Finally, the aggregated effects of combined measures have been calculated. It was necessary to use model assumptions (e. g. square fields) for calculating the gross margin losses for farmers of some coexistence measures (e. g. isolation distances).

In addition to the above tasks, the effect of seed purity on the evolution over time of adventitious GM presence in non-GM oilseed rape production was also evaluated in order to build on the previous Coexistence study (Bock *et al,* 2002).

I. Maize

I.1. Biology

Maize is an open pollinating crop (only about 5% self-pollination; Purseglove, 1972) and predominantly wind-pollinated. Male and female flowers are separated on the plant, and most of the varieties currently used display protandry (i.e. male flowering begins before female flowering) (Struik & Makonnen, 1992; Emberlin *et al*, 1999). Pollen is spread from plant to plant through physical contact between neighbouring plants and by wind. Most of the pollen released remains within a few metres of the emitting plant, and the quantity of pollen dispersed diminishes with distance (Raynor *et al*, 1972). The distance between emitting and receiving fields, their shapes (Lavigne *et al*, 1996; Klein *et al*, 2005), synchronisation of flowering (Du Plessis & Dijkhuis, 1967; Hall *et al.*, 1981, Boyat *et al.*, 1984, Bassetti & Westgate, 1994), and climatic conditions (Lonnquist & Jugenheimer, 1943) are major factors explaining cross-pollination rates. However, up to now, it is difficult to quantify the small amount of pollen disseminated to far away points through convective fluxes and its role in long-distance pollination (Emberlin, *ibid.*, Brunet *et al*, 2003; Aylor *et al.*, 2003).

Single seeds or ears remain on the ground after harvesting, and germination has been observed. However, under the most common European conditions (ploughing in the majority of the cropping systems, including maize, and cold winter climate) volunteers are rare and easily controlled by agricultural techniques.

Out-crossing to wild relatives is not an issue for maize as no wild relatives (e.g. teosinte) are established in Europe (Ellstrand *et al*, 1999).

Maize landraces are still cultivated in various parts of Europe and are often linked to specific adaptations to particular farming systems and environments (Rebourg *et al.*, 2003). The presence of transgenic DNA in traditional landraces is still under investigation (Quist & Chapela, 2001, Christou, 2002 - for a contradiction -, Ortiz-Garcia *et al*, 2005).

Seed purity is critical as seeds can be a source of adventitious GM presence in agriculture and industry. Most of the maize varieties cultivated in the EU are hybrids. Seeds are produced in fields where the amount of pollen emitted is low in comparison with the amount emitted by crop production fields. There are two explanations for this difference: first, the number of male flowers in seed production fields is lower (tassels of the female lines are cut) and, second, the amount of pollen produced by tassels of the male parent "line" is at least four times lower than the amount produced by tassels of hybrid varieties. Seed production is therefore highly susceptible to cross-pollination from neighbouring crop production fields.

I.2. Background

Maize is a major crop in the EU and is used in several different ways. For forage maize, the entire plant is harvested before seed ripening and fed either directly or in the form of silage to livestock. Grain maize is grown for its dry seed, which is processed into a range of animal and human foods. Current levels of grain maize production in Europe are detailed in Table 1. There is also a significant area under forage maize in some countries (more than 1 000 000 ha in France, for example).

Sweet corn is harvested before the cobs have had a chance to ripen so that the seeds still contain mobilised sugars; the grains are consumed whole.

Table 1: Grain maize production in EU (ha)

Country	1997	2002
European Union (15)	***4 357 251***	***4 320 600***
Austria	188 311	200 000
Belgium-Luxembourg	6 405	40 000
France	1 858 000	1 808 000
Germany	369 600	395 000
Greece	210 645	210 000
Italy	1 039 229	1 060 000
Netherlands	12 700	22 000
Portugal	185 914	132 000
Spain	486 447	453 600

Source: Fraunhofer ISI company survey 2004

Under the EU legislation, several GM traits are authorised for crop cultivation, e.g. Mon 810, Bt 176. T25 (However, no maize varieties are registered for this trait). However, Spain is the only EU country growing a significant area with GM crops: 58 000 hectares in 2004, representing 12% of the total crop production area (James, 2004). Less than 1 000 ha were sown with Mon 810 in Germany in 2004; 492.8 ha were registered to authorities in France in 2005[10].

I.3. Methodology

The main steps in the maize production process are illustrated in Figure 1.

After estimation of the relative role of each critical point in the final level of adventitious presence, the following assumptions were made:

- in the case of crop production, seed impurities and GM presence due to machinery were taken into account by adding them to the main source of admixture which is cross-pollination;
- in the case of seed production, the contribution of basic seed and machinery use to adventitious presence is considered nil since drastic production rules have already been introduced to ensure seed lot purity. Among other measures, seed producers must carefully clean all machinery involved in seed production processes, remove off-type plants during field inspections and maintain very large isolation distances around parental seed production fields. Thus, only pollination was considered to contribute to admixture.

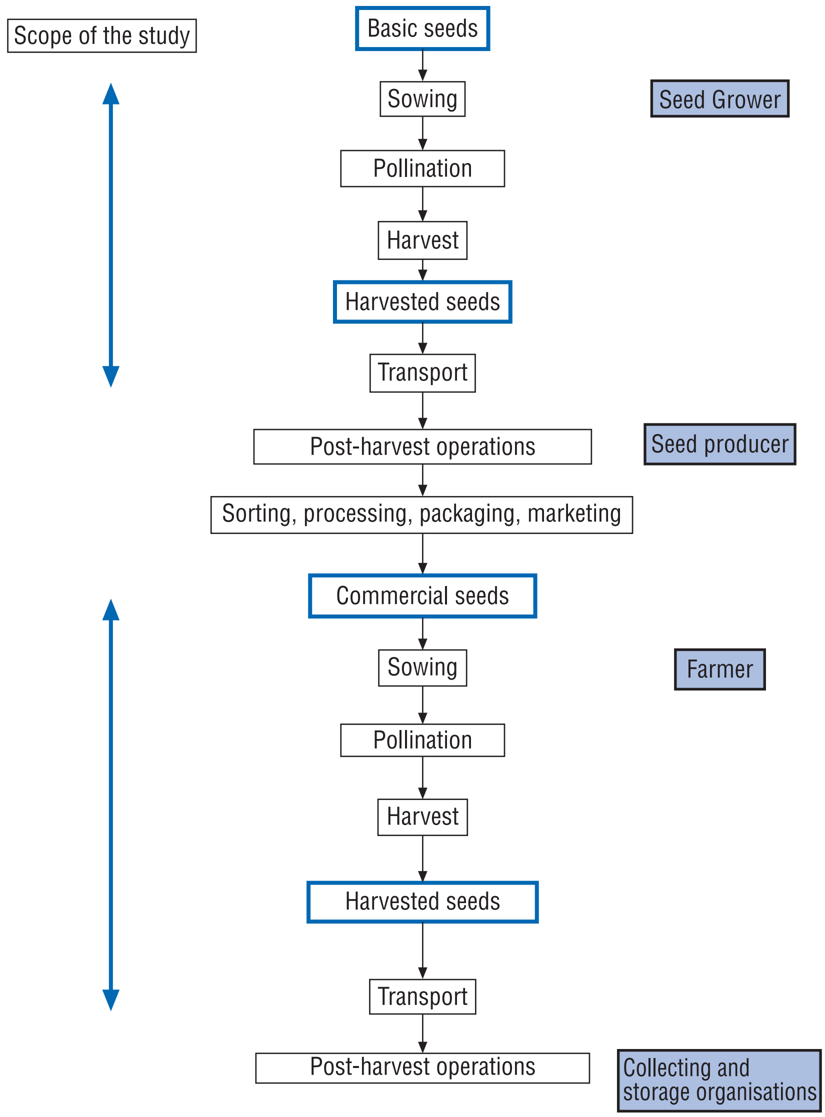
In both cases, the MAPOD® gene flow model (Angevin *et al*, 2001) was used to estimate adventitious presence due to cross-pollination. This model was developed during a study which objectives were to assess the economic relevance and technical feasibility of non-GM supply chains in France (Le Bail & Meynard, 2001). On-going research programs are dealing with the validation of the model (See Appendix 1 for details). A specific study was carried out to review the existing gene flow models (See also Appendix 6) and their state of validation. One of the main interests of MAPOD® is to be spatially explicit, i. e. to take into account several sources in an agricultural landscape rather than a single emitter and a single receptor. This is more representative of potential coexistence contexts. Furthermore, the effects of some agricultural practices are simulated by this model allowing to test some changes in practices.

Simulations were run on landscapes representative of two French regions: the *département*[11] of "Pyrénées-Atlantiques" in south-west France for seed production and the "Poitou-Charentes" region in western France for crop production (see § 1. 5.4, insets 1 and 2, Appendix 2).

The feasibility of coexistence between GM and non-GM systems was evaluated assuming a 10% and 50% share of GM maize varieties in the maize-growing area plus compliance with the following levels for adventitious GM presence:

10 Source :French Ministry of Agriculture.
11 French administrative district.

Figure 1: Review of the maize supply chain – scope of the study



- 0.1%, 0.3% and 0.5% for seed production;
- 0.1% and 0.9% for crop production.

For all cases, heterozygous GM maize was taken into consideration (although other genetic structures can be addressed in the same way). Indeed, actual Bt maize varieties are heterozygous[12], which means that only one copy of transgene is present and that half of the pollen grains produced by the GM plant would bear the transgene. It should be noticed the results could differ in the case of stacked genes that could be inherited separately from each other.

I. 4 Effect of genetic structure

Throughout this study, adventitious GM presence rates were evaluated as the percentage of harvested grains carrying the transgene. This way of quantification is not directly equivalent to the result obtained from DNA-based quantification of the adventitious GM presence (using PCR13 methodology).

In GMO quantification using PCR-based methods, the GM proportion in a given substrate is estimated by calculating the transgenic genome copy number in the total maize genome copy

12 Source: GEVES, French group for seed and variety study.
13 PCR: Polymerase Chain Reaction.

number. Thus, two PCR reactions are carried out, one amplifying the transgene to determine the number of copies of it, the other amplifying an endogenous gene in maize to determine the total number of genome copies of maize in the sample.

Maize kernels used for PCR analysis are made up, mainly, of a tegument, an embryo and an endosperm. The DNA origins of those tissues are different. Endosperm cells are triploid and result from the fusion of two maternal polar nuclei with one sperm nucleus. Embryo cells are diploid and result from the fusion of one haploid maternal nucleus and one haploid male nucleus. Finally, teguments are diploid and wholly of maternal origin. Trifa and Zhang showed in 2004 that the proportion of these elements depends on the variety. Generally, tegument DNA can be ignored as it accounts for not more than 3.5% of the total DNA. Endosperm and embryo DNA ratios were broadly similar and, in this study, ranged from 36.27% to 59.41% for the endosperm and from 38.56% to 59.55% for the embryo.

In addition to the genetic structure of the GM variety (homozygous, heterozygous, stacked), it is therefore important to know the DNA content ratio of the different tissues in relation to the total DNA content in order to be able to express the relation between the results given by the model (% of seeds) and by the PCR method.

By way of example, consider the situation where a maize silk from a non-GM female plant is pollinated by a pollen grain carrying one copy of a transgene. Under these conditions, half of the embryo's DNA and one third of the endosperm's DNA would be GM.

Assuming that the harvested grain presents the following relative DNA content ratio of tissues:

- Embryo = 48% of DNA,
- Endosperm = 49% of DNA,
- Tegument = 3% of DNA,

the percentage of DNA bearing the transgene in the grain is: 48%*(1/2)+49%*(1/3)+3%*0 = 40.3%.

In the case of heterozygous GM maize, the adventitious GM presence rates expressed as percentage of seeds as evaluated by the model should therefore be multiplied by 0.403 to obtain the genetic quantification that would be obtained by PCR methods.

For more complex genetic structures, such as stacked genes, case-by-case studies should be performed to relate the percentage of GM seeds to the DNA quantification by PCR.

I. 5. Crop production

I.5.1. The three sources of adventitious presence taken into account in the estimates

Among the many potential sources of adventitious presence, three main critical points were considered:

1. presence of GM seeds in non-GM certified seed lots; four levels were considered[14];
2. cross-pollination due to pollen flow between fields; the effect of the diversity of landscapes and of practices was assessed through intensive simulations;
3. admixture due to harvesting machinery; different situations were taken into account (see Insets 1& 2).

I.5.2. Adjustments to farming practices

Simulations with MAPOD® were carried out to evaluate the impact of current practices as well as the feasibility of alternative practices. Different strategies were tested:

- **Spatial isolation**: Farmers in the region studied had to maintain an isolation distance between GM and non-GM crops.

14 0.01% (detection threshold), 0.1%, 0.3% and 0.5%.

Increasing isolation distances is an effective way of decreasing adventitious presence by cross-pollination. However, the feasibility of this measure must be studied case by case, depending on plot characteristics (area, perimeter, etc.) and the agricultural landscape surrounding the farm.

- **Time isolation:** Separating flowering times is one option proposed to maize seed producers in France (GNIS[15], 2003). This can be achieved by providing a choice of varieties, some flowering earlier than others. It is easier to fulfil this requirement by choice of variety than by sowing on different dates. Climate, in particular, could affect this practice, limiting the days available for sowing or synchronising flowering time (periods of high or low temperature). Nevertheless, this delay in sowing is easier to implement in Southern Europe.

- **Characteristics of GM and non-GM fields**: The form and spatial distribution of GM and non-GM fields are determined at the time of sowing. Some flexibility is possible at this stage or at harvest, as the farmer can choose to harvest only part of the non-GM plot or to sow some non-GM maize in the GM field.

  - Non-GM buffer zone: the coexistence guidelines published by the Commission in July 2003 (Recommendation 2003/556/EC) specify that the farmers who introduce the new production type should bear responsibility for implementing the farm management measures necessary to limit gene flow**.** Sowing an area of non-GM maize all around the GM field could be an interesting strategy for limiting or diluting gene flow from the GM field to the non-GM field. Farmers can consider this area as a refuge, limiting the development of resistance[16].

  - Discard width: The discard width of a non-GM field is an area of variable size around the edge of the field that is not included in the final harvest. The use of discard widths involves separately harvesting the margins and the central part of the field. These separate harvestings and discarding of the part of the non-GM plot closest to the neighbouring GM plot are likely to reduce the adventitious presence in the main body of the field. The effect of this strategy was tested even though it is to be implemented by non-GM crop farmers. It provides a basis for comparison with the measures considered in the previous JRC-IPTS Coexistence Study (Bock *et al.*, 2002).

The feasibility of discard widths and non-GM buffer zones should be considered in the light of the costs of these practices. The harvests from the discard width and the non-GM buffer zones are sold as GM grain. Consequently, the costs of these practices depend on the difference in selling price between GM and non-GM maize.

Current research on the floral physiology of maize (e.g. to induce cytoplasmic male sterility or apomixis) could markedly reduce the out-crossing potential of maize. The potential impact of such new varieties was tested, taking into account the fact that they produce less pollen, to determine the adjustments to be made to the requirements for coexistence.

I. 5. 3. Simulation scales

Two complementary studies were implemented: one on field scale, the other on landscape scale. The first type of study allows conclusions to be drawn on the absolute efficiency of each change in practices. The second type provides a means of testing the feasibility of

15 GNIS: Groupement National Interprofessionnel des Semences (National interprofessional association for seeds and plants).
16 Case of insect-resistant maize.

these changes by taking into account actual field patterns (plot size and shape; dispersed/clustered fields, etc).

France is the leading maize producer in Europe (EUR 15). The Poitou-Charentes region has been chosen for a case study for several reasons:

- *The area under grain maize*. Poitou-Charentes is the third largest grain maize producing region. It accounts for about 11% of the area under maize in France (11.2% in 2000, 10.9% in 2002) and about 12% of French grain maize production, depending on the year.
- *The potential for adoption of GM varieties in this region*. GM maize varieties are an alternative for farmers with problems controlling weeds (particularly since the banning of atrazin in France) or pests.
- In particular, Poitou-Charentes is a region susceptible to European and Mediterranean corn borer infestations. Farmers in this region could therefore opt for GM maize as a means of combating these pests. In 1998 Poitou-Charentes was one of the regions growing the first Bt[17]-varieties registered in France.

The landscape patterns of the four sub-regions studied are shown in the maps in Appendix 2 (Courtesy of the Institute for the Protection and Security of the Citizen, Joint Research Centre).

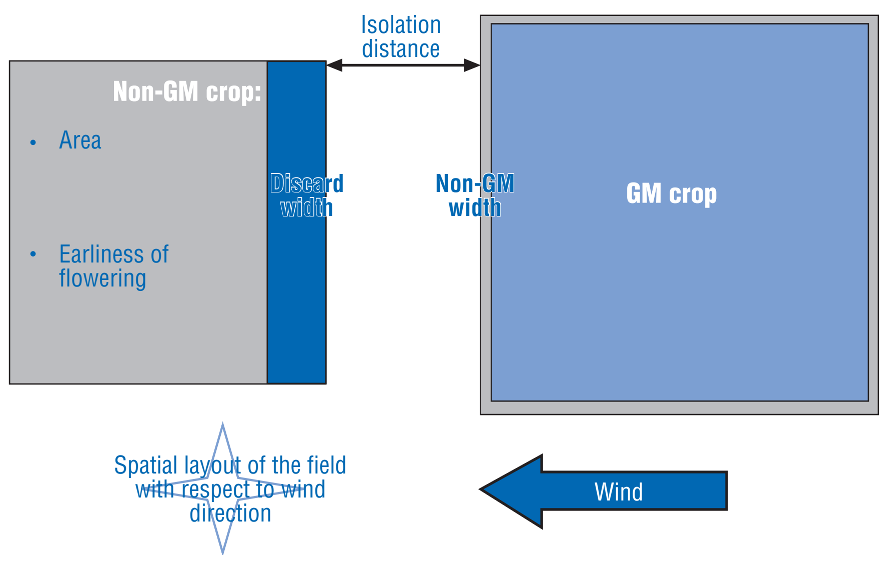
I.5.4. Field scale study

I.5.4.1 Methodology

The first study used one GM and one non-GM field for precise assessment of the impact of the various strategies on cross-pollination and rank them according to their efficiency.

A simple field-to-field situation was considered (Figure 2). The simulations were based on the meteorological conditions prevailing in Poitou-Charentes and different field characteristics to allow accurate definition of the conditions required to achieve adventitious presence below the 0.9% or 0.1 % thresholds.

Figure 2: Experimental plan for the field scale study with MAPOD®



NB: The factors tested during simulations are shown in blue.

17 Bt: Bacillus thurigiensis. This bacteria produces toxin crystals that are lethal for Lepidopteran larvae. Bt genetically modified organisms (maize, cotton, etc.) carry the gene producing the toxin.

In the study region (Poitou –Charentes), 95% of the fields have an area lower than 15 ha and 65% have an area lower than 5 ha. In the study we considered a 15 ha GM field (worst case scenario) and several cases for the non-GM field area: 3 ha, 5 ha, 7.5 ha, 10, 12.5 ha and 15 ha.

I.5.4.2. Results

For each combination of factors considered (field layout with respect to wind, relative field sizes, flowering time-lag, non-GM buffer zone, and isolation distance) the adventitious GM presence in the non-GM harvest due to cross pollination was estimated using the MAPOD® model. The whole dataset was then analysed[18] and the results are summarized in the decision tables below. For the various combinations of factors considered, Tables 2 and 3 indicate if set thresholds can be achieved, and if not, what additional distances should be implemented to meet them.

For all simulations reported in those tables, adventitious GM presence due to certified seeds and machinery was not taken into consideration. Nevertheless, Tables 2 and 3 could be used as well for decision-making[19] introducing GM impurities in seed lots or due to machinery. In this case, first the percentage of adventitious GM presence due to seed and machinery has to be estimated to find out the maximum level of adventitious presence that could be afforded due to cross-pollination. To keep within a threshold of 0.9% of GM seeds, if the adventitious GM presence in seeds were 0.3% and admixture due to machinery were 0.1%, measures would have to be considered to keep the adventitious presence due to cross-pollination below 0.5%.

Simulation results indicate that wind is the major factor for maize cross-pollination. Time-lag flowering is the second factor while isolation distances and non-GM buffer zones have more or less the same impact. The decision-making tables were structured by considering the degrees of freedom of farmers on these factors:

- first of all, determine the situations farmers cannot easily modify: wind parameters which are independent of agricultural practices, relative sizes of fields which will determine the GM/non-GM pollen ratio;
- then, depending on the targeted cross-pollination rate, estimate if additional measures are requested;
- finally, choose the combination of agricultural practices (time-lag flowering between GM and non-GM varieties, non-GM buffer zones and isolation distances) by taken into consideration their technical feasibility and their costs.

To illustrate how to use Tables 2 and 3, let us consider some situations:

- Considering wind parameters of Poitou-Charentes), Table 2 indicates that no specific measure has to be taken by farmers to achieve a cross-pollination rate between 0.5% and 0.9% if GM fields are located strictly downwind of non-GM fields, whatever the relative field sizes (Table 2).
- If this is not the case, additional measures are to be considered, for example a 20 m isolation distance will be enough to keep the GM level of non-GM fields with an area > 5 ha below 0.9% (Table 3).
- For other situations, various combinations of measures can be chosen by farmers to achieve specific cross-pollination rates. For example, considering a 15 ha GM plot upwind of a 4 ha non-GM field and assuming that the seeds are pure, an isolation distance of 50 m would be sufficient to meet a 0.9% threshold even if the varieties are synchronous (no flowering time-lag). Alternatively, a 20 m isolation distance combined with sowing an 18 m

18 Taking into account validation results for interpretation.
19 In the case of heterozygoty for the transgene (most common situation now), x% of GM seeds in a non-GM seed lot would contribute to around x% of the final adventitious presence in the product harvested.

non-GM buffer zone would be effective. If no isolation distance is possible (adjacent fields), a 60 degree-days (° day) time lag in flowering would be necessary (Table 3).

To illustrate how to use Table 2 or Table 3 while taking into consideration other sources of admixture (seed and machinery), let us consider the following case. If the percentage of GM impurities in seeds were 0.3% and the potential impact of machinery 0.1%, a 100 m isolation distance or a 50 m isolation distance and an 18 m non-GM buffer zone around the GM field, or a 60 degree-days time lag in flowering would keep the GM presence below 0.9% for the worst case scenario of non-GM fields located downwind of GM fields.

Although these tables were elaborated from a conventional field scale study (one pollen source, one pollen recipient), it provides decision-makers with a first tool to carry out a preliminary diagnosis about the feasibility of coexistence in various situations. Of course, due to inter-regional variability (climatic conditions, sizes of fields), the figures may change from one region to another. Nevertheless, a sensitivity analysis was performed and suggested that the rationale for such a diagnosis would be applicable in other situations. Moreover, performing new simulations with specific regional parameters would be easy to carry out.

In order to refine the diagnosis at the regional level and to increase the precision of cross-pollination rates for individual fields, it should be considered that various GM fields could contribute to the cross-pollination which therefore has to be estimated by taking into account the actual spatial pattern of fields over landscape. This is the purpose of the next section.

I.5.5 Landscape study

I.5.5.1 Methodology

In the second part of the study, actual landscape situations were considered in order to take into account that GM fields would be distributed over space and represent several sources of GM pollen. Such realistic situations were not considered in former coexistence studies. Moreover, this landscape approach covers a great diversity of field sizes and shapes.

Simulations were run on four actual landscape situations in the Poitou-Charentes region (2001 spatial distribution). These situations are described in Insets 1, 2 and 3 and Appendix 2. Three types of farms were considered (see Insets 1 & 2). All three use the same maize cultivation techniques but differ in the way they use and manage machinery.

From the analysis of maize field distribution over landscape, it came out that fields were not randomly distributed but rather clustered due to various reasons (soil constraints, irrigation strategy). Therefore, two cases were analysed separately (Figure 3):

- In the first case, farmers owning fields in a given cluster decide amongst themselves whether or not to grow GM maize on all the fields in the cluster. This cluster isolation strategy requires collaboration between farmers if it is to be efficient. The degree of collaboration depends on the number of farmers owning fields in the cluster and how used they are to working together. In this case, only inter-cluster coexistence (coexistence between clusters) was considered.
- In the second case, one or more farmers in a single cluster decide independently to introduce GM maize on some of their fields. This go-it-alone strategy leads to the coexistence of GM and non-GM maize within a single cluster. In this case, it is important to differentiate adventitious presence due to inter-cluster coexistence from that due to intra-cluster coexistence (coexistence of GM and non-GM fields within the same cluster).

Four field patterns were chosen to run simulations (see Appendix 2). For each situation, the fields sown with GM maize were selected taking into account the spatial organisation of the landscape, the type of coexistence to be tested and the presence of GMOs in the landscape.

Table 2: Decision table for determining isolation distances (m) necessary to keep adventitious GM presence rates due to cross-pollination below a defined threshold for a 15 ha GM maize[20]. The non-GM field is situated upwind of the GM one. See also Figure 2.

<table>
<tr><th rowspan="2">Non-GM field area</th><th rowspan="2">Flowering time-lag</th><th rowspan="2">Non-GM width</th><th colspan="11">Cross-pollination rates</th></tr>
<tr><th>0.9%</th><th>0.8%</th><th>0.7%</th><th>0.6%</th><th>0.5%</th><th>0.4%</th><th>0.3%</th><th>0.2%</th><th>0.1%</th><th>0.05%</th><th>0.01%</th></tr>
<tr><td rowspan="16"><5 ha</td><td rowspan="4">0°day</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td>20</td><td rowspan="2">20</td><td>50</td><td rowspan="4">100</td><td rowspan="4">300</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">20</td></tr>
<tr><td>12 m</td><td rowspan="2">0</td></tr>
<tr><td>18 m</td></tr>
<tr><td rowspan="4">30°days</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td rowspan="2">20</td><td rowspan="3">50</td><td rowspan="4">200</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td></tr>
<tr><td>12 m</td><td rowspan="2">0</td></tr>
<tr><td>18 m</td><td>20</td></tr>
<tr><td rowspan="4">60°days</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td>20</td><td rowspan="4">100</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td><td rowspan="3">0</td></tr>
<tr><td>12 m</td></tr>
<tr><td>18 m</td></tr>
<tr><td rowspan="4">90°days</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td></tr>
<tr><td>12 m</td></tr>
<tr><td>18 m</td></tr>
<tr><td rowspan="16">5 ha < x < 10 ha</td><td rowspan="4">0°day</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td>20</td><td rowspan="3">20</td><td>100</td><td rowspan="4">300</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">50</td></tr>
<tr><td>12 m</td></tr>
<tr><td>18 m</td><td>0</td></tr>
<tr><td rowspan="4">30°days</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td rowspan="3">20</td><td>200</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td><td rowspan="3">150</td></tr>
<tr><td>12 m</td></tr>
<tr><td>18 m</td><td>0</td></tr>
<tr><td rowspan="4">60°days</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td>100</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td><td rowspan="3">50</td></tr>
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<tr><td>9 m</td><td rowspan="3">0</td></tr>
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<tr><td>18 m</td></tr>
<tr><td rowspan="16">> 10 ha</td><td rowspan="4">0°day</td><td>0 m</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td rowspan="4">0</td><td>20</td><td>20</td><td>50</td><td rowspan="4">200</td></tr>
<tr><td>9 m</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">20</td></tr>
<tr><td>12 m</td></tr>
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<tr><td>9 m</td><td rowspan="3">0</td></tr>
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</table>

NB: Flowering time lags are expressed in growing degree-days (° days). ° days are calculated by taking the sum of the averages of the daily high and low temperature each day compared to a baseline (6°C for maize in France). For instance, in the studied cases, a day during flowering period represents on average 15 growing degree days. Values on coloured background are isolation distances in meters.

20 With a heterozygous GM maize variety.

Table 3: Decision table for determining isolation distances (m) necessary to keep adventitious GM presence rates due to cross-pollination below a defined threshold for a 15 ha GM maize[21] field. The non-GM field is situated downwind of the GM one. See also Figure 2.

<table>
<tr><th rowspan="2">Non-GM field area</th><th rowspan="2">Flowering time-lag</th><th rowspan="2">Non-GM width</th><th colspan="11">Cross-pollination rates</th></tr>
<tr><th>0.9%</th><th>0.8%</th><th>0.7%</th><th>0.6%</th><th>0.5%</th><th>0.4%</th><th>0.3%</th><th>0.2%</th><th>0.1%</th><th>0.05%</th><th>0.01%</th></tr>
<tr><td rowspan="16">< 5 ha</td><td rowspan="4">0°day</td><td>0 m</td><td rowspan="2">50</td><td rowspan="3">50</td><td rowspan="4">50</td><td>100</td><td rowspan="3">100</td><td rowspan="4">100</td><td rowspan="3">150</td><td rowspan="3">200</td><td rowspan="4">300</td><td rowspan="4">X</td><td rowspan="4">X</td></tr>
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<tr><td>9 m</td><td rowspan="3">100</td></tr>
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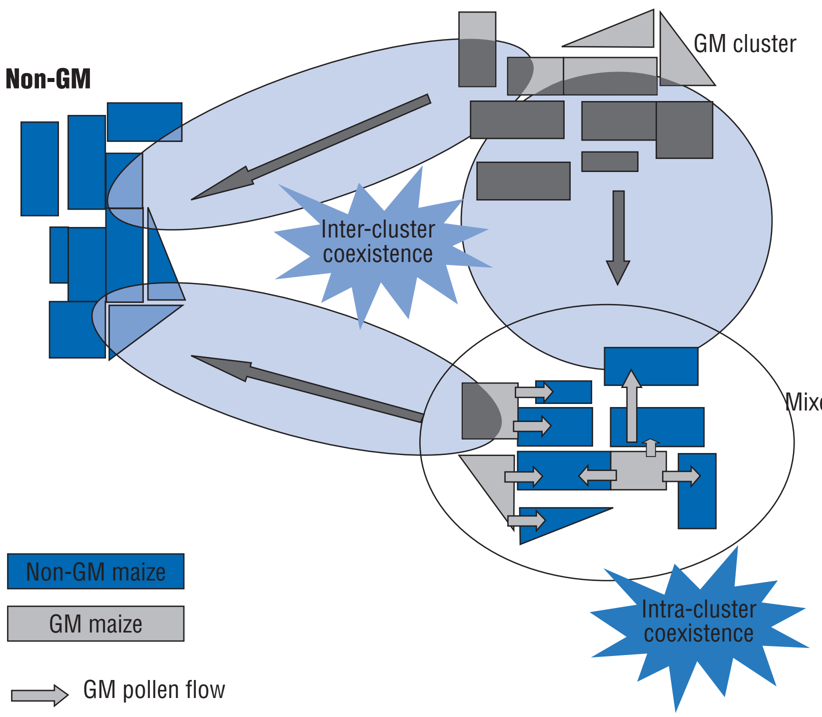
</table>

NB: A cross (X) means that the threshold cannot be met. Values on coloured background are isolation distances in meters.

21 With a heterozygous GM maize variety.

Figure 3: Cross-pollination and coexistence within and between clusters



In both types of case studied, scenarios with several different wind directions were simulated in order to assess the actual variability under real conditions. Indeed, a statistical analysis was carried out on 10 years of regional climatic data. The distribution of main wind directions during flowering period was determined. The daily wind variability was taken into account in simulations according to frequencies calculated from these climatic data.

As the wind intensity during flowering period is not very variable in this region, a ten year average was considered. Furthermore, an analysis was carried out to assess the sensitivity of the simulation results to the phenomenon of wind gusts. Its results were taken into account when drawing conclusions of simulation output data.

Estimation of adventitious presence due to machinery

The adventitious presence due to the combine harvester when harvesting a non-GM field after a GM field is significant only in the first trailer load collected. In the rest of the harvest, it could be considered insignificant since the harvesting machine has been flushed by several tonnes of non-GM maize.

The total adventitious GM presence due to machinery for all the non-GM fields on the farm therefore depends on:

- the organisation of harvesting: if all the non-GM maize is collected before or after the GM maize the rate of admixture will be very low. Conversely, if GM and non-GM maize are collected over the same period, the rate will be higher;
- field size: the larger the non-GM field, the smaller the proportion of trailers with a significant rate of adventitious GM presence due to machinery is likely to be.

In the study, three types of trailer were defined and the percentage of the area where cross-pollination will be small enough to achieve adventitious GM presence rates in the trailer below 0.1% or 0.9% was evaluated for each one and on real landscapes.

Trailer type 1 corresponds to:

- all the trailers of grain collected from farm 1 (see Inset 2);
- all the trailers of grain collected from farms 2 and 3 except the first trailer of grain collected in a non-GM field harvested after a GM field.

For trailers of type 1, the risk of admixture due to machinery is considered zero[22].

Trailer type 2 corresponds to the first trailer of grain collected in a non-GM field harvested after a GM field from farm 2. For trailers type 2, the risk of admixture due to machinery has been put at 0.1%[23]. Moreover, according to expert opinion, it would be impossible to get an absolute cleaning.

Trailer type 3 corresponds to the first trailer of grain collected in a non-GM field harvested after a GM field from farm 3. For trailers type 3, the risk of admixture due to machinery was estimated at 0.4%.[24].

Inset 1: Farm type characteristics in the maize crop production study (Poitou-Charentes)

Region	**Aunis plain**	
Farm type	*Conventional*	*Organic*
AUA	116 ha (80 – 120 ha)	100 ha
Grain maize/AUA	20 – 40%	5 - 10%
Average plot size	5 – 15 ha	
Distance between maize plots	< 1 km. Plots are grouped	
Drill ownership	30% individual 70% collective	
Combine harvester	50% individual 15% collective 35% enterprise	30% individual 15% collective 55% enterprise
Drying facilities	Mostly through CSOs[25] (4 or 5 farms have drying facilities)	100% CSOs
Storage	CSOs (1 or 2% of farms have storage facilities)	100% CSOs

Inset 2: Use of machinery in different farm types

Farm 1

- Conventional farm where the farmer owns its equipment (drill, combine harvester and means of transport);
- Organic farm owning or sharing equipment.

Farm 2 Conventional farm, producing GM maize and:

- Owning or sharing its equipment but making sure that the combine harvester is cleaned correctly; or
- Making use of an agricultural service supply agency for the harvest but signing a quality charter with that agency to guarantee that the combine harvester is cleaned between GM and non-GM fields.

Farm 3 Conventional farm producing GM varieties, sharing its equipment with other farms or making use of an agricultural service supply agency for the harvest.

In these cases, it was assumed that the combine harvester was not cleaned between GM and non-GM fields.

22 According to expert opinion.
23 www.machinerylink.com/resources/ipg/article/harvester_clean_out.asp
www.extension.iastate.edu/Pages/grain/publications/grprod/02icmm.pdf
24 www.extension.iastate.edu/Pages/grain/publications/grprod/02icmm.pdf
www.machinerylink.com/resources/ipg/article/harvester_clean_out.asp confirmed by expert opinion
25 CSO: Collecting and storage organisation.

Inset 3: Scenarios designed for the landscape study

Situation	% GMOs	Type of coexistence	Scenarios for the introduction of GM maize
1	10%	Inter-cluster	GM maize is introduced into the landscape in a random way.
	50%	Inter-cluster	
2	10%	Intra-cluster Inter-cluster	One farmer decides to sow GM maize on all the fields he owns in a cluster (possibly due to agronomic problems).
	50%	Intra-cluster Inter-cluster	All the farmers in one cluster decide to produce only non-GM maize. The other two clusters produce mainly GM maize, but in each cluster one farmer decides to produce non-GM maize.
3	10%	Intra-cluster Inter-cluster	Two farmers decide to test a GM variety, sowing it on their smallest fields, situated in two of the four clusters.
	50%	Inter-cluster	All the farmers in the main cluster decide to grow GM maize on all their fields in the cluster.
4	10%	Intra-cluster	The three biggest farmers sow 10% of their area with GM maize (to test it, for instance). This leads to the spatial dissemination of GMOs in the cluster due to regrouping of the fields owned by each farmer.
	50%	Intra-cluster	The biggest farmer in the cluster decides to introduce GM maize on all the fields he owns in the cluster. This leads to the spatial concentration of GM fields.

See also maps in Appendix 2.

Based on machinery data for the Aunis plain, three types of farm were defined with different systems for cleaning the machinery (particularly the combine harvester, the leading source of adventitious presence after cross-pollination).

I.5.5.2. Results

As adventitious GM presence due to seed impurities and machinery is added into the calculation of the overall rate, the maximum level of cross-pollination is shown in Table 4. These rates are very variable.

The percentage of the total area where the rate exceeds the targets (0.1% and 0.9%) depends on the overall (cumulative) level of adventitious GM presence (machinery plus seed purity). For instance, it cannot be kept below an upper level of 0.1% in trailer 2 if the seed impurities rate is significant (>0.01%) while in trailer 3 it is impossible to comply with this maximum regardless of seed purity.

Simulations were carried out for the four situations representing different types of coexistence (see Inset 3 for details of scenarios). Eight wind direction hypotheses were considered for each situation. The results were aggregated on the basis of the type of coexistence, machinery management and percentage of GM maize in the landscape. For current practices, these results

Table 4: Maximum affordable levels of adventitious GM presence due to cross-pollination after considering seed and machinery sources of GM material

		Maximum adventitious GM presence (AP)											
		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	0.09%		no AP		X		0.89%		0.79%		0.49%	
	0.1	no AP		X		X		0.8%		0.7%		0.4%	
	0.3	X		X		X		0.6%		0.5%		0.2%	
	0.5	X		X		X		0.4%		0.3%		no AP	

NB: A cross (X) means that the threshold cannot be met.

Tables 5 and 6: Percentage of the landscape area where the adventitious GM presence in the trailer is below 0.1% or 0.9%

Inter-cluster co-existence		Maximum adventitious GM presence											
		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	100%	76%	69%	22%	0%		100%		100%		100%	
	0.1	69%	22%	0%									
	0.3	0%										100%	92%
	0.5									100%	95%	69%	22%

Intra-cluster co-existence		Maximum adventitious GM presence											
		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	53%	57%	9%	8%	0%		98%	97%	97%	96%	93%	91%
	0.1	9%	8%	0%				98%	97%	96%	95%	86%	90%
	0.3	0%						96%	92%	93%	91%	75%	79%
	0.5							86%	90%	83%	85%	9%	8%

are shown in Tables 5 and 6 and expressed as a percentage of the total landscape area where the specified rates of adventitious presence are achieved.

For the "inter-cluster" cases where GM and non-GM fields are in separate clusters (see Figure 3), the 0.9% threshold is always achieved for farm 1 where no adventitious presence due to machinery occurs, whatever the seed purity considered. If machinery is not properly cleaned[26], low GM presence in seeds allows achieving the 0.9% threshold. Indeed, in this inter-cluster case, isolation distances between clusters are high enough to keep cross-pollination at a low level and the key factors are then GM presence in seeds and machinery cleaning. Nevertheless, even in this case, the 0.1% GM level can only be achieved with almost pure seeds and no admixture due to machinery.

However, in the intra-cluster situations with a large number of adjacent fields, the 0.9% threshold is not always achievable, not even for farm type 1 where trailers are not shared with GM crop growers and with almost pure seeds. Indeed, cross-pollination is already over 0.9% for some small non-GM fields adjacent to GM fields. Simply by cleaning machinery the 0.9 % threshold becomes feasible for 85-90% of the trailers. Ensuring 100 % compliance would need additional measures. Lowering the GM presence in seeds from 0.5% down to 0.3% seems to be more efficient to facilitate coexistence than further reductions of this GM presence in seeds. As for the 0.1% threshold, it is only achievable for some fields, with pure seeds and no admixture due to machinery. Such a GM level is thus considered as not achievable at landscape level with current practices in the intra-cluster case.

It should be noticed that the impact of the share of GM crop in the region (be it 10 % or 50 %) in coexistence feasibility is low, as suggested also in the previous JRC-IPTS study. Even in some cases, the adventitious presence values for the scenario of 10% GM share in the region are lower than for the 50% share scenario. This illustrates that is the distribution of GM fields in the landscape what is important for coexistence rather than the global penetration of the GM technology in the region. Results show that 10% GM fields are dispersed in the landscape appear to be more difficult to manage than 50% GM maize grouped in cluster.

Effect of non-GM buffer zones in GM fields

For this part of the study, only one of the landscape situations was considered (situation 4, cf. Appendix 2 and Figure 4). The field-scale study (cf. section I.5.4.2) showed that the non-GM buffer

26 It should be pinpointed that only the first trailers are concerned by this type of admixture.

zone strategy is of value only if GM and non-GM fields are located close to each other. This strategy was therefore analysed for the coexistence of GM and non-GM fields within the same cluster. For 10% GM maize in the landscape, non-GM buffer zones of 9 m and 18 m were created around each GM field. For 50% GM maize in the landscape, the same non-GM buffer zones were created around aggregated GM fields within a cluster, rather than around individual GM fields (see Appendix 3 for details of the results).

The estimated adventitious GM presence rates obtained for situation 4 in a landscape with 10% GM maize are set out in Figure 4. For each case[27], the percentage of adventitious GM presence was calculated for eight different wind directions, with the downwind and upwind situations as extreme cases (see intervals in Figure 4).

This "buffer zone" strategy reduces the GM presence in non-GM fields and would make easier the achievement of the 0.9% threshold within clusters. Nevertheless, it is not always sufficient to keep rates below 0.9% in all fields, regardless of the adventitious GM presence due to machinery and seed purity considered. Indeed, in the worst case (wind blowing from GM to non-GM field, with no time-lag in flowering), a non-GM buffer zone of 18 m cannot keep maximum rates below 0.9% in fields 24 and 26. These fields are highly sensitive due to their position in contact with GM fields and their small area compared to the closest GM fields.

In this specific case, either the buffer zone should be widened or it should be combined with a flowering time-lag strategy.

For instance, a non-GM maize strip 9 m or 18 m wide combined with a flowering time-lag of 30 degree-days is sufficient to reduce rates due to cross-pollination to below 0.6% and 0.5% respectively for all fields if 10% of the maize in the landscape is GM.

Effect of difference in flowering time

Inter-cluster coexistence

The effect of flowering time-lag is clear from the tables in Appendix 4a. A time-lag of 30 degree-days makes it possible to achieve lower adventitious GM presence rates in each field with 50% GM maize in the landscape, with an average reduction of 0.1% over the situation with no flowering time-lag. Time-lags of 60 and 90 degree-days highly reduce rates in each field and lead to cross-pollination rates below 0.09% with 50% GM maize in the landscape and below 0.005% with 10% GM maize in the landscape.

Intra-cluster coexistence

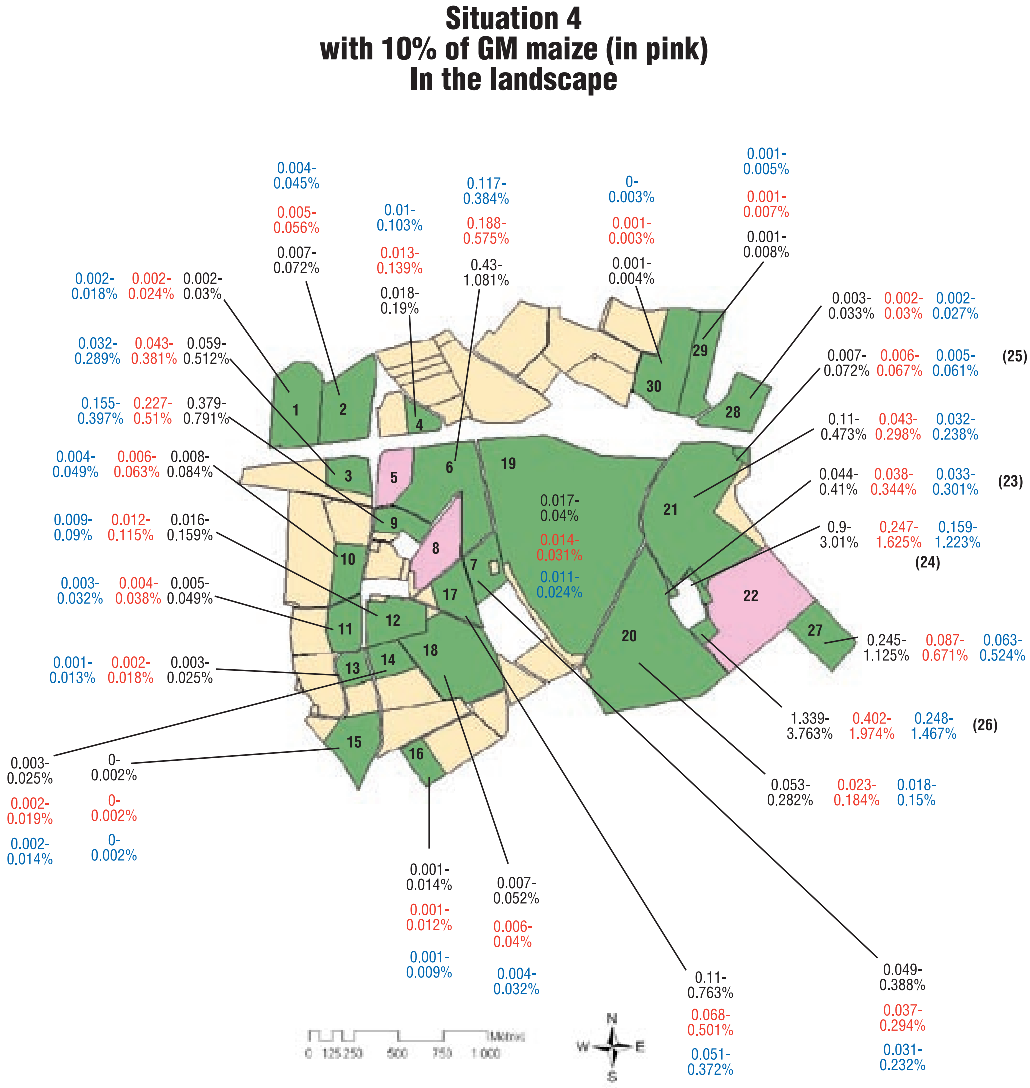
For intra-cluster coexistence (Appendix 4b), flowering time-lags could make it possible to achieve the 0.9% threshold under certain conditions with regard to seed purity and machinery cleaning. A time-lag of 30 degree-days makes it possible to achieve rates due to cross-pollination of less than 0.9% in each field and thus achieve the 0.9% threshold when there are no other sources of adventitious presence.

A time lag of 60 degree-days produces rates due to cross-pollination of less than 0.4% and thus ensures the 0.9% threshold achievement even if GM presence in seeds is up to 0.5%. A flowering time-lag of 90 degree-days brings the cross-pollination rate down to 0.09%.

Consequently, a 90 degree-days flowering time-lag between GM and non-GM varieties for situations where admixture due to machinery is zero and the GM rate in seed is below 0.01% is the only way to keep the adventitious GM presence below 0.1%.

27 No buffer zone, 9 m buffer zone and 18 m buffer zone.

Figure 4: Maximum and minimum adventitious GM presence rates due to cross-pollination evaluated with MAPOD® for each field without a non-GM maize strip, with 9-metre non-GM maize strip and with 18-metre non-GM maize strip



Black: with no non-GM buffer zone; Red: with 9 m non-GM buffer zone; Blue: with 18 m non-GM buffer zone

I.5.6. Regional analysis of the effect of introducing isolation distances

Isolation distance is a coexistence measure with a robust effect on reducing GM adventitious presence due to cross pollination in maize (see results of field scale simulations in Tables 2 and 3). However, mandatory isolation distance is a coexistence measure with particular features since its feasibility of application is not equal for all farmers, because the spatial distribution of maize fields is not random. Farmers whose neighbouring fields lie beyond a given isolation distance will have no constraints in implementing this coexistence measure if they decide to sow GM varieties. Other farmers will be basically unable to implement it.

Using an actual maize landscape GIS data, we simulated what share of fields would be affected in Poitou-Charentes by introducing different isolation distances. First, the number of maize fields in the region having neighbouring maize fields within a given isolation distance was estimated. The results provide an indication, for a given isolation distance, of how many fields will be in need of measures arranged with neighbouring fields. This first result overestimates the number of "hot spots" (those in need of consultation for decision taking between different owners) because different fields may belong to the same farmer. Therefore, the results are expressed introducing actual data on ownership of maize fields[28] (Figure 5). The results can also be expressed as total area of maize affected.

As an example, Figure 6 simulation results show that introducing a mandatory isolation distance of 50m in Poitou-Charentes originates a need for consultation and agreement with neighbouring owners (1 or 2 farmers) for 28% of the total number of maize fields (what represents 42% of the total maize area).

These figures vary according to the isolation distance considered. For instance, implementing a 100 m isolation distance increases the number of fields having neighbours owning maize fields to 32%, and a 300 m distance increase this figure to 57 % (Figure 6).

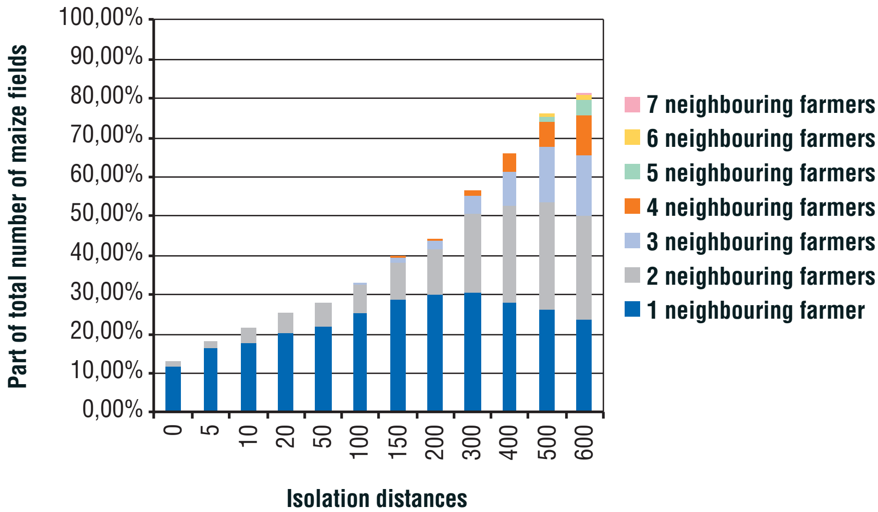
Therefore isolation distances in practice affect a number of farmers that may not be able to freely choose the production type since the positions of their fields relative to other owners' fields difficult compliance with the corresponding thresholds, even if segregation measures are taken. Other farmers, conversely, will not experience the effect of mandatory distances in their decision to grow or not GM crops. The goal would be to produce a tool for reducing isolation distances to figures that are effective but minimally disruptive (for example in combination with other measures examined in this report).

I.5.7. Economic effects of coexistence measures in maize crop production

Variable production costs of €687/ha and an income of €950/ha in the year 2004 were taken as the baseline for calculation of the economic effects of coexistence measures in maize crop production. Taking into consideration compensation payments for the Poitou-Charentes region, a gross margin of €743/ha is obtained (Teyssier, 2004).

The impact of a series of coexistence measures on the GM maize grower's gross margin depends on the potential economic performance of the

Figure 5: Maize fields (%) in the Poitou-Charentes region having neighbouring farmers owning maize fields within a given isolation distance



Black: with no non-GM buffer zone; Red: with 9 m non-GM buffer zone; Blue: with 18 m non-GM buffer zone

28 Input landscape, field and ownership data provided by the Institute for the Protection and Security of the Citizen, Joint Research Centre of the European Commission.

cultivated GM maize[29] for which no empirical data is available for France so far. Findings in scientific literature were taken as input in order to quantify the potential economic performance of planting GM maize versus its conventional counterpart. An economic advantage of €43/ha (on the gross margin) for Bt maize compared to non-GM varieties was estimated mainly due to increasing yields of Bt maize and savings in pesticide use.

An overview of the gross margin losses due to individual coexistence measures suggested for maize crop production is provided in Table 7. Cleaning machinery causes additional costs mainly due to additional labour requirements and higher renting fees if machinery is shared by farmers. In particular for cleaning a combine harvester additional costs exceeding €55 per cleaning have to be calculated for shared machinery (Table 7). Cleaning operations are time consuming activities which result in higher opportunity costs when sharing rented machinery. Cleaning an own combine harvester would results in just €3.81 per cleaning operation.

Changing the flowering times between maize varieties causes substantial losses of income for the GM crop growers. This relates in particular to changing from a very late to a late variety due to significant reductions in yields.

The losses related to discard widths on the non-GM field (which is harvested separately) differ significantly depending on the width of the discard width and the size of the non-GM field. For a 15 ha GM field and neighbouring non-GM fields between 1 ha and 5 ha the losses in farmers income range between €1.27/ha and €11.40/ha. Big differences in the per-hectare costs (ranging from around €17/ha to €78/ha) can also be observed for non-GM buffer zones around GM fields, depending mainly on the GM adoption rate in the region and the estimated economic performance of GM maize (Table 7).

In addition to the economic effects of individual coexistence measures, the costs of non-GM buffer zones in a landscape were analysed (see Figure 4 for details[30]). Based on the simulations of the level of adventitious

Table 7: Additional costs or gross margin losses of farmers of individual coexistence measures in maize crop production in France

Additional measure	Costs or gross margin losses of individual measures
Clean the machines a) single seed driller b) combine harvester c) transport - trailer or truck	Costs of shared machinery[1)]: €38.38/cleaning €56.84/cleaning €1.48 /cleaning
Time isolation	Change from very late to late (30°days): €201/ha Change from late to mid-early (60°days): €46/ha
Discard width on the non-GM-field - extra harvest	6 m discard width: €1.27 – €2.85/ha[3)] 12 m discard width: €2.55 – €5.70/ha[3)] 24 m discard width: €5.10 – €11.40/ha[3)]
Non-GM buffer zones around the GM field	€60.54/ha - €78.07/ha [4)]

1) Renting fees for collectively used machinery were used for calculating the costs of shared machinery.
2) GMA = Gross margin.
3) The first figure is for a neighbouring non-GM field of 5 ha, and the second for a non-GM field of 1 ha.
4) The first figure is a 50% GM adoption rate in a region with clustered fields, while the second is for a 10% GM adoption rate with dispersed fields.

29 Assuming cultivation of insect resistant Bt maize in the region.
30 The economic analyses considered GM adoption rates of 10% and 50% in the region (see situation 4 in Inset 3).

presence of GM pollen in different fields, big variations can be observed in the additional costs of non-GM buffer zones, if such zones were necessary, depending on the sizes of the GM fields, the width of the buffer zones as well as the underlying assumptions concerning the economic performance of Bt maize in France: in the case of a 10% GM adoption rate in the region, the per-hectare costs of non-GM buffer zones range between around €9 (1.14% of the gross margin per hectare) and €17 (2.16% of the gross margin) for a 9 m wide buffer zone and between around €16 and €30 in the case of an 18 m wide buffer zone (Appendix 5). Assuming a 50% GM adoption rate in maize crop production in Poitou-Charentes and that the non-GM buffer zones are located within each GM field, the additional per-hectare costs vary between around €3.77 and around €50 in the case of an 9 m wide buffer zone and between €6.79 (0.8% of the gross margin per hectare) and €60 (8% of the gross margin per hectare) when a 18 m buffer zone is considered (Appendix 5). In particular, in very small GM fields of below 1 ha, substantial additional costs arise when non-GM buffer zones have to be established within each field.

The final step was to calculate the additional costs for a non-GM buffer zone around a cluster of eight GM fields with a 50% adoption rate for GM maize in the region[31]. Compared to the additional costs of establishing buffer zones within each GM field, significant cost reductions can be achieved by establishing a single non-GM buffer zone for the whole cluster of GM fields. This holds true for all field sizes and assumptions concerning the potential economic performance of planting GM maize in France. Taking an 18 m wide buffer zone, when it is necessary to meet the threshold of 0.9% in the neighbouring non-GM fields, the additional per-hectare costs of a "clustered" buffer zone accounts for €4.8 (equivalent to 0.6% of the gross margin per hectare) (Appendix 5). Important cost savings observed with "clustered" non-GM buffer zones. These cost savings from clustered" buffer zones are substantially higher in the case of smaller GM fields (Appendix 5).

These figures have been calculated considering that the additional costs of introducing non-GM buffers result from differences in the gross margin of GM and non-GM maize, additional labour requirements for land use and management as well as extra machinery costs due to double ways. However, based on the Spanish experience growing Bt maize, it can be assumed that the GM maize grower will harvest both types of maize together and will label the total grain harvested as GM maize. This assumption would significantly reduce the non-GM buffer costs shown in the previous paragraphs.

Isolation distance is a particular measure since it does not affect all farmers equally. Fields are not randomly distributed on a common physical landscape. Farmers whose neighbour fields lie beyond isolation distance will have no constraints in their decision-making of planting or not GM varieties and will experience no economic impact at farm level. However, farmers intending to use GM varieties but with neighbour non-GM maize fields falling within isolation distances will be constrained in their choice (see Figure 5). Consensus experts' opinion is that farmers will manage these fields by sowing non-GM maize. At farm level, this cost amounts to the difference in economic performance between the GM and non-GM maize varieties. At regional level, the economic effect will depend on the physical landscape area affected. Other aggregated economic consequences of a reduced use of GM crop varieties at regional level would need further study.

I.5.8 Conclusions for maize crop production

The study indicates that, for a typical maize production region such as Poitou-Charentes in France, the 0.9% threshold can be achieved with

31 In this case plots number 19, 20, 21, 22, 23, 24, 25 and 26 are considered GM maize in Figure 4.

current practices in most of the fields as far as GM presence in seeds does not exceed 0.5 % and sowing and harvesting equipment is thoroughly cleaned.

Cross-pollination between GM and non-GM fields varies considerably with landscape, field characteristics, variety characteristics in terms of emitted pollen, and wind conditions. Nevertheless, by considering the worst-case scenario (e.g., small non-GM fields downwind of GM fields), the 0.9% threshold can be ensured everywhere with simple rules like adequate isolation distances.

Due to the great variability, a flexible decision-support system taking into account key factors (isolation distances, area of the non-GM field, flowering time-lag, and even the amount of pollen produced by both GM and non-GM varieties) may be valuable to minimise overall segregation costs in those situation where isolation distances may be difficult to implement (e.g., clustered fields).

The spatial organisation in Poitou-Charentes, where maize fields are grouped around the irrigation wells, is well suited to a cluster strategy (generally one cluster per water supply point). In this type of strategy, the farmers in each cluster could decide amongst themselves to cultivate GM or non-GM maize. This is the only strategy capable of achieving very low adventitious presence (below 0.1%). Furthermore, adventitious presence below 0.9% could easily be achieved with no cooperation between farmers from neighbouring clusters for 10% and 50% GM maize in the landscape, if the combine harvester is cleaned thoroughly after harvesting of GM crops (by flushing with part of a tank of non-GM grain, for instance).

If GM and non-GM maize are to coexist in the same cluster, where there is no room for isolation distances, and as long as GM presence in seeds remains below 0.5% and machinery is thoroughly cleaned, different strategies could achieve adventitious presence rates below 0.9%:

- ensuring a flowering time lag of 60 degree-days between GM and non-GM varieties. This strategy could be difficult to implement because it depends heavily on the climate of the year and the GM varieties must flower earlier than the non-GM varieties. It would involve a loss of yield for the GM maize grower and require coordination of the choice of variety;
- setting up, in the GM field, an 18 metre wide buffer zone with non-GM maize combined with a flowering time-lag of 30 degree-days if there are very small non-GM fields within the cluster;

Cooperation between farmers may substantially ease the implementation of segregation measures. This might be difficult for farmers who own fields in several clusters.

As cleaning combine harvesters is a time-consuming but important task, it might be interesting to harvest GM and non-GM varieties in different, well-spaced periods in order to reduce the number of cleaning operations (Le Bail and Meynard, 2001).

Among the various measures, when no isolation distances are feasible (intra-cluster case) a non-GM buffer zone appears to be the best way to safeguard coexistence. Its economic effects depend on the width of the non-GM buffer zone, the relative sizes of GM and non-GM fields and the economic difference between GM and non-GM maize. The loss of gross margin could be drastically reduced if GM fields were clustered and the non-GM buffer zones were established around the cluster and not for each individual GM field within the GM cluster. In this case, cooperation between farmers might be necessary but would lead to substantial cost savings.

In this sense, the level of additional costs should be interpreted cautiously since they can only be estimated case by case.

Currently it is not possible to give any empirical results concerning the overall economic net effects of cultivating Bt maize in France. This is basically due to the missing practical experience with planting this crop in the case study region. Therefore, additional research is required in order to quantify the net economic benefits which farmers might have if they cultivate Bt maize and have to implement additional coexistence measures.

I.6. Seed production

I.6.1 Background and current data on impurity levels

Maize seed production in Europe covered 126 311 ha in 2003. France is the leading seed producer in Europe with 49 822 ha, well ahead of Hungary (27 100 ha) and Romania (14 500 ha). In France 50% of seed production is concentrated in the south-west region and two *départements*[32] (Landes and Pyrénées-Atlantiques) account for 25% of the national production[33].

Maize varieties are hybrids and seed production plots are therefore set up with separate rows of fertile male lines and detasseled female lines. Such production schemes are more sensitive to cross-pollination by surrounding maize crop fields because:

- only male-line plants produce pollen;
- those male lines emit fewer pollen grains than commercial hybrids;
- male-line plants are not in the same rows as recipient female-line plants.

Certified seeds are produced on the basis of contracts between farmers and seed producers under a regulatory framework including statutory measures (to ensure seed purity and quality) as well as an official quality control system. The main characteristics of maize seed production in France are as follows:

- around 1 300 varieties are produced every year but the area required for each variety is highly variable (depending on market share);
- 6 600 individual seed contracts were concluded in 2004 (averaging 8 ha each, see Table 9 and Figure 6);
- one contract was concluded per variety but farmers usually produce seeds for two varieties on average;
- in maize production areas like south-western France, producing seeds over a large area (5 497 ha) while complying with the legal isolation distances is possible because farmers have adopted a clustering strategy; seed plots are currently grouped together[34] (see Figure 7) creating large areas (tens of hectares) allocated to seed production.
- 1090 ha of basic seed production in 2003.

Current legal isolation distances are set out in Table 8. In recent years, it has become possible to reduce isolation distances by planting extra male fertile rows around seed production plots. These extra male rows act as “protection” for female plants by making foreign pollen less competitive. If different male lines are present within the same cluster, an isolation distance of 100 m must be maintained between them.

Thanks to such practices, seed purity has been improved over the last 20 years, as illustrated in Figure 8, and cross-pollination from surrounding fields is on average 0.3%, although still a significant percentage of lots (30 – 40 %) exceed this threshold and 10-15% of the lots are over 0.5%[35].

32 Administrative district.
33 Source: Courtesy of GNIS.
34 Called “cluster” in this report.
35 NB: These varietal impurity rates due to cross-pollination are estimated from phenotypic, not genotypic, observations.

Table 8: Isolation distances (in metres) for maize seed production

Type of seed	OECD	EU	Spain	France
Basic seed	200	200	300	400
Certified seed	200	200	220	300 (seed cluster < 10 ha) 200 (seed cluster ≥ 10 ha)

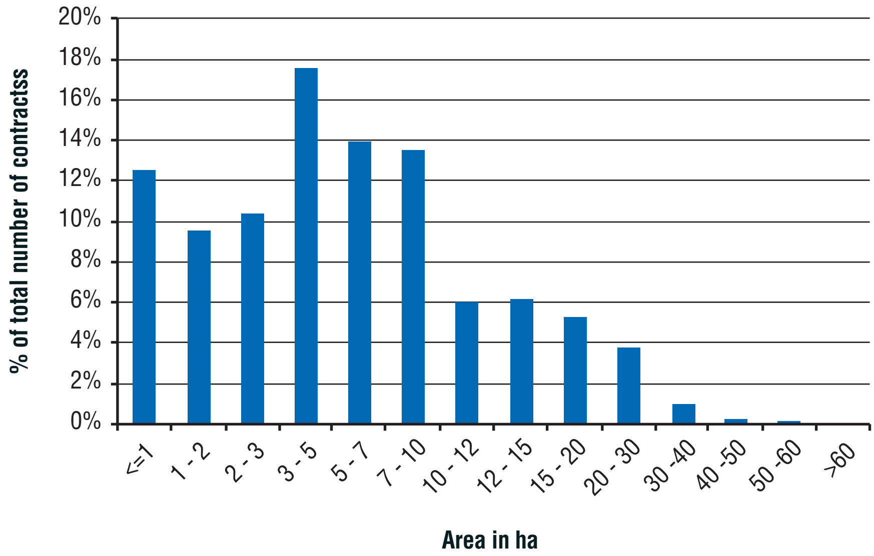
Source: OECD (2004), MAPA (1986), GNIS (2003).

Table 9: Maize seed production in France; field size distribution (2004)

	< 2 ha	2 ha < < 5 ha	5 ha < < 10 ha	> 10 ha	Total number of fields
France	2 862	4 419	2 615	1 261	11 157
%	25.65	39.61	23.44	11.30	
Aquitaine region	1 293	1 686	987	391	4 357
%	29.68	38.70	22.65	8.97	
Midi-Pyrénées region	611	948	728	470	2 757
%	22.16	34.38	26.41	17.05	
West	254	537	344	259	1 394
%	18.22	38.52	24.68	18.58	
South-East	704	1 248	556	141	2 649
%	26.58	47.11	20.99	5.32	

Source: Courtesy of Arvalis-Institut du Végétal and SOC[36].

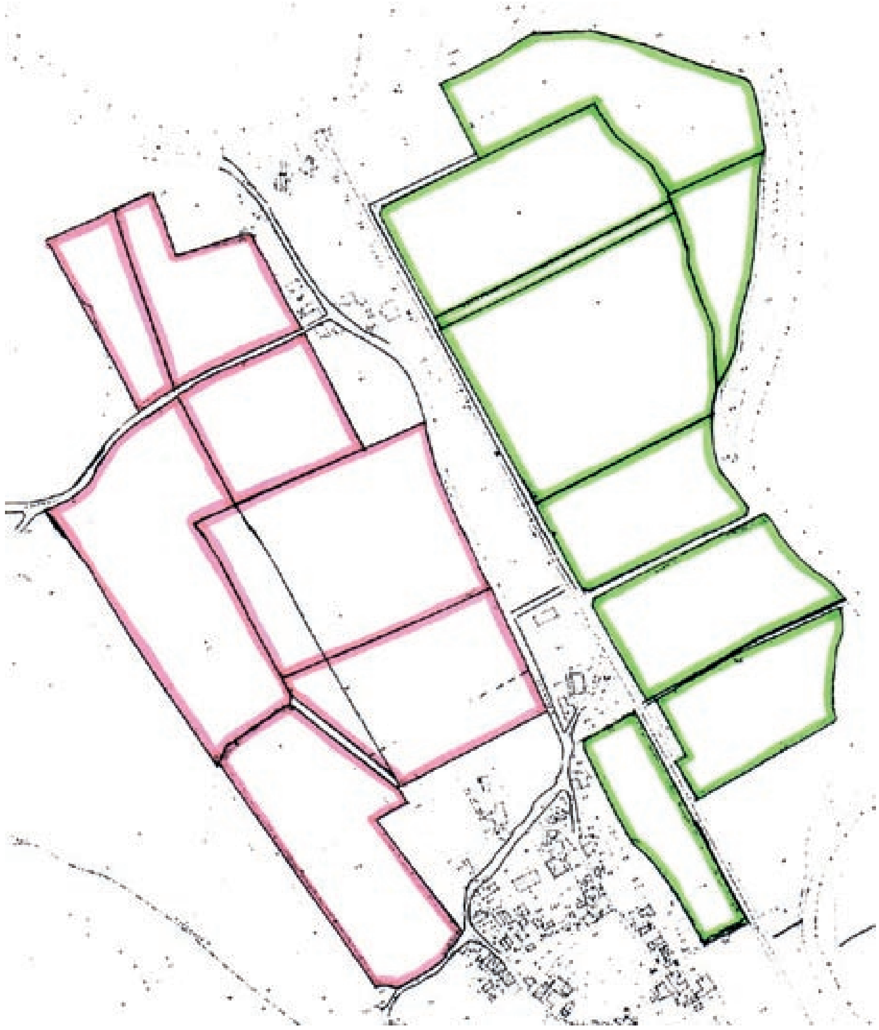
Figure 6: Maize seed multiplication contracts in France (2003)



Source: Courtesy of Arvalis-Institut du Végétal and SOC.

36 SOC: Service Officiel de Contrôle (official control service).

Figure 7: Typical organisation of seed production fields in South-West France



Source: Arvalis - Institut du Végétal.

This seed production area consists of two spatially isolated units (pink/green). In each unit, pollination is ensured by one male line only in order to maintain a low level of adventitious GM presence in seed.

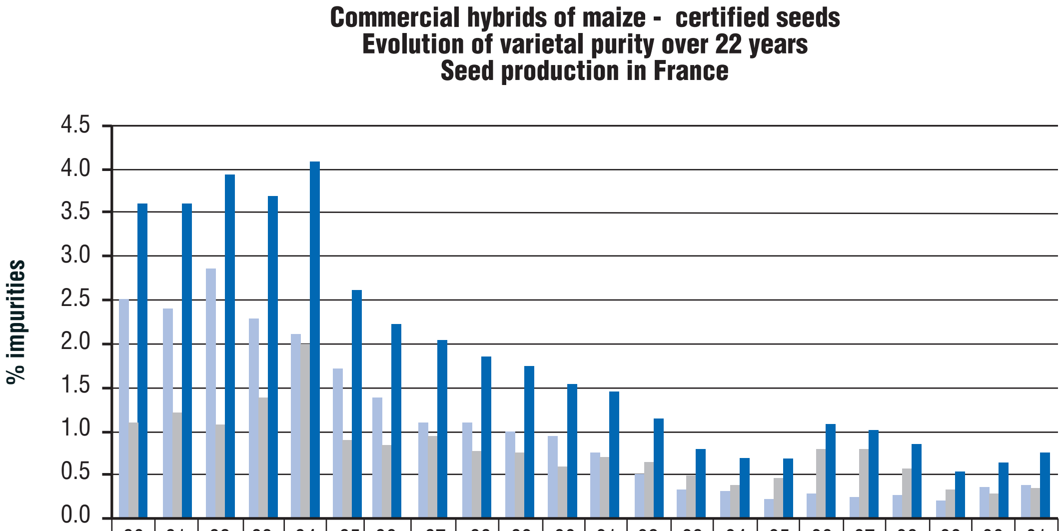
I.6.2 Sources of adventitious presence

Sources of adventitious presence in seed production (see Figure 9) are similar to those in crop production but, due to seed production characteristics and regulation, they are not equally important.

Among the six potential sources of adventitious presence of GM seeds, after taking into consideration expert opinion several sources were discarded from the seed production analysis:

- current practices already include thorough cleaning of sowing machines and harvesters; adventitious presence due to machinery was therefore not taken into consideration here;
- transport and storage aspects were not addressed for the same reasons;
- purity of basic seed is a potential source of GM presence. Under the current regulations (GNIS, 2003), an isolation distance of 400 m is mandatory. This results in a high level of purity, even if not always 100%. It has been stated that, under the scenarios envisaged in terms of GM crop introduction, it would be possible to meet levels below 0.1%.

Figure 8: Overview of seed production quality in France



	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01
% self-pollinated plants	2.5	2.4	2.85	2.3	2.1	1.7	1.38	1.11	1.09	1	0.94	0.75	0.49	0.33	0.3	0.23	0.28	0.24	0.26	0.2	0.35	0.38
% outcrosses	1.1	1.2	1.07	1.4	2	0.9	0.85	0.93	0.76	0.75	0.6	0.71	0.66	0.48	0.38	0.46	0.79	0.78	0.58	0.32	0.29	0.36
% total off types	3.6	3.6	3.92	3.7	4.1	2.6	2.23	2.04	1.85	1.75	1.54	1.46	1.15	0.81	0.68	0.68	1.07	1.01	0.84	0.53	0.64	0.74

Post-control year	Outcrosses %		
	0.3 % ≤	0.5 % ≤	> 0.5 %
2004	*67% 515*	86% 143	14% 104
2003	*77% 608*	90% 104	10% 74
2002	*59% 397*	80% 143	20% 138
2001	*57% 666*	90% 389	10% 109
2000	*72% 714*	88% 166	12% 116

By courtesy of SOC.
NB: These cross-pollination rates are estimated from phenotypic, not genotypic, observations.

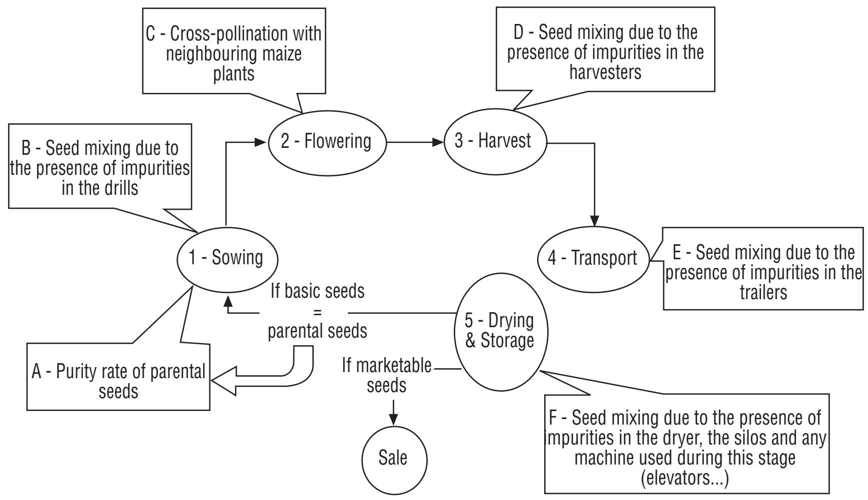
Consequently, no specific analysis of basic seed was carried out in this study.

The main source of adventitious presence is cross-pollination with GM maize and, in view of the existence of clustering, two types of coexistence were addressed:

- coexistence between GM and non-GM seed production plots within a single cluster when the transgenic trait is borne by a male line (seed-seed case)[37];
- coexistence between non-GM seed production plots and surrounding GM maize crop production fields (seed-crop case).

37 If the transgenic trait is borne by the female line, there is no specific coexistence issue as long as detasseling is carried out correctly.

Figure 9: Potential sources of adventitious presence during maize seed production



I.6.3 Methodology

The relative effects of various factors affecting the cross-pollination rate were assessed through a field-scale study similar to the study carried out for maize crop production based on seed production characteristics in Pyrénées Atlantiques. The following factors were considered:

- relative sizes of GM fields and non-GM seed plots;
- wind direction (upwind or downwind with average wind speed of 3 m/s);
- flowering time-lag between GM and non-GM plots;
- isolation distances (from 100 m to 1 000 m);
- number of extra male rows for protecting seed plots from cross-pollination;
- relative pollen production between varieties and lines.

The detailed protocol for simulations is set out in Figure 10. Wind speed and the amount of pollen emitted were considered constant although they could depend on local environments and varieties. However, analyses of sensitivity to these factors were carried out and the results were taken into account before drawing conclusions.

Assumptions:

- Fields are square;
- Amount of pollen produced per plant:
  - 2 000 000 for seed production;
  - 8 000 000 for crop production.
- Sowing density (in number of plants per hectare):
  - 96 000 for male plants in seed production;
  - 75 000 for crop production.
- GM crop production maize is heterozygous.

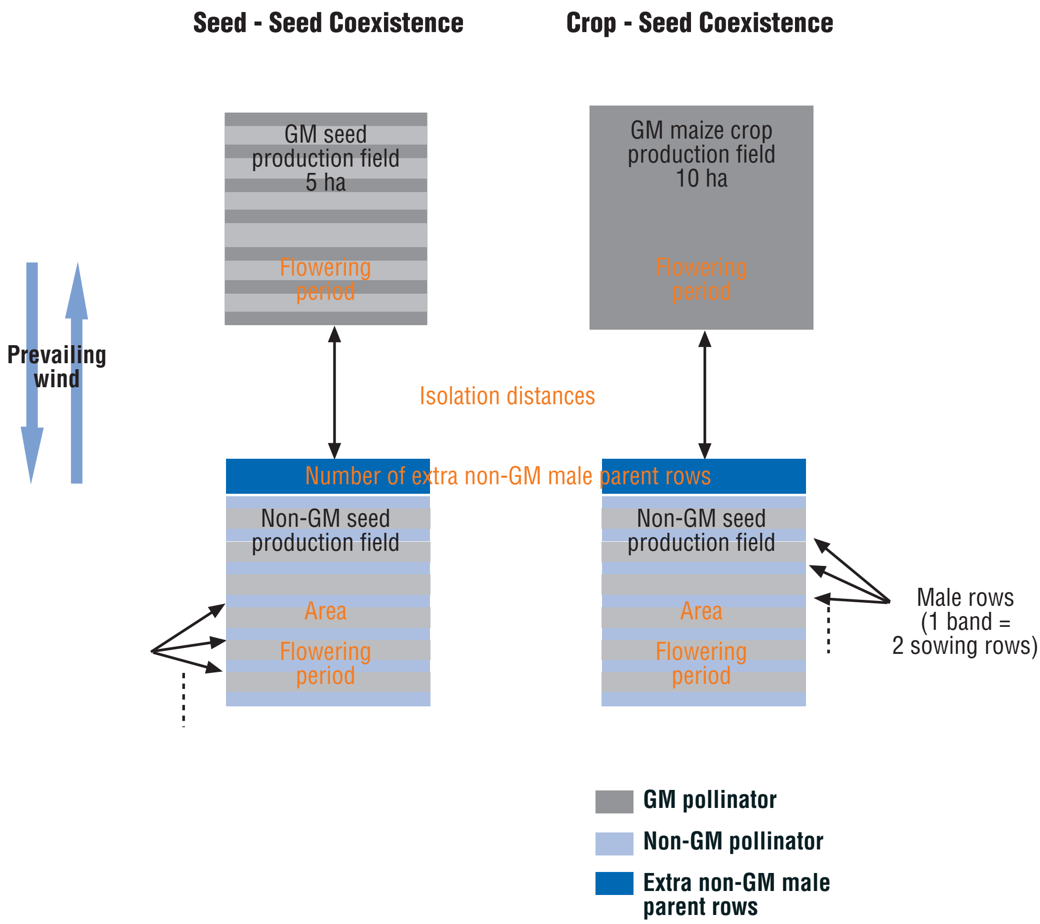
I.6.4 Results and discussion

(i) Coexistence between GM and non-GM seed plots (seed-seed coexistence)

Table 10 reports the results obtained from a simulation using the MAPOD® model with identical average pollen production levels for both GM and non-GM lines (2 million pollen grains per male-line plant)[38]. Results for an average situation are set out below, but a sensitivity analysis was performed with different amounts of pollen to assess the importance of this factor (see Appendix 7).

38 Additional simulation results with various levels of pollen production can be found in the report on maize.

Figure 10: Protocol for simulations in the case of maize seed production



Outcrossing levels estimated with current practices (100 m isolation distance between different male lines) range between 0.11% (equal field sizes and the non-GM seed plot is upwind of the GM one) and 0.77% (small seed plot and the non-GM seed plot is downwind of the GM one). These figures can be considered as estimates of the lower and upper bounds and are consistent with quality control datasets which give similar ranges (see Figure 8).

Adventitious presence rates depend heavily on wind direction and on the relative sizes of non-GM and GM seed production plots. In most of the actual situations (well-oriented plots with respect to wind and balanced plot sizes between GM and non-GM), adventitious presence below 0.5% or 0.3% are always achievable and no additional measures need to be taken.

If plots are badly oriented with respect to the wind (non-GM seed plots downwind of GM seed plots), cross-pollination rates are higher but still remain around 0.5% for balanced plot sizes. In addition, if there were non-balanced plot sizes (non-GM seed plots smaller than GM plots), additional measures would be available and efficient:

- increase isolation distances;
- grow varieties with different flowering time-lags (see Table 10);
- increase the size of non-GM seed plots.

Depending on the situation, it might be easier to increase the size of non-GM seed production plots rather than increasing isolation distances. This is, however, a measure that needs to be taken by non-GM seed producers, which may not be in line with legal coexistence requirements in some Member States. With respect to the time-lag strategy, precocious flowering patterns in hybrid varieties and female parents are quite similar.

Under these circumstances, it would be very difficult for the GM seed producer to ensure a flowering time-lag.

In conclusion, the results indicate that, as long as seed production plot sizes are balanced ensuring coexistence between GM and non-GM seed production within a cluster is feasible for a threshold of 0.5%, it does not imply changing established production methods and does not involve additional costs. The exception would not be very small non-GM seed plots. To achieve a 0.3% threshold, care should be taken to allocate GM and non-GM seed plots with the right orientation with respect to the wind. If this is not feasible, additional measures should be taken, either by balancing plot sizes or by increasing isolation distance. This should not be a major organisational problem since it could be specified in the contracts of farmers in the specific cluster.

(ii) Coexistence between GM maize production plots and non-GM seed plots (crop-seed coexistence)

Table 11 reports the results obtained from a simulation using the MAPOD® model with average pollen production levels (2 million pollen grains per male-line plant in seed plots, 8 million pollen grains per GM plant in commercial fields)[39].

As the quantity of pollen emitted can vary, depending on the varieties, a sensitivity analysis was performed with different amounts of pollen (see Appendix 7).

In these simulations, outcrossing levels estimated with current practices (200 m isolation distance if the non-GM seed plot is larger than 10 ha, 300 m otherwise) range between 0.24% (equal field sizes and upwind situation) and 1.05% (small seed plot and downwind situation). Since in south-west France most seed production plots are concentrated within "clusters", these figures would apply to "peripheral" plots only (while the figures for internal plots would be lower). Once again, these figures can be considered as estimates of the lower and upper bounds of sensitive situations. They are consistent with quality control datasets which give similar ranges (see Figure 7).

Adventitious presence rates depend heavily on wind direction (even more than for seed-seed or crop-crop scenarios) and on the relative sizes of non-GM seed production plots and GM grain production fields.

In favourable situations (well-oriented plots with respect to wind and balanced plot sizes between GM and non-GM), thresholds of 0.5% and 0.3% are always achievable and no additional measures would need to be taken. Levels of 0.1% would be very difficult to achieve, unless very large isolation distances are established.

However, if plots are badly oriented with respect to the wind, cross-pollination rates are much higher and remain over 0.5%, with current isolation distances required by seed companies, even for balanced field sizes between GM crop production and non-GM seed production.

In seed-crop coexistence, it is more difficult to allocate seed production plots within landscapes in such a way that they are always well-oriented or large enough with respect to GM crop production fields. Indeed, this would require coordination with neighbouring farmers who are not necessarily themselves involved in a contractual relationship with seed companies. In other words, GM maize growers would have to pay attention to potential seed production sites in the vicinity.

Therefore, in these sensitive situations which could occur for at least some plots (on the periphery of the cluster), in each seed production "cluster" in regions where maize production density is high, additional measures should be taken.

39 Additional simulation results with various levels of pollen production can be found in the report on maize.

- Table 11 clearly illustrates that increasing isolation distance is technically a very efficient way to reduce adventitious presence in non-GM seed production when fields are badly oriented: it might be possible to increase the size of seed plots located on the edge of a cluster and to allocate seed plots for varieties with a small market share to the centre but this cannot always be applied in practice;
- the planting of extra male parent rows does not seem to be as efficient as anticipated when the French regulations were drawn up. The simulation results indicate that an additional isolation distance of 100 m is much more effective than planting 20 extra male parent rows[40]. This is corroborated by a specific analysis of the relative amount of pollen produced by these male rows with respect to the total amount of non-GM pollen. Extra male rows do have a real "protecting" (or diluting) effect on the neighbouring female-line rows but this effect over the whole seed plot remains limited.

In conclusion, the results indicate that ensuring coexistence between commercial GM crop fields and non-GM seed production plots may be difficult to achieve. For this reason, at least for some seed plots badly oriented with respect to the wind, additional measures should be taken. Among potential measures, increasing isolation distances is technically the most efficient. As the newcomer, the farmer producing GM grain could also use the flowering time-lag strategy, when and where possible. In all cases, information between farmers and with seed companies would be necessary.

I.6.5 Economic effects of additional coexistence measures in maize seed production

Seed-seed coexistence

Due to lack of publicly available data on the economics of maize seed production in France, the cost structure of maize seed production was estimated with the help of expert interviews. The data can regarded as valid for the years 2003 and 2004.

To estimate the economic effects of the coexistence measures suggested, it was assumed that a yield of 3.5 t of maize seed per hectare generates a total income of €3 365/ha from maize seed production in France. Taking into account variable production costs of €2 177/ha and additional compensation payments, a gross margin of €1 488/ha was taken as the baseline for the cost calculations for maize seed production. The first step was to quantify the opportunity costs of the different additional measures assuming a 5 ha square GM maize seed field.

The economic effects of increasing isolation distances were calculated for a kind of worst-case scenario in which the farmer producing GM maize seed has to reduce his seed producing area and plant the most economic crop (i.e. wheat) as an alternative. This results in gross margin losses of almost 22% in the case of an additional 100 m isolation distance and almost one third of the gross margin if an extra 150 m isolation distance is added (Table 12). Planting additional male parent rows on the non-GM seed field reduces yield from the field which might be compensated for by the farmer producing GM maize seed. For this measure substantial opportunity costs of around 16% of the gross margin have to be added, particularly

40 20 rows correspond to a width of ~ 0.8*20 = 16 m.

Table 10: Adventitious presence in the "seed-seed" case depending on the relative size of seed plots, isolation distance, number of male rows and wind direction

Type of coexistence	Area of non-GM seed plot (in ha)	Isolation distance (in m)	Number of extra male parent rows	Adventitious presence (%)		Flowering time-lag (in degree-days) necessary to achieve ("downwind" situation")		
				Upwind (3m/s)	Downwind (3m/s)	0.5%	0.3%	0.1%
Seed-seed (GM seed plot of 5 ha)	0.5	100	0	0.22	0.79	90	90	120
			2	0.21	0.77			
			8	0.19	0.71	60		
			20	0.17	0.63			
		200	0	0.09	0.35	0	60	90
			2	0.08	0.33		30	
			8	0.08	0.31			
			20	0.07	0.28		0	
		300	0	0.05	0.2			
		400	0	0.03	0.13			60
	1	100	2	0.18	0.66	60	90	120
		200	0	0.08	0.31	0	30	90
		300	0	0.05	0.18		0	
		400	0	0.03	0.12			60
	2.5	100	2	0.14	0.52	30	90	120
		200	0	0.06	0.25	0	0	90
		300	0	0.04	0.15			
		400	0	0.03	0.1			60
	5	100	0	0.11	0.4	0	60	120
			2	0.11	0.4			
			8	0.1	0.37			
			20	0.09	0.34			
		200	0	0.05	0.19		0	90
			2	0.05	0.19			
			8	0.05	0.18			
			20	0.04	0.17			
		300	0	0.03	0.12			60
		400	0	0.02	0.08			0

In addition, for each situation, the flowering time-lag necessary to achieve 0.1%, 0.3% or 0.5% thresholds in the worst-case scenario (the non-GM plot downwind of the GM one) was calculated. For example, current isolation rules (100 m + 2 male rows) for small non-GM seed plots (0.5 ha) would not be sufficient in the "downwind" case to achieve 0.5 % and would require a flowering time-lag of 90°days between varieties to achieve 0.3%. Alternatively, it would be sufficient to allocate GM and non-GM plots in such a way that the non-GM plot would be upwind of the GM one.
Rows highlighted in deep blue correspond to current isolation practices in French seed production.

if 18 additional male rows have to be cultivated (Table 12). Changing the flowering time of the seed maize varieties cultivated also has negative effects on yield which are quite substantial in the case of switching from very late to late varieties (30 degree-days). Farmers' loss of income due to this measure would total around 30% of the gross margin from maize seed production. The income losses are significantly lower if the flowering time is switched from late to mid-early varieties (Table 12).

Table 11: Adventitious presence in the "seed-crop" case depending on relative field sizes, isolation distance and wind direction

<table>
<tr><th rowspan="2">Type of coexistence</th><th rowspan="2">Area of non-GM seed cluster (in ha)</th><th rowspan="2">Isolation distance (in m)</th><th rowspan="2">Number of extra male parent rows</th><th colspan="2">Adventitious presence (%)</th><th colspan="3">Flowering time-lag (in degree-days) necessary to achieve ("downwind" situation)</th></tr>
<tr><th>Upwind (3m/s)</th><th>Downwind (3m/s)</th><th>0.5%</th><th>0.3%</th><th>0.1%</th></tr>
<tr><td rowspan="33">Seed-crop (GM crop field size 10 ha)</td><td rowspan="11">1</td><td>100</td><td>0</td><td>0.99</td><td>3.41</td><td>120</td><td rowspan="2">120</td><td>150</td></tr>
<tr><td rowspan="2">200</td><td>0</td><td>0.43</td><td>1.66</td><td rowspan="3">90</td><td rowspan="5">120</td></tr>
<tr><td>20</td><td>0.36</td><td>1.42</td><td rowspan="3">90</td></tr>
<tr><td>300</td><td>0</td><td>0.26</td><td>1.05</td></tr>
<tr><td>400</td><td>0</td><td>0.18</td><td>0.73</td><td>60</td></tr>
<tr><td>500</td><td>0</td><td>0.13</td><td>0.53</td><td>30</td><td rowspan="2">60</td></tr>
<tr><td>600</td><td>0</td><td>0.1</td><td>0.4</td><td rowspan="5">0</td><td rowspan="3">90</td></tr>
<tr><td>700</td><td>0</td><td>0.08</td><td>0.31</td><td>30</td></tr>
<tr><td>800</td><td>0</td><td>0.06</td><td>0.24</td><td rowspan="3">0</td></tr>
<tr><td>900</td><td>0</td><td>0.05</td><td>0.19</td><td rowspan="2">60</td></tr>
<tr><td>1000</td><td>0</td><td>0.04</td><td>0.15</td></tr>
<tr><td rowspan="11">5</td><td>100</td><td>0</td><td>0.63</td><td>2.25</td><td rowspan="3">90</td><td>120</td><td>150</td></tr>
<tr><td rowspan="2">200</td><td>0</td><td>0.31</td><td>1.2</td><td rowspan="3">90</td><td rowspan="4">120</td></tr>
<tr><td>20</td><td>0.27</td><td>1.07</td></tr>
<tr><td>300</td><td>0</td><td>0.19</td><td>0.77</td><td>60</td></tr>
<tr><td>400</td><td>0</td><td>0.14</td><td>0.54</td><td>30</td><td rowspan="2">60</td></tr>
<tr><td>500</td><td>0</td><td>0.1</td><td>0.4</td><td rowspan="6">0</td><td rowspan="3">90</td></tr>
<tr><td>600</td><td>0</td><td>0.08</td><td>0.3</td><td rowspan="5">0</td></tr>
<tr><td>700</td><td>0</td><td>0.06</td><td>0.23</td></tr>
<tr><td>800</td><td>0</td><td>0.05</td><td>0.18</td><td rowspan="3">60</td></tr>
<tr><td>900</td><td>0</td><td>0.04</td><td>0.15</td></tr>
<tr><td>1000</td><td>0</td><td>0.03</td><td>0.12</td></tr>
<tr><td rowspan="11">10</td><td rowspan="2">100</td><td>0</td><td>0.48</td><td>1.72</td><td rowspan="2">90</td><td rowspan="2">120</td><td rowspan="4">120</td></tr>
<tr><td>20</td><td>0.41</td><td>1.49</td></tr>
<tr><td>200</td><td>0</td><td>0.24</td><td>0.94</td><td>60</td><td>90</td></tr>
<tr><td>300</td><td>0</td><td>0.15</td><td>0.61</td><td>30</td><td rowspan="2">60</td></tr>
<tr><td>400</td><td>0</td><td>0.11</td><td>0.43</td><td rowspan="7">0</td><td rowspan="3">90</td></tr>
<tr><td>500</td><td>0</td><td>0.1</td><td>0.32</td><td>30</td></tr>
<tr><td>600</td><td>0</td><td>0.06</td><td>0.24</td><td rowspan="5">0</td></tr>
<tr><td>700</td><td>0</td><td>0.05</td><td>0.19</td><td rowspan="2">60</td></tr>
<tr><td>800</td><td>0</td><td>0.04</td><td>0.15</td></tr>
<tr><td>900</td><td>0</td><td>0.03</td><td>0.12</td><td>30</td></tr>
<tr><td>1000</td><td>0</td><td>0.02</td><td>0.1</td><td>0</td></tr>
</table>

In addition, for each situation, the flowering time-lag necessary to achieve 0.1%, 0.3% or 0.5% thresholds in the worst-case scenario (non-GM plot downwind of GM one) was calculated.
Rows highlighted in deep blue correspond to current isolation practices in seed production. Non-GM seed production areas are larger than those considered in the seed-seed case as clusters usually contain several seed plots.

The second step was to calculate the economic effects of combined coexistence measures, as simulated by MAPOD® model in the worst-case situation (non-GM field downwind of the GM one). First, the economic effects of coexistence measures between GM and non-GM seed plots (seed-seed scenario) were estimated. These results should be interpreted having in mind the difficulty

Table 12: Costs/income losses due to individual coexistence measures in maize seed production in France

Additional coexistence measure	Costs/income losses in €/ha	% of variable production costs	% of gross margin
Increasing isolation distance by:			
100 m (wheat as alternative crop)	322	14.8	21.6
150 m (wheat as alternative crop)	483	22.2	32.5
Planting additional male rows on non-GM seed maize field			
6 additional male rows	80.85	3.7	5.4
18 additional male rows	242.5	11.1	16.3
Changing flowering time of cultivated maize varieties from …			
Very late to late (30°days)	446.8	20.5	30.0
Late to mid-early (60°days)	114.0	5.2	7.6

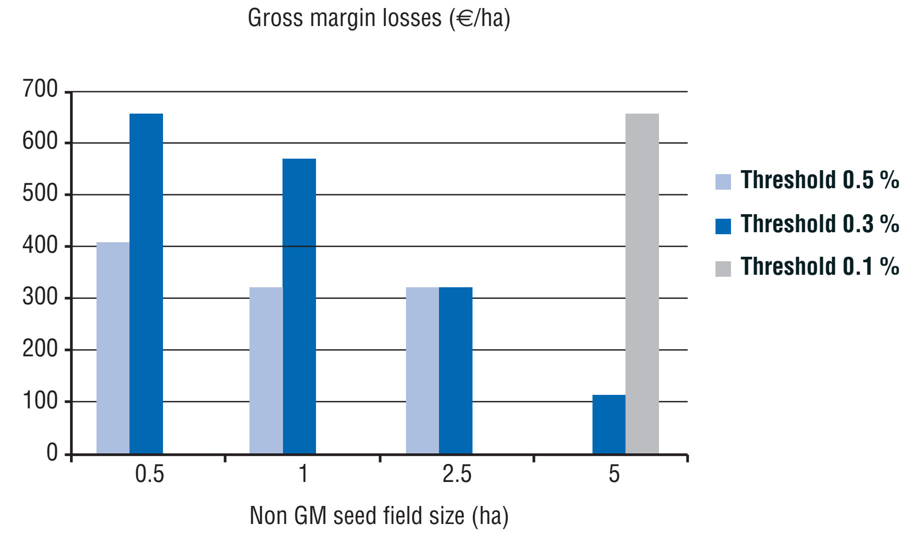
of quantification of the opportunity costs of increasing isolation distances. If the opportunity costs of increasing isolation distances are taken into account, the income losses for farmers due to the suggested coexistence measures can reach significant levels often exceeding 40% of the gross margin for maize seed production in France. This relates, in particular, to small non-GM seed production plots and low thresholds for adventitious presence of GM material (Appendix 11). The lowest per-hectare costs of combinations of coexistence measures necessary to meet a defined threshold differ considerably, depending on the sizes of neighbouring non-GM seed production plots. In order to meet a threshold of 0.5% in maize seed production, opportunity costs of around €410/ha have to be assumed (almost 28% of the gross margin) in the case of very small non-GM seed plots of 0.5 ha, while this threshold can be met without any additional costs in the case of 5 ha non-GM seed plots (Figure 11). The same picture emerges if a 0.3% threshold has to be met: in the case of 0.5 ha non-GM seed plots, gross margin losses of around €650/ha (around 44% of the gross margin) have to be expected, which fall to around €114/ha in the case of non-GM seed plot sizes of 5 ha. The gross margin losses of additional measures to meet a 0.1% level add up to more than €650/ha even in the "best case" 5 ha non-GM seed plots (Figure 11). It is therefore recommended to balance seed production plot sizes and to take care of the spatial pattern of GM and non-GM plots.

The next step was to calculate the economic effects of additional coexistence measures without the opportunity costs of isolation distances. The opportunity costs of this measure were not taken into consideration because they are very variable, depending on the organisational measures which seed breeding companies and seed producing farmers choose to implement in order to avoid a sharp reduction in the economically attractive maize seed production. In this case the opportunity costs of coexistence measures rarely exceed 20% of the gross margin for maize seed production (Appendix 8).

Seed-crop coexistence

The economic effects of coexistence measures were calculated for the crop-seed situation (i.e. a field producing a GM crop is in the neighbourhood of non-GM maize seed fields). By increasing isolation distances or planting 20 additional male parent rows, a significant

Figure 11: Gross margin losses due to the most effective coexistence measures (isolation distances, flowering time-lag, extra male parent rows) for different thresholds and field sizes of non-GM neighbouring fields in maize seed production situated downwind of GM fields



Note: This figure combines all the measures identified.

reduction in the levels of adventitious presence of GM material can be achieved in all non-GM seed field sizes simulated. Substantial opportunity costs of up to 20% of the gross margin for maize crop production can be expected if large numbers of additional male parent rows are planted, while increasing isolation distances causes no great gross margin losses in the crop-seed situation. The opportunity costs of increasing isolation distances are estimated at up to 5% of the gross margin for maize crop production in cases where a non-GM variety of maize is planted on the "isolation strip" of the GM maize crop field. Alternatively, if wheat is planted on this strip the opportunity costs will be up to 2% of the gross margin for maize crop production. It can be concluded that, in contrast to the seed-seed situation, in the crop-seed situation increasing isolation distances between GM crop and non-GM seed maize fields is a very cost-effective way of meeting thresholds of 0.5% or 0.3% for the adventitious presence of GM material in maize seeds.

Organisational effects of increasing isolation distances

The following analysis of organisational effects of increasing isolation distances in maize seed production is based on interviews with seed companies and a meeting in Paris with representatives of the seed industry.

If isolation distances were increased in maize seed production, re-organisation of fields used for maize seed production would be required in regions where GM varieties would be multiplied[41]. This process would lead to a reduction of the total area used for maize seed production in a specific region if maize seed production is organised according to a centralised plan. The more likely outcome is that individual seed multipliers will not produce GM seeds where this is economically not attractive. In particular, in regions with small field sizes significant absolute and relative reductions of the maize seed producing area could be expected. The loss of maize seed producing area would

41 It is assumed that multiplying of GM seeds offers a benefit compared to the current situation and that there is a demand for GM seeds in the EU.

result in a significant decline in the amount of certified maize seed produced in a specific region which might be followed by a loss of potential turnover from seed as well as declining market shares for the company concerned. Furthermore, additional time and management costs would be needed for re-organising the seed-producing area in the region due to increasing isolation distances. This would lead to rising fixed costs and declining profit margins for certified seed production both for seed breeding and multiplying companies as well as for farmers cooperating with them. Due to the decreasing area used for maize seed production, the diversity of seed varieties multiplied in a specific region could decline, not least in order to limit the additional costs of increasing isolation distances. Besides this, additional conflicts could be expected between seed producers during the decision-making process to see which farmers could participate in the economically attractive multiplication of seeds. As stated above, such a negative scenario is not likely, as GM seed multiplication will only take place if it adds value relative to the current situation.

One argument which was strongly stressed during the interviews with seed companies was the potential re-allocation of GM certified seed production to regions outside the EU. Due to the significant impact on costs, it was regarded as almost impossible to achieve bigger isolation distances in small-scale production areas like many maize seed producing regions in France or Germany, for example. Major factors for the allocation of seed producing areas are the production costs in a specific region as well as the security and quality of production. Countries like France or Germany were regarded as being competitive in maize seed production despite relatively high production costs, but this picture might change in future if costs were to increase significantly because higher isolation distances were required in case of multiplying GM seeds. In such a scenario, it was regarded as "realistic" that areas of GM certified maize seed production might be re-allocated step-by-step to regions outside the EU.

I.7. General conclusions for maize

This study found that the cross-pollination levels varied substantially, depending on the situations under consideration. This variability is significant even in a small region such as the one considered in Poitou-Charentes. However, the study indicates that, in a majority of situations, a 0.9% threshold can be achieved as long as proper machinery cleaning is performed and GM presence in seeds remains below 0.5%. This is mainly due to the fact that numerous fields are already isolated over landscape.

In the worst-case scenarios (adjacent fields, small non-GM fields, non-GM fields downwind of GM fields), simple coexistence rules, such as isolation distances, can ensure that coexistence is technically feasible. As such rules could lead to higher costs and in some cases to unequal effects on the farmer's freedom of choice, a diagnosis based on a flexible decision-support system may ease the coexistence and substantially reduce additional costs and facilitate choice to the maximum possible number of farmers. Such a system should take into account key factors such as isolation distances, climate, landscape patterns, flowering time-lag and even the amount of pollen produced by both GM and non-GM varieties.

It could be based on the results of the landscape gene flow modelling together with:

- a statistical analysis with the aid of GIS tools to determine the feasibility of measures proposed and especially the need for collaboration between farmers (see section I.5.6);
- an economic model evaluating the cost of scenarios.

Very low GM levels in non-GM production such as 0.1% can only be achieved if:

- GM presence in non-GM seeds is almost nil;
- No adventitious presence is due to machinery;

Non-GM fields are isolated enough from GM fields, the isolation distances depending on the climate, the varieties used and the level of GM cultivation in the region. In the landscape studied this will be impossible to achieve within a cluster.

The level of GM presence in seed production has an effect on the feasibility of coexistence between GM and non-GM grain maize. The lower the adventitious GM presence in non-GM seed, the higher the likelihood of meeting the 0.9% threshold in the subsequent grain maize production. As an example, given the climate conditions in Poitou-Charentes, if the adventitious presence in seed were to be cut from 0.5% to 0.3%, it would be possible to reduce isolation distances necessary under worst case conditions, and suitable for all field sizes, from 100 to 50 metres without additional measures necessary during cultivation. However, such a reduction in adventitious presence in seed may lead to higher constraints during seed production (e.g., a 200 metre increase in isolation distances in some situations), Facing such alternatives, the technical feasibility and the overall cost-benefit balance have to be addressed case by case. These increases and decreases in isolation distances are particularly important in the "Poitou-Charentes" and "Pyrénées-Atlantiques" contexts where maize is sown on a large proportion of the AUA.

Alternative measures for decreasing pollen flow from GM to non-GM fields could be obtained through biological containment. Indeed, decreasing cross-pollination by GM pollen in non-GM fields entails decreasing the amount of pollen emitted by GM fields. It is now possible to grow "CMS" varieties which are made by mixing cytoplasmic male sterile (CMS) hybrids with fertile hybrids. In this case, the effect on adventitious presence can be estimated as proportional to the decrease in the amount of pollen emitted. With a ratio of 75/25 (75% CMS), the adventitious presence in the neighbouring non-GM fields will decrease by 75%.

In this study, average values were considered for some key factors (e.g., production of pollen or wind speed). A preliminary sensitivity analysis was performed and it came out that the general conclusions would not change. Nevertheless, for implementing a case-by-case diagnosis, such variability factors should be taken into consideration. Anyway, whatever the coexistence rules adopted are, it might occur that thresholds could not be achieved in specific cases. Safety factors could be put in place but lead to drastic additional costs. The economic analysis comparing additional costs due to safety factors and losses due to unachieved thresholds is still to be performed.

II Sugar beet

II.1. Background

Sugar beet (*Beta vulgaris ssp. vulgaris* L.) is a biennial species displaying vegetative development and sucrose accumulation in the root during the first year and reproductive development, bolting and flowering during the second year. The crop is harvested at the end of the first year of development, before it can flower and produce seeds. The cultivation of GM sugar beet is not yet allowed in the EU, but the DG JRC/IPTS prospective study (Lheureux *et al*, 2003) gives several proposals of pipeline GM varieties potentially commercialized for the next 5 years.

Due to outcrossing from the wild population in seed production areas or under certain favourable climatic conditions, bolting and flowering can occur during the first year and, if not strictly controlled, leads to subsequent infestation of annual weed beets.

Beet is a self-incompatible, wind-pollinated plant that produces large amounts of pollen over a long flowering period. In the seed production areas of southern France and northern Italy, seed producers are faced with the problem of managing isolation distances between fields producing seed for different varieties or for different beet subspecies, such as beetroot and fodder beets. Seed producers also have to cope with the management of wild populations: *Beta vulgaris ssp. maritima*, wild annual beets growing both in the fields and in field margins. The major seed production regions are northern Italy and southern France but seeds are sold across Europe. Seeds are produced under individual contracts between growers and seed companies, which provide basic seeds or plants and collect harvested seeds in accordance with the "interprofessional agreement" for this sector. As seed production schemes are similar in France and Italy, the south-west region of France was selected as a case study in this project.

Germany and France are the main sugar beet crop production areas (around 400 000 ha each). Santerre in France and Lower Bavaria in Germany are typical production regions and were selected as case studies (see Appendix 11). Sugar beet cultivation is organised along the lines laid down in the EU Sugar Regime in 1968. Under this arrangement, the market is organised on the basis of quotas, with each sugar producer being allocated a sugar quota.

Farmers can grow sugar beet if and only if they have been allocated "delivery rights" to cultivate sugar beet. This regime ensures a real traceability of the supply chain.

II.2. Sources of admixture

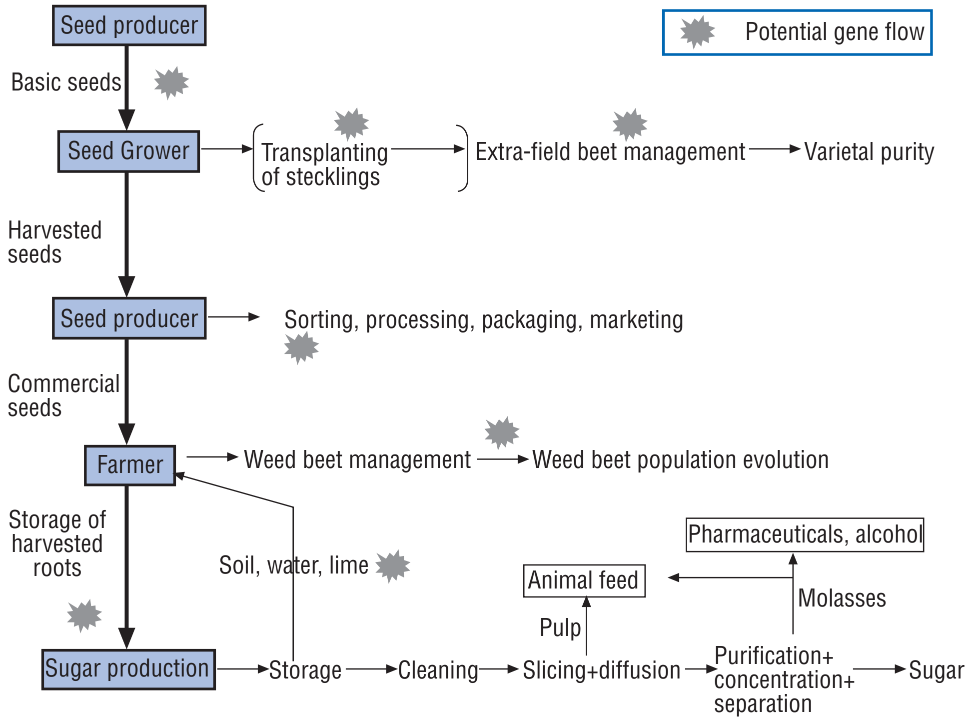
Figure 12 describes the sugar beet supply chain from basic seeds to the sugar plant. Several critical steps potentially related to coexistence issues have been identified:

1. GM presence in basic seeds;
2. Commingling during transport of basic seeds;
3. Production of beet seeds with or without steckling production;
4. Management and transport of seed lots;
5. Management of weed beets in root production fields;
6. Management of harvested roots;
7. Return of by-products of the sugar production chain.

II.3. Coexistence in sugar beet crop production

Sugar beet is cultivated for its root and is harvested before flowering. In a non-GM field, three sources of GM presence are possible:

Figure 12: Review of the sugar beet supply chain and identification of the major points of potential gene flow between GM and non-GM plants



- Presence of GM seeds in non-GM seed lots (see II.4);
- GM seeds remaining in sowing machines coming from GM sugar beet fields;
- Annual beets (annuality trait or vernalisation) which can flower, be pollinated by GM fields and lead to potential GM volunteers (annual weed beets).

However, these weed beets are unlikely to be harvested with sugar beet roots in the subsequent beet crops because:

- Bolters are often pulled up before harvesting in order to avoid seed production and as their long stems may cause problems with the machinery;
- Most bolters are located outside the sowing row and are therefore not harvested;
- If bolters are caught up by the harvester, they are likely to be eliminated due to their small root size.

Thus, bolting and cross-pollination may result in the presence of GM weed beets in non-GM fields (leading to weed control problems in the case of herbicide-tolerant crops) but not the commingling of GM and non-GM sugar beet roots beyond the field.

The GM presence in non-GM production will be due mainly to the GM presence in sown seeds (assuming that no commingling occurs during sowing and harvesting operations). Where the adventitious GM presence in non-GM seeds remains below 0.1% or 0.9%, the percentage of GM roots will consequently remain below the defined thresholds.

Therefore, if seed purity is guaranteed, adventitious presence in crop production can be avoided by applying the following measures:

- During sowing: thoroughly cleaning the drill or other machinery involved to avoid adventitious seed presence;
- During harvesting: thoroughly cleaning the harvester between different types of crops (a simple washing process requiring little time) or assigning machinery to a particular type of production;

- During post-harvesting: carefully applying the existing system of traceability for distinguishing beet piles. The accidental mixing of GM and non-GM beets is unlikely to occur because beet roots are big enough and heavy enough to make adventitious presence unlikely if beet piles are not adjacent;
- During transport: thoroughly cleaning lorries when moving from GM to non-GM piles (rapid operation);
- Concerning by-products: applying the labelling regulations (pulp and molasses use is already prohibited in organic farming).

II.4. Seed production

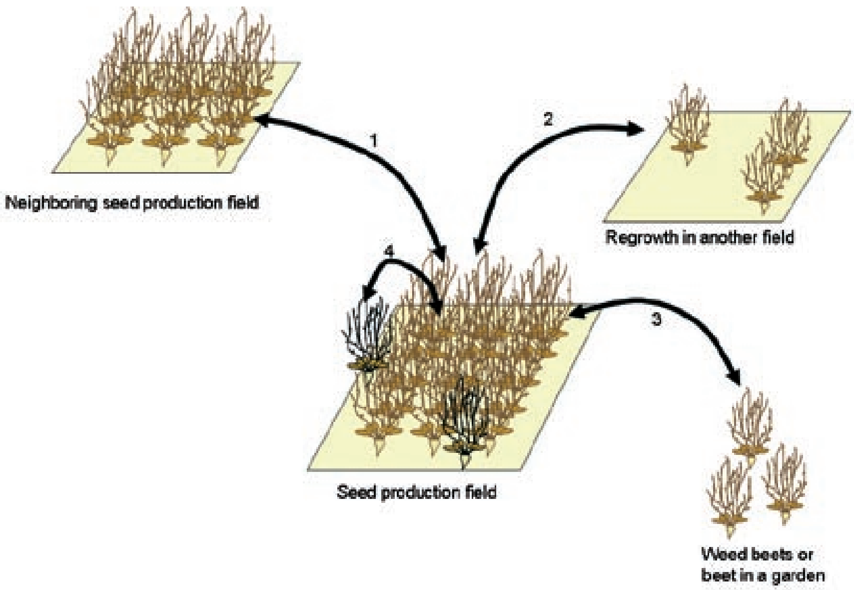
II.4.1. Background

In France, sugar beet seed production is carried out under contract with seed companies and must comply with the requirements of the multiplication industry, in the form of the GNIS[42]. An interprofessional agreement also specifies seed production quotas as well as the annual seed prices, which depend on seed quality. FNAMS[43] has published a technical guide to area management in order to help farmers to produce seeds with the required varietal purity rate (Broucqsault & Nardi, 1995). During seed production, the technicians of seed companies manage the distribution of seed production fields in the region, supervise farmers, provide them with technical assistance and monitor their fields in order to ensure that management rules are correctly applied. Seed production techniques are detailed in Appendix 9.

The seed production area is organised to minimise gene flow between the various forms of beets, which are all inter-fertile, i.e. sugar beet can cross with wild beets, fodder beets, red beets or Swiss chards.

Under the interprofessional agreement, an overall varietal impurity rate of 0.2% is acceptable,

Figure 13: Major sources of foreign pollen during beet seed production



1) another field used for beet seed production
2) re-growth in a field used for seed production the year before
3) wild beet populations in field margins and gardens
4) re-growth within a given field from a previous seed production cycle

42 Groupement National Interprofessionnel des Semences.
43 Fédération Nationale des Agriculteurs Multiplicateurs de Semences: National federation of seed growers (farmers)

with a maximum of 0.1 % annual and 0.1% red beets and fodder beets. For higher rates of varietal impurities, case-by-case negotiation is required to determine whether seed lots are accepted or rejected. If seed lots are not accepted, they must be destroyed under the supervision of SOC.

II.4.2. Sources of admixture

The potential sources of gene flow between seed production fields and their environment are summarised in Figure 13. Gene flow may occur between crops in two neighbouring fields or between the crop in a field and volunteers from a previous crop in that field or in another field, or between one field and wild beet populations in field margins or gardens.

In order to minimise the varietal impurity rate, several measures have been put in place:

- Seed production fields must be isolated.
- Seed growers have to control any source of admixture:
  - Between two beet seed productions, growers have to control plant re-growth.
  - The complete elimination of all plants of the same species as sugar beet (such as mangolds, fodder beet and Swiss chard) is compulsory. Under French law, producers are authorised to visit any fallow or set-aside land, as well as neighbouring gardens, within a range of at least one kilometre.
- Crops are carefully monitored over the complete growing cycle.
- Harvest, transport and storage conform to rules aimed at limiting seed losses and adventitious admixture between lots.

Beet seed production is thus already strictly regulated. Potential sources of admixture before, during and after beet seed production are summarised in Table 13.

II.4.3. Adjustments of farming practices

According to an opinion issued by an official working group of the French Ministry of Agriculture (Collective, 2002), strict compliance with existing rules for minimising gene flow between beet forms should be sufficient to limit GM levels in non-GM seed production to an order of magnitude of 0.5%. Nevertheless, to ensure long-term coexistence and to take into account the cumulative effects that would occur with crops like sugar beet, the work group proposed to take into consideration a "safety factor"[44] and to:

Table 13: Summary of the crucial points for coexistence between supply chains in beet seed production

Position in the supply chain	Risk of admixture
Before seed production	Varietal impurities in basic seeds Between stecklings and volunteers from a previous year Between lots of stecklings produced in the nursery
During seed production	Varietal impurities in stecklings Gene flow from another production field Re-growth from a previous year Gene flow from re-growth in another field Gene flow from wild populations
After seed production	Risk of exchanges between lots on the production farm Exchanges during transport

44 For maize, as no cumulative effects over time exist, the measures will be much more easily adjusted over time.

- reinforce existing rules for 0.5% — isolation distances, management of re-growth by methods not involving non-selective herbicides for GM seeds tolerant to such herbicides — plus additional measures for thresholds lower than 0.5%;
- to strictly control and monitor of these measures (time-consuming).

Based on expert opinion, Table 14 summarises the additional measures that could be implemented (for a full description of the measures, see Appendix 10).

The feasibility of such reinforced rules has been validated through a trial carried out in a steckling nursery, covering seed production in two consecutive years at three sites (Sicard, 2003).

Problems with the management of seed production at regional level are of importance for the management of coexisting supply chains. For example, public recording of the history of seed production fields would seem to be essential, given the possibility that a farmer may change seed company and given the risks associated with GM re-growth in a field used for GM production in year n and located close to a non-GM production field in year n+1. Therefore, fields for the production of GM stecklings and seeds should be registered with an official, public body to limit the risks of adventitious presence, as is already the case for some other species.

II.4.4. Economic effects of additional measures in sugar beet seed production

To estimate the economic effects of additional long term coexistence measures, we assumed a total income of €6 240/ha from sugar beet seed

Table 14: Specific practices used to limit admixture levels to 0.1%, 0.3% and 0.5% in sugar beet seed lots

Step in the production process		*Current practice /* additional measure		Threshold %
1	**Nursery plot management**	*Field pattern precisely defined on a map /* Map of the region with location of fields with GM seed production		0.1; 0.3
2	**Sowing**	*Careful cleaning of the drill between two plots /* Careful control of drill cleanliness = 0.5 h/variety plot/year		0.1
3	**Steckling harvest**	*Preparation and conditioning of steckling on the nursery plot /* Careful supervision = Quality assurance		0.1; 0.3
		Plot monitoring in subsequent years / Supervision of potential re-growths over several years and, in the event of weed beets occurring: a) destruction by hand pulling b) as an alternative, destruction by spraying selective herbicide Total time spent: 2h/ha		0.1; 0.3; 0.5
4	**Destruction of excess stecklings**	*Spraying of total herbicide after lifting /* Change to selective herbicide		0.1; 0.3; 0.5
5	**Seed production**	*Field identification to ensure precise interval between two seed crops /* Map of the region with location of fields with GM seed production		0.1; 0.3
6	**Isolation distance**	*Between pollinators of same ploidy: 300 m /* 1000 m isolation distance if the gene is borne by the pollinator	0.5h/ha	0.1; 0.3; 0.5
		Between pollinators of different ploidy: 600 m / Map of the region with location of fields with GM seed production:	0.5h/ha	0.1; 0.3
		Between sugar beet seed production and other types of beets:1000 m / Common management of production area by seed companies	0.5h/ha	0.1; 0.3
		Global management of wild beets and re-growths in seed production area / Increase the area where this must be done = 5 h/year		0.5
		Global management of wild beets and re-growths in seed production area / Increase the area where this must be done = 10 h/year		0.3
		Global management of wild beets and re-growths in seed production area / Increase the area where this must be done = 25 h/year		0.1
7	**Planting**	Destruction of excess stecklings on the seed production plot: no additional costs		
8	**Field management**	No costs of additional measures calculated for this study (see Appendix 10).		

Step in the production process		*Current practice/* additional measure	Threshold
9	Pollinator destruction	*Ploughing to speed up emergence of re-growth (e.g. false sowing) /* Very careful false sowing (period of intervention: just after harvest)	0.3
		One false sowing / One additional false sowing with use of rotary harrowing or Danish cultivator = 1 additional soil tillage	0.1
		Conventional machine cleaning in the field / In-field cleaning with water of mower machine used for pollinator destruction = 0.5 h/ha	0.1; 0.3
10	Harvest	*Combines cleaned in the field /* Combines must be cleaned more carefully with water before leaving each field (transportation loss) and on the farm (admixture between fields) = additional labour time	0.1; 0.3; 0.5
11	Transport and Storage	No costs of additional measures calculated for this study (see details in Appendix 10).	
12	Post harvest	*Control of re-growth the following year /* Control of re-growth over the 3 following years (1 h/ha/year, including hand pulling)	0.3
		Control of re-growth the following year / Control of re-growth over the 3 following years (3 h/ha/year, including hand pulling)	0.1
13	Seed cleaning and processing	No costs of additional measures calculated for this study (see details in Appendix 10).	
14	Distribution	No costs of additional measures calculated for this study (see details in Appendix 10).	

Seed production techniques are detailed in Appendix 9.

production based on a yield of 1.95 t/ha and a price of €3 200/t in the year 2004 (FNAMS, *pers. comm*). Taking into account variable production costs of €3 060/ha, a gross margin of €3 180/ha in 2004 forms the baseline for calculating costs for sugar beet seed production in France (FNAMS, *pers. comm.*). An overview of the costs of long-term coexistence measures for the different thresholds in sugar beet seed production is given in Table 15. For a threshold of 0.5%, the total costs of additional coexistence measures amount to almost €197/ha, which equals 6.2% of the gross margin for sugar beet seed production. Most of this amount is accounted for by the requirement to clean the harvester with water after each plot (63%) and the general management and supervision of an increased area of sugar beet seed production (19%). The additional measures required to achieve a threshold of 0.3% in sugar beet seed production cost around €246/ha (7.7% of the gross margin). Most of these costs are again accounted for by the requirement to clean the harvester with water after each plot (50%) and the general management and supervision of an increased production area (31%) (Table 15). Switching to a threshold of 0.1% can be expected to nearly double the costs of long-term coexistence measures compared with the 0.3% threshold. Around 15% of variable production costs will be necessary to meet the threshold of 0.1%, with almost half of this going on the supervision and global management of an increased production area. The switch from a 0.5% to a 0.1% threshold is likely to bring about a considerable increase in the costs of measures required in the final production field, while the costs of measures carried out in the nursery field will remain below €40/ha regardless of the threshold level.

II.5. Conclusions on coexistence in sugar beet production

Bolting and cross-pollination may result in the presence of GM weed beets in non-GM fields (leading to weed control problems in the case of herbicide-tolerant crops) but not the commingling of GM and non-GM sugar beet roots beyond the field. Thus, GM presence in non-GM production will be mainly due to the level of GM presence in sown seeds (assuming that no commingling occurs during sowing and harvesting operations). Where the adventitious GM presence in non-

Table 15: Additional costs of long term coexistence measures for different thresholds in sugar beet seed production

Costs of additional measures	0.1%		0.3%		0.5%	
	€/ha	%	€/ha	%	€/ha	%
Nursery field						
Precisely defined map with location of GM fields	3.81	1%	3.81	2%	3.81	2%
Careful control of drill cleanliness	3.81	1%	-			
Extra supervision of potential re-growths	15.22	3%	15.22	6%	15.22	8%
Destruction of stecklings - use of selective herbicide	12.83	3%	12.83	5%	12.83	7%
Seed production field						
Field identification and mapping	3.81	1%	3.81	2%	3.81	2%
Additional mechanical or chemical destruction of wild beets and re-growths (25/10/5 hours for supervision and global management)	190.25	42%	76.1	31%	38.05	19%
Additional false sowing to destroy pollinators	70.31	16%	-		-	
In-field cleaning of mower machine	3.81	1%	3.81	2%	-	
Cleaning of combine with water after each plot	123.24	27%	123.24	50%	123.24	63%
Additional control of re-growth	22.83	5%	7.61	3%	-	
Total costs	449.90	100%	246.42	100%	196.95	100%
Proportion of variable production costs	14.7%		8.1%		6.4%	
Proportion of gross margin	14.1%		7.7%		6.2%	

GM seed production remains below the defined threshold (0.1% or 0.9%), there is no coexistence issue for sugar beet crop production.

The key issue for the coexistence of GM and non-GM sugar beet is therefore the need to ensure seed purity.

- In France, seed production is already tightly controlled because of the drastic impact that adventitious admixtures have already had on conventional varieties (control of the annuality trait). Seed production usually accepts less than 0.2 % of varietal impurity. Acception of seed lots with higher levels is negotiated case by case.
- The improvements that have been proposed aim at strengthening current measures, in order to avoid long-term cumulative effects, with the strict management of re-growth plants by methods which do not include non-selective herbicides for GM seeds tolerant to such herbicides, as well as an improvement in seed lot labelling and the traceability of fields used in the GM seed supply chain.
- The way the transgene is introduced into the variety has been identified as a critical point with implications for the entire supply chain. If the transgene is borne by the pollinator, rules for managing seed production areas must be considerably strengthened because pollen donors produce huge amounts of pollen likely to flow from GM seed production fields to other fields or wild beet populations. Nevertheless, paternal inheritance limits gene flow between transgenic sugar beet crops and other crops in root production areas.
- If the transgene is borne by the mother plant, the management of seed production areas focuses on the control of re-growth in the years after seed production. Coexistence is easier to ensure if re-growth is managed carefully. However, management is more difficult in root production fields. In these fields, if the transgene is borne by the mother

plant, every bolter in transgenic sugar beet fields, whether genetically annual or vernalised, will bear the transgene and thus all the pollen produced in these fields is a potential source of admixture with other weed beet populations. Additional measures are therefore required to manage weed beet populations in transgenic sugar beet fields.

- Problems related to the management of the agricultural region are of importance. As seed companies and seed growers operate in the same areas, GM steckling and seed production sites should be registered very carefully and managed through an official public body. The seed production history would then be publicly available and thus ensure that non-GM seed production could not occur near a field where GM seed production had been carried out the year before.
- For thresholds of 0.5% or 0.3% adventitious presence of GM varieties, the costs of additional long term coexistence measures for sugar beet seed production will be below 8% of the gross margin for this crop. If a threshold of 0.1% has to be met, however, a doubling of these costs can be expected (Table 15).

II.6. Weed beet: an agronomic issue to be considered

Although there is no specific coexistence issue for sugar beet root production, agronomic issues resulting from the development of weed beets in herbicide-tolerant (HT) varieties should be considered over a long-term perspective in the farm and because of the possibility of conflicts between neighbour farmers.

Indeed, technical issues arise for the management of weed beets if the weed beet population becomes resistant to herbicides. The presence of weed beet in sugar beet crops results in a reduced sugar yield (approximately 10% sugar yield loss per weed beet plant per m²[45]) and difficulties with harvesting and sugar extraction. These problems result from differences in the reproductive cycle, as sugar beet is biennial and weed beets are annuals. The appearance of an HT weed beet population in a non-GM field and the subsequent weed control problems may create interest conflicts between non-GM and GM crop growers.

Simulations were carried out on typical farms (France and Bavaria – Appendix 12, 13 & 14) with the GeneSys®-Beet model (Sester *et al*, 2003 & 2004, see Appendix 11). The aim was to rank cropping systems according to the risk of the development of transgenic weed beet populations.

II.6.1. Effect of GM presence in seeds

The impact of various levels — 0.1%, 0.3% and 0.5% — of adventitious presence of GMseeds was simulated. No differences were observed, regardless of the situation tested. Thus, agricultural practices seem to be the main driving force behind the development of weed beet populations.

In the simulations where best practices for weed beet management were applied (baseline), the risk appeared to be well controlled in the fields without GM sugar beet. Nevertheless, other situations were also tested to represent various potentially high-risk situations (quality of bolter management, variations in soil tillage, etc.).

II.6.2. Effect of changing practices

Adjustments in GM crop grower practices to decrease the weed beet population in non-GM fields were tested (see detailed scenarios in Appendix 14). Ploughing has a major effect on the development of the weed beet population: fields with simplified soil tillage had smaller seed

45 Source: ITB (French technical institute for sugar beet).

banks than fields with the conventional cropping system. Furthermore, the annual ploughing of fields with transgenic sugar beet in rotation generally resulted in higher levels of infestation than the basic cropping system. Plots with the organic cropping system had seed banks with the smallest percentage of GM seeds in each simulation. This may be due to the three years of alfalfa in rotation. Weed beets cannot survive this period and therefore cannot produce seeds.

Having the transgene present in the pollinator during seed production also appears to limit gene dispersal effectively and this method was generally the best way to limit field infestation. This means of introducing the transgene makes it possible to manage bolters generated by accidental pollination by annual beets, as the resulting bolters are sensitive to a non-selective herbicide. However, this type of variety creates other problems in the management of seed production, as discussed above. Lastly, to prevent gene dispersal from their fields, hand pulling of bolters appeared to be one of the best solutions for farmers of transgenic sugar beet. This practice is highly feasible as it is already used in current cropping systems.

Simulations were run considering actual agricultural landscapes and crop allocation (Appendix 12 & 13). Therefore a range of isolation distances between GM and non–GM fields was tested. Results show that it could be possible for the GM crop grower to manage weed beet infestation risk by changing techniques in his fields without having to implement isolation distances with neighbouring non-GM crops.

II.6.3. Economic effects of weed beet management in sugar beet crop production

In a first set of simulations for sugar beet crop production in Picardie (France) and Lower Bavaria (Germany), best practices for weed beet management were applied in non-GM fields surrounding the GM beet fields (baseline, see Appendixes 12 and 13). Weed beet populations appeared to be well controlled in these fields. Thus, no extra-costs have to be calculated for weed beet management measures. Nevertheless, other situations were tested in a second set of simulations to represent various potentially high-risk situations in neighbouring non-GM fields (for instance, poor quality of bolter management). In the next step of the project, the impact of different measures applied by the GM crop grower on the GM seed content in the seed banks of both the GM field and neighbouring non-GM fields was simulated.

For France, variable production costs of €720/ha and a gross margin of €2 569/ha formed the baseline for the economic analysis where sugar beet crop production is concerned (CEDUS,

Table 16: Costs of adapting current weed beet management practices in sugar beet crop production

Critical points	Adaptation of current practice	Measure cost (€/ha)	
		France	Germany
Sowing	Cleaning the drilling machine	24.00	26.89
Cultivation	Two rounds of hand pulling to destroy weed beets	15.22	21.00
Total costs (€/ha)		**39.22**	**47.89**
% of variable production costs (A quota)		**5.5%**	**4.4%**
% of gross margin (A quota)		**1.5%**	**1.4%**

NB: For the purposes of this study, hand pulling is regarded as an additional measure in the management of herbicide-tolerant sugar beet crop production.

46 Figures presented in this paragraph represent an average of the years 2001 to 2003.

2004, Teyssier 2003)[46]. With variable production costs of €1 090/ha and a gross margin of €3 505 / ha (Bavarian State Research Centre for Agriculture, *pers. comm.*, 2004[47]), the respective figures are slightly higher in Lower Bavaria compared to Picardie. To control critical points in sugar beet crop production, additional cleaning of a (rented) drilling machine and two rounds of hand pulling of weed beets in GM fields[48] in both regions would be required. The total costs of these measures were calculated to be €39.22/ha in France and €47.89 in Germany (Table 16), equal to 1.5% or 1.4% of the gross margin, respectively.

The effect of hand pulling in the GM fields on the GM seed content in the seed banks of neighbouring non-GM fields was simulated in different situations. The corresponding costs are shown in Table 17. A high efficiency for the first hand pulling of weed beets in GM fields can be observed, in particular for neighbouring non-GM fields without hand pulling. In this case, the relative costs of the first hand pulling of weed beets on GM fields are often below €2/1000 seeds. Where the initial adventitious presence of GM seeds is relatively low, the relative costs of the first hand pulling of weed beets on the GM field might exceed €5/1000 seeds (Table 17). However, this measure still can be recommended as a "precautionary activity" since the absolute costs of two rounds of hand pulling are around 2% of the total variable production costs of sugar beet crop production in France and Germany.

It should be noted that extra costs would certainly be lower as this practice is already used in current cropping systems.

II.7. General conclusion for sugar beet

The way the transgene is introduced in the variety has been identified as a critical point with implications along the whole supply chain. If the transgene is borne by the pollinator parent, rules for managing seed production areas must be strengthened because pollen donors produce a huge amount of pollen, and pollen flow from GM seed production fields to other fields or wild beet populations will occur over a wide area. Nevertheless, this paternal inheritance will limit gene flow between transgenic sugar beet crops and other crops where there is coexistence in root production areas.

If the transgene is borne by the mother plant, the management of seed production areas will

Table 17: Efficiency of coexistence measures for neighbouring non-GM fields (without hand pulling) in different farm types in sugar beet crop production (50% adoption of GM in region)

Measure on the GM field	Farm 1 France (large, clustered fields)	Farm 2 France (large, dispersed fields)	Farm 3 France (small, dispersed fields)	Farm 4 Germany (small, dispersed fields)
	Number of GM seeds in seed bank after 15 years			
0 hand pulling	3 960	9 090	33 200	1 640
1 hand pulling *	399	393	3 640	196
2 hand pullings *	210	202	1 360	96
Costs of reducing GM seeds in seed bank of neighbouring fields (€/1000 seeds)				
1 hand pulling *	2.14	0.88	0.26	7.27
2 hand pullings *	40.26	39.84	3.34	105.00

** For the purposes of this study, hand pulling is regarded as an additional measure in the management of herbicide-tolerant sugar beet crop production.*

47 Personal communication on economics of sugar beet crop production, August 2004.
48 For the basic situation, it is assumed that there is no hand pulling in GM fields (bolters are controlled by glyphosate spraying).

have to focus on the control of re-growth plants in the years after seed production. With careful management of re-growth, coexistence is easier to ensure. However, management is more difficult in root production fields. In transgenic sugar beet fields, every bolter, whether genetically annual or vernalised, will bear the transgene and all the pollen produced in these fields is then a potential source of admixture with other weed beet populations. This requires additional measures to manage weed beet populations in GM sugar beet fields (hand pulling for instance) but does not require to implement isolation distances with non-GM fields.

The results on management of HT weed beets have been obtained through simulations with the GeneSys-Beet model, but should be used carefully because GeneSys-Beet is a new model and in the process of validation (See Appendix 11). In addition, as the aim with the model is to rank cropping systems, the specific data for each cropping system should be used as they stand but always compared with basic situations.

To conclude this study for the sugar beet supply chain, it is important to note that sugar beet is a very specific case of coexistence. On the one hand, seed production is already very strictly controlled because of the drastic impact that adventitious admixture could have even on conventional varieties. On the other hand, the sugar beet crop area has no problem with harvest purity except for adventitious GM seed presence in seed lots or admixture between harvest piles. However, this is very limited because the harvest is not seeds but large roots.

III. Cotton

III.1. Background

Cotton (*Gossypium spp.*) is the most important non-food crop in the world. This fact has made it one of the main targets of biotechnology. The cultivation of GM varieties of cotton is widespread throughout the world, with an increasing trend over recent years (ICAC[49] has estimated that 26% of the world cotton area will make use of GM varieties in 2005/06). The cultivation of GM cotton is not yet allowed in the EU, but several proposals are in the regulatory pipeline. Although European cotton only represents less than 1.5% of the world's total cotton area, the wide and quick expansion of GM varieties makes it interesting to study coexistence in the European context.

With 90 000 ha, Spain is the EU's second largest cotton producer behind Greece (ICAC, 2004), and 98% of the Spanish cotton crop area is concentrated in Andalusia, in the south of the country (MAPA, 2004).

The specific objectives derived from the general objectives of this project are to:

- Identify sources and estimate levels of adventitious admixture of GM in non-GM cotton;
- Propose agricultural practices adapted to coexistence scenarios and estimate the levels of adventitious admixture under current agricultural practices and under the proposed adapted practices.

  The scope of this study includes:

- Cotton growing in Andalusia, including the whole production cycle from farm to ginning factory;
- Seed production farms and fibre production farms (See Appendix 15);
- Presence of GM cotton in the region: 10% and 50%;
- Thresholds of GM cotton presence in non-GM production: 0.1% and 0.5% for seed production; 0.1 and 0.9% for fibre production;
- GM cotton based and non-GM cotton based farming production systems.

III.2. Identification of possible sources of admixture

By analysing cultivation techniques, possible sources of admixture between GM and non-GM cotton were identified for the case of coexistence both on the farm and in the region. In the entire production process, from the planting of the crop to the entry of the product into the ginner, nine possible points have been identified as potential sources of admixture. These are:

A) **Seeds from the previous year's harvest,** which remain on the ground, giving rise to new cotton plants and mixing with the crop. However, due to climatic and agricultural practices in the Guadalquivir Valley and according to the experts consulted, the admixture from this source is negligible.

B) **Seeds for sowing**, which may contain GM cotton seeds as an impurity. It is assumed that:

   - Imported seeds might contain GM seeds while the seeds produced in Spain do not. As 50% of the sown seeds are imported (mainly from the United States and Australia), the maximum probability of a cotton seed lot being a source of adventitious GM admixture is considered to be 50%;

49 ICAC: International Cotton Advisory Committee

- The level of impurity for seed production is the maximum percentage of off-type plants for the basic seed (to obtain R1) that is permitted under current legislation, that is, 0.2%[50]
- All these impurities (off-type plants) are due to GM cotton.

These assumptions lead to the worst-case scenario. It is assumed that the effect of introducing GM cotton in Spain on seed purity would be negligible, but only during the first years of adoption.

C) **Seed storage**, both in private warehouses and on the farm itself. If storage is in bulk, there could be a risk of admixture between seeds of GM and non-GM varieties. According to the experts consulted, however, farmers currently buy packaged, certified seed. Under current legislation, certified seed must ensure a minimum specific purity. So bulk of certified seed respect this threshold and therefore, risk of adventitious admixture in farm storage can be considered nil.

D) **Sowing**, where admixture could take place between the seeds remaining in the drill after sowing of GM cotton on another plot. The probability that the drill has been previously used to sow a plot of GM cotton is equal to the proportion of GM cotton grown on the farm or in the region, i.e. 10% or 50%, depending on the scenario considered.

E) **Cross-pollination**. The cotton plant is almost autogamous, but does have a certain rate of outcrossing (as a consequence of pollination by insects), which varies between the different production zones around the world. According to the experts consulted, the outcrossing rate in Andalusia is estimated at 1%.

F) **Harvesting**. Cotton residue (both seeds and fibre) from the previous plot remains in the harvester. This residue will mix with the cotton harvested later. If the previous plot contains GM cotton, adventitious admixture will occur. According to experts, the amount of cotton that remains in the harvester from the previous plot is about 20 kg. This residual cotton might be reduced to 4 kg by a single cleaning operation.

G) **Transport**. Cotton is transported from the plot where it has been harvested to the intermediate warehouse or directly to the ginner, with cotton residue (both fibre and seeds) remaining in the back of the truck or in the trailer after unloading. The amount of cotton that might remain in the trailer after unloading is around 10 kg, according to the experts. If the trailer is cleaned, which is already done in seed producing fields, the amount of cotton remaining is negligible, and is considered here to be zero.

H) **Intermediate storage**. In the opinion of the experts, the intermediate storage of cotton represents an extremely high fire risk and cotton is not usually stored by the farmer on the farm. Thus, intermediate storage will only be in the warehouses of ginners, which do not form part of this study. However, the evaluation of admixture risk during this storage would require a specific study.

I) **Crop remains**, including both fibre and seeds, which are left after the harvest and which could become mixed with the product harvested in the following season. In the opinion of the experts consulted, however, the practices used to eliminate crop remains make it impossible for plant material from the previous season (season n-1) to mix with the harvest of the current season (season n).

III. 3. Definition of farm types

Studies were carried out with conventional farms producing non-GM cotton and with mixed

50 Under Order APA 3321/2003, of 20 November, which modifies the Technical Regulations for the Control and Certification of Oil-bearing Plant Seeds and the Technical Regulations for the Control and Certification of Fibre Plants.

farms, called "coexistence farms" since they produce both GM and non-GM cotton (10% or 50%, in the two scenarios).

Farms producing cotton for fibre, both conventional and coexistence farms, are broken down into small farms (shared machinery) and large farms (own machinery). No distinction is made between farms of different sizes producing cotton for seed, since they are usually small and care is taken to clean the machinery thoroughly to prevent admixture.

The types included in the first scenario are numbered 1 to 6. In this scenario (10% GM cotton on the farm and in the region), no type 5 is considered, as it was estimated that on a small farm (5 hectares of cotton) it would be unusual to sow only 10% of GM cotton (5 000 m^2).

In the table 18, the average size of farm, the average cotton crop area on the farm and the average cotton plot size on the farm are shown. For seed cotton farms, insufficient information was available to calculate any of these three values, but as expert opinion indicates they are small farms, the calculations are for an average plot size of 2.77 hectares.

III.4. Estimation of Levels of Adventitious Admixture

In order to estimate the levels and risks of adventitious admixture for each farm type and each scenario, a probabilistic method has been used. Basic parameters and relations among variables have been obtained from an expert panel in order to build the calculation model. This model determines the maximum level of adventitious presence of GM cotton in non-GM cotton caused by each possible source of admixture (critical points of the production process). Moreover, the model can evaluate the risk of adventitious GM presence in terms of the probability of it not exceeding an established threshold.

In order to determine the levels and risks of adventitious admixture under the two scenarios for GM cotton adoption in the region (10% and 50%), 6 farm types are considered (Appendix 15).

A set of current farming practices has been identified for each farm type to estimate the baseline level of adventitious presence of GM cotton in non-GM cotton. Taking into account these practices, the sources of adventitious admixture (critical points) are: seed impurities, seeds

Table 18: Cotton farm type characteristics

Production	Farm types		Characteristics			
	10% scenario farm types	50% scenario farm types	Production system	Average farm size	Average cotton crop area on farm	Average size of cotton plot
Seed	**1**	**1'**	**Conventional** (100% non-GM)			2.77 ha
Fibre	**2**	**2'**	**Coexistence** (10%-50% GM)			2.77 ha
	3	**3'**	**Small conventional** (100% non-GM and shared machinery)	16 ha	5 ha	2.77 ha
	4	**4'**	**Large conventional** (100% non-GM and own machinery)	160 ha	30 ha	9.70 ha
	-	**5'**	**Small coexistence** (50% GM and shared machinery)	16 ha	5 ha	2.77 ha
	6	**6'**	**Large coexistence** (10%-50% GM and own machinery)	160 ha	30 ha	9.70 ha

remaining in the drill after sowing of GM cotton on another plot, cross-pollination, cotton (seed and fibre) from the previous plot remaining in the harvester (harvesting) and in the back of the trailer (transport). The rate of seed impurity is considered to be 0.2% (current Spanish legislation) for seed production and 0.5%[51] for fibre production. All seed impurities are considered to be GM impurities. The *Current* rows in Table 21 show the maximum contribution of each admixture source to the final estimated presence of GM cotton in non-GM cotton with current practices.

Under the current practices as defined in the study, the levels of adventitious GM presence are estimated to range from 0.36% to 1.82% for the farm types considered.

The contribution of cross-pollination is negligible due to the fact that the cotton plant is 99 % autogamous. Seed impurities are an important source of adventitious admixture in all farm types, especially in seed production farms.

Harvest and transport are two relevant sources of admixture in small farms with shared machinery.

Current practices are sufficient to ensure compliance with the highest threshold (0.5%)in seed production farms in both scenarios.

In the 10% GM cotton scenario, the probability of exceeding the threshold of 0.9% of GM presence in fibre production is very low. Only small non-GM farms using shared machinery have a small risk of admixture (6%). However this probability increases in the 50% GM cotton scenario, mainly in farms that share machinery (Table 21).

III.5. Practices Adapted to Coexistence Scenarios

Taking into account the contribution of each potential source of admixture, a set of adapted practices has been proposed in order to reduce the final presence of GM cotton (Table 19) to comply with the thresholds. These farming practices might already be used by GM-cotton farmers. Some of the farm types studied therefore do not have to take measures to implement such practices, although they will be benefiting from them.

The adapted practices were selected by an expert panel from a list of practices compiled from the literature. These practices are easy to implement and consist of compulsory cleaning of the drill, harvester and trailer after sowing, harvesting and transport from GM cotton plots.

Since all these proposed practices correspond to those currently used in seed production, they will not reduce the adventitious presence of GM cotton on seed producer farms.

The maximum admixture levels under this set of adapted practices in fibre production are estimated to range from 0.62% (large farms with own machinery) to 0.77% (small farms with shared machinery).

The results obtained (Table 21) show that this set of practices could keep the adventitious presence of GM cotton under the threshold of

Table 19: First proposal for the adaptation of agricultural practices (adapted practices 1)

Sources of adventitious admixture	Proposed adaptation of current practice 1
Sowing	Obligatory cleaning of the hoppers of the drill after sowing of GM plots
Harvesting	Obligatory cleaning of the harvester after harvesting of GM plots
Transport	Obligatory cleaning of the trailer after transport of GM cotton

51 Labelling thresholds for GM adventitious presence in seeds proposed by the scientific committee on plants (SANCO/1542/2003).

0.5% for seed production and 0.9% for fibre production in both scenarios for GM cotton in the region (10% and 50%).

However, the lowest level (0.1%) cannot be guaranteed. Although the probability of meeting this threshold has increased, the adapted practices are not sufficient by themselves since the probability of not exceeding this threshold varies between 25% and 50% depending on farm types and the GM cotton scenario (Table 22).

Table 20: Second set of adapted measures

Sources of adventitious admixture	Proposed adaptation of current practice 2
Seed for sowing	Reduction in seed impurity percentage permitted under current regulations
Sowing	Obligatory use of separate machinery on GM and non-GM plots
Harvesting	Restrictions on shared use of harvesters (different machines for GM and non-GM crops)
Transport	Obligatory cleaning of the trailer after transport of GM cotton

Table 21: Maximum estimated levels of adventitious presence of GM cotton in non-GM cotton for different farm types studied

Farm type		Set of farming practices	Maximum estimated levels of admixture: Critical Point (sources of adventitious admixture)					
			Seed for sowing	Sowing	Cross Pollination	Harvest	Transport	Total Admixture
Seed Production	**Conventional** (100% non-GM)	***Current***	0.21%	0.01%	-	0.14%	-	**0.36%**
		Adapted 1	0.21%	0.01%	-	0.14%	-	**0.36%**
		Adapted 2	0.10%	-	-	-	-	**0.10%**
	Coexistence (GM + non-GM)	***Current***	0.21%	0.01%	-	0.14%	-	**0.36%**
		Adapted 1	0.21%	0.01%	-	0.14%	-	**0.36%**
		Adapted 2	0.10%	-	-	-	-	**0.10%**
Fibre Production	**Small** (shared machinery) **Conventional** (100% non-GM)	***Current***	0.52%	0.17%	0.10%	0.69%	0.34%	**1.82%**
		Adapted 1	0.52%	0.01%	0.10%	0.14%	-	**0.77%**
		Adapted 2	0.10%	-	0.10%	-	-	**0.20%**
	Large (own machinery) **Conventional** (100% non-GM)	***Current***	0.52%	0.05%	0.05%	0.20%	0.10%	**0.92%**
		Adapted 1	0.52%	-	0.05%	0.04%	-	**0.62%**
		Adapted 2	0.10%	-	0.05%	-	-	**0.15%**
	Small (shared machinery) **Coexistence** (GM + non-GM)	***Current***	0.52%	0.17%	0.10%	0.69%	0.34%	**1.82%**
		Adapted 1	0.52%	0.17%	0.10%	0.69%	0.34%	**1.82%**
		Adapted 2	0.10%	-	0.10%	-	-	**0.20%**
	Large (own machinery) **Coexistence** (GM + non-GM)	***Current***	0.52%	0.05%	0.05%	0.20%	0.10%	**0.92%**
		Adapted 1	0.52%	-	0.05%	0.04%	-	**0.72%**
		Adapted 2	0.10%	-	0.05%	-	-	**0.15%**

NB: Studies were carried out with conventional farms producing non-GM cotton and with mixed farms, called "coexistence farms" since they produce both GM and non-GM cotton (10% or 50%, in the two scenarios)

A second set of stricter practices (Table 20) is proposed, mainly consisting of not allowing the sharing of machinery between GM cotton plots and non-GM cotton plots for all farm types, and reducing the legal limits for seed impurity. These measures will ensure compliance with the 0.1% level for the adventitious presence of GM-cotton in non-GM cotton (Tables 21 and 22). Nevertheless, these practices are more difficult to implement and their associated additional costs are difficult to assign exclusively to GM plots.

III.6. Economic effects of coexistence measures in cotton production

III.6.1 Economic effects of coexistence measures in cotton seed production

A typical farmer earns a total income of €3 178/ha from cotton seed production in Andalusia, with total variable production costs amounting to €2 107/ha. This results in an average gross margin of €1 071/ha in 2004 (DAP, *pers.*

Table 22: Probability of not exceeding the threshold for adventitious presence with current practices and with the two proposed sets of adapted practices

Farm type		Set of farming practices	Probability of not exceeding proposed threshold			
			10% GM cotton in the region		50% GM cotton in the region	
			Threshold 0.1%	Threshold 0.5% / 0.9%	Threshold 0.1%	Threshold 0.5% / 0.9%
Seed Production	**Conventional** (100% non-GM)	***Current***	45%	100%	25%	100%
		Adapted 1	45%	100%	25%	100%
		Adapted 2	100%	100%	100%	100%
	Coexistence (GM + non-GM)	***Current***	45%	100%	25%	100%
		Adapted 1	45%	100%	25%	100%
		Adapted 2	100%	100%	100%	100%
Fibre Production	**Small** (shared machinery) **Conventional** (100% non-GM)	***Current***	34%	94%	4%	52%
		Adapted 1	45%	100%	25%	100%
		Adapted 2	100%	100%	100%	100%
	Large (own machinery) **Conventional** (100% non-GM)	***Current***	50%	100%	50%	100%
		Adapted 1	50%	100%	50%	100%
		Adapted 2	100%	100%	100%	100%
	Small (shared machinery) **Coexistence** (GM + non-GM)	***Current***	Unrealistic case (See Appendix 15 for explanations)		3%	50%
		Adapted 1			25%	100%
		Adapted 2			100%	100%
	Large (own machinery) **Coexistence** (GM + non-GM)	***Current***	44%	100%	13%	97%
		Adapted 1	50%	100%	50%	100%
		Adapted 2	100%	100%	100%	100%

NB: Thresholds for GM cotton presence in non-GM production: 0.1% and 0.5% for seed production; 0.1% and 0.9% for fibre production

Table 23: Costs of individual additional measures in cotton production (€/ha)

Additional measures	Small farms	Large farms
Cleaning the drilling machine	12.48	10.35
Alternative solution: renting a separate drilling machine	90.10	
Clean the harvester	20.86	17.15
Alternative solution: renting a separate harvester	251.44	
Cleaning the trailer	6.60	6.60
Alternative solution: renting a separate trailer	59.42	

comm.). In order to comply with a threshold of 0.5% adventitious GM presence in cotton seed production, no additional measures are required besides those already in place for certified seed production. Thus, no additional costs are borne by GM cotton seed producing farmers.

III.6.2 Cost effects of coexistence measures in cotton fibre production

In cotton fibre production, economic performance differs between small and large farms in Andalusia. While a total income of €3 001/ha can be earned with this crop for both farm types, small farms have slightly higher variable production costs of €2 059/ha, resulting in a gross margin of €943/ha compared with €1 007/ha for large cotton-producing farms in 2004 (DAP, *pers. comm*) (for details of the farm types see appendix 15). Additional coexistence measures are necessary for small farms to achieve the 0.9 threshold. For large farms, even where current practices already ensure this 0.9% threshold, the same set of coexistence measures has been recommended.

The additional costs of the suggested coexistence measures are shown in Table 23.

As example, the additional costs for a small farm not producing GM cotton itself but sharing machinery with neighbouring farms amount to around €40/ha per year for the cleaning of equipment. This figure accounts for 1.9% of the current gross margin per hectare in Andalusia. However, this figure should be calculated as percentage of an hypothetical GM grower's gross margin which is suppose to be higher. As general conclusion, we can say that ensuring coexistence of GM cotton and conventional cotton has a negligible economic effect at farm level.

IV. Effect of time and seed purity on the level of adventitious GM presence in the case of rapeseed

The coexistence of GM, non-GM, and organic rapeseed crops was addressed in a previous coexistence study (Angevin *et al*, 2001, *in* Bock *et al*, 2002). Here we address two specific objectives that had not yet been covered: 1) to estimate the impact of the level of seed purity on the final level of adventitious presence, 2) to estimate the effect of long time periods on the final level of seed impurities in harvests.

IV.1. Material and methods

A model approach was adopted using GeneSys®-rape (Colbach *et al*, 2001 a & b). GeneSys®-rape aims at forecasting the effects, both in time and in space, of cropping systems and of rapeseed varieties on gene flow from rapeseed crops to rapeseed volunteers. It takes into account the actual spatial patterns of landscapes, crop rotations, and seed persistence.

The same type farms and cropping systems described as in the 2002 coexistence study (Bock *et al.*, 2002) were used:

- IM (former farm 1): conventional farm with medium-sized fields, intensive management;
- OM (2): organic farm with medium-sized fields;
- OS (2'): organic, with small fields;
- IL (3): conventional, with large fields, intensive management;
- OL (4): organic, with large fields.

The factors analysed were:

- The type of production:
    - crop production;
    - hybrid seed production (more sensitive to cross-pollination from external fields).
- The quality of sown rapeseed lots, either commercial certified seeds or farm-saved seeds:
    - the GM content of farm-saved seeds depended on the past gene flow simulated in the region;
    - for certified seeds, various impurity rates (0, 0.1, 0.3 and 0.5%) were tested.
- The impact of the genotype of GM varieties was analysed by comparing gene flow and harvest purity for the usual homozygous AA varieties to those observed where heterozygous Aa varieties were used.
- The proportion of GM rapeseed in the region: 10% or 50%.

Table 24 summarises the various simulations performed for each farm and each introduction scenario.

The analysed output variable was the % of GM seeds in non-GM harvests (ranging from 0 to 100%) for:

- rape crop production (food and feed harvests);
- hybrid seed production (in IM, OM and OS farms only).

The level of the adventitious presence of GM material was simulated at two dates to address the effect of time on adventitious presence:

- during the second rotation after the introduction of GM rape in the region (7-13 years);

Table 24: Simulated changes in seed lot quality and genotype of GM rapeseed varieties

Simulation	Type of seeds	% GM seed impurities	GM variety
1 = basic system	certified	0	AA
2	certified	**0.1**	AA
3	certified	**0.3**	AA
4	certified	**0.5**	AA
5	**Farm-saved**	0	AA
6	certified	0	**Aa**
7	certified	0.1	Aa
8	certified	0.3	Aa
9	certified	0.5	Aa

- after approximately 50 years (43-49 years).

IV.2. Effect of seed purity on the adventitious presence of GM in non-GM crop production

The adventitious presence of GM in non-GM crop production varied considerably between years and fields. On average, GM rates in non-GM harvests increased with the GM presence in conventional seeds roughly in an additive manner. Nevertheless, the relative effect of seed purity was highly dependent on the farm size (See Figure 14).This relative effect was much higher for large-sized field farms (IL or OL),because the other main sources of adventitious presence (cross-pollination, volunteers) are less important and therefore, seed purity is the key source of varietal impurities. The same occurred with hybrid seed production where isolation distances reduced the impact of incoming GM pollen and consequently increased the relative effect of GM presence in conventional seeds.

IV.3. Effect of time on adventitious GM presence in harvests

Adventitious presence did not increase significantly after 50 years compared to the second rotation after the introduction of GM varieties in the region (Figure15) whatever the initial seed purity is. The only exception was with the use of farm-saved seeds (see IV.4).

IV.4. Use of farm-saved seeds

Percentages of GM seeds were highest when farm-saved seeds were used (Figure 15 - FS-AA-0): they increased approximately 3- to 4-fold by

Figure 14: Effect of seed purity on adventitious presence in crop production (AA genotype)

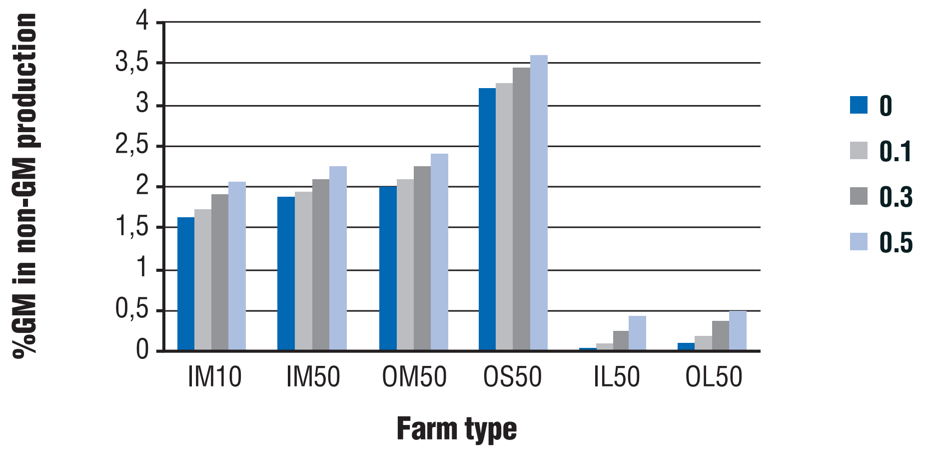
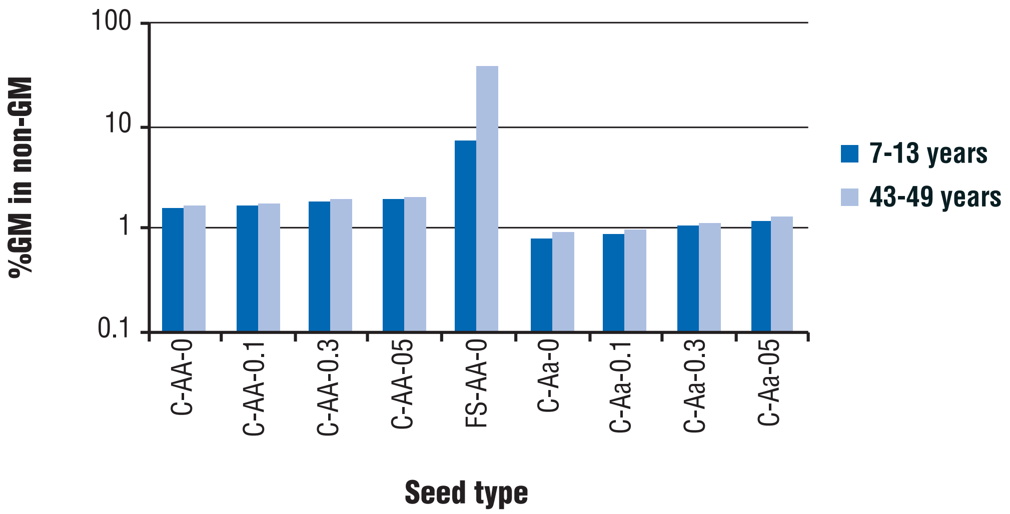


Figure 15: *Effect of time on adventitious presence (IM farm - 10% GM rapeseed)*



the second rotation after the introduction of GM varieties, and by more than 20-fold after 50 years, as noted above. In fact, the impurity rate of the farm-saved seeds increased linearly with time due to the cumulative effect of using the harvest of one year to sow the next year's crop.

IV.5. Effect of the genotype of GM varieties

The use of Aa GM varieties instead of AA varieties significantly decreased the mean adventitious GM presence rates in crop production fields. However, this did not lead to better compliance with the thresholds in the simulations performed.

IV. 6. Conclusion

On average, GM rates in non-GM harvests increase roughly with the GM presence in conventional seeds in additive manner, whatever the farm considered. Nevertheless, the relative effect of seed purity is highly dependent on the farm size. This relative effect was much higher for large-sized field farms because the other main sources of adventitious presence (cross-pollination, volunteers) are less important and therefore, seed purity is the key source of varietal impurities.

The levels of adventitious presence do not increase significantly after 50 years compared to the second rotation after the introduction of GM varieties in the region, except in the case of farm-saved seeds, which led to a continuous increase.

However, the effect of cropping systems over time is much higher than the effect of seed purity. Even if the seed purity has to be taken into consideration, it is not sufficient to ensure that the resulting harvest complies with impurity thresholds in all cases. Changes in cropping systems such as those analysed and proposed in the previous coexistence study (Bock *et al*, 2002) are essential to maintain harvest purity.

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Figures and Insets

Tables

Acronyms and Definitions

AGPME: Asociacion General de Productores de Maiz de España (Spanish association of maize growers)

AUA: Area Under Arable crop

Bt: Bacillus thurigiensis

CSO: Collecting and Storage Organisations

° day: Growing degree days are calculated by taking the sum of the averages of the daily high and low temperature each day compared to a baseline (6°C for maize in France). For instance, in the studied cases, a day during flowering period represents on average 15 growing degree days.

CTPS: Comité technique Permanent de la Sélection (Permanent Technical Committee for Plant Breeding)

DAP: Empresa Pública de Desarrollo Agrario y Pesquero

DNA: Deoxyribonucleic acid

EU: European Union

EC: European Commission

FNAMS: Fédération Nationale des Agriculteurs Multiplicateurs de Semences (National federation of seed growers (farmers))

GEVES: Groupe d'Etude et de Contrôle des Variétés et des Semences (French group for seed and variety study)

GITEL: Groupement d'intérêt Technique et Economique des Légumes (Technical and Economical interest grouping for vegetables)

GM: Genetically Modified

GMO: Genetically Modified Organism

GNIS: Groupement National Interprofessionnel des semences et des plants (National interprofessional association for seeds and plants)

INA-PG: Institut National Agronomique Paris-Grignon (Paris-Grignon National Agronomics Institute)

INRA: Institut National de la Recherche Agronomique (National Institute for Agronomic Research)

IPTS: Institute for Prospective Technological Studies

IRTA: Institut de Recerca i Tecnologia Àgroalimentaries (Spanish Institute for Food and Agricultural Research and Technology)

ITB: Institut Technique de la Betterave (French technical institute for sugar beet)

JRC: Joint Research Centre

OECD: Organisation for Economic Cooperation and Development

MAPA: Ministerio de Agricultura, Pesca y Alimentacion (Spanish Ministry of Agriculture, Food and Fisheries)

PCR: Polymerase Chain Reaction

ROSACE: Réseau d'Observation des Systèmes Agricoles pour le Conseil et les Etudes (System set up by the French Chambers of Agriculture for typing agricultural holdings)

SPFGB: Syndicat des Producteurs Français de Graines de Betteraves (French syndicate of sugarbeet seed growers)

SOC: Service Officiel de Contrôle (official control service)

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Appendixes

Appendix 1: Description of the MAPOD®-maize model (Angevin *et al*, 2001)

Model structure

The first module determines the flowering date for female flowers, expressed in degree-days, as a function of climate and sowing date (Durand, 1969, Derieux & Bonhomme, 1982, 1990). Most of the varieties currently used display protandry, which means that male flowering begins several days before female flowering. The duration (in days) of this time lag can be used to calculate the flowering time for male flowers. Drought stress and sowing density affect protandry.

Modelling the dynamics of male and female flowering then makes it possible to estimate the amounts of pollen produced by GM and non-GM varieties, respectively, and the number of receptive silks for non-GM maize varieties. Factors affecting the viability of pollen and the receptivity of silks are taken into account. The composition of the pollen cloud in the air around the plants is therefore known on a day-to-day basis for the entire flowering period.

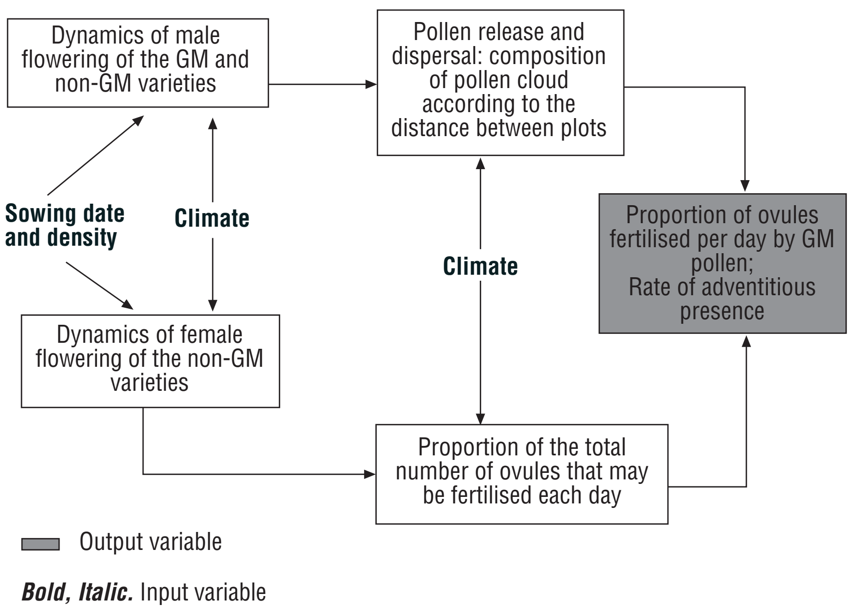
Pollen dispersal is simulated by Klein's equation (2000, 2003). It is a function of distance from the emitter, and its parameters are the direction and mean speed of the wind during the course of flowering and the difference in height between the panicle from which the pollen is emitted and the receptive silks. The composition of the pollen cloud at a given site in a non-GMO field is determined by the pollen dispersal curves for all the plants in the neighbourhood, whether close or further away.

Each day, the frequency of GM seeds is calculated as the ratio of the number of non-GM ovules fertilised by GM pollen to the total number of ovules fertilised. These daily results are pooled to provide the total frequency of GM seeds in the harvest.

Input data

Field plan: Form and size of fields, location of GM plants.

Structure of the MAPOD® model



Climate (data per day): Temperature; rain; wind: speed and direction.

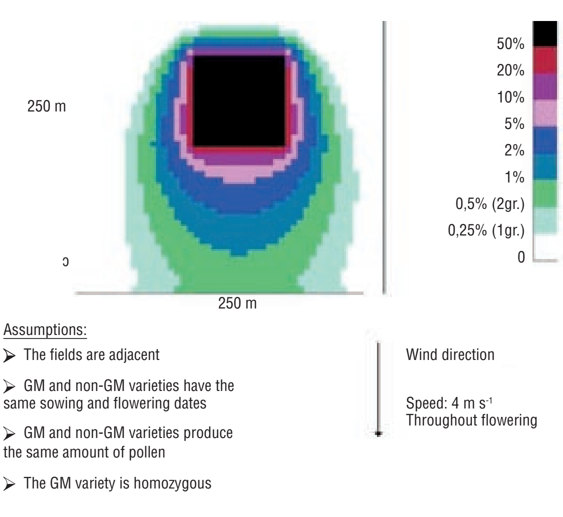
Parameters for the pollen dispersal function: Tassel height of each variety, Cob height of non-GM variety.

Cropping systems: Sowing dates and densities, drought stress before flowering, drought stress during flowering.

Variety: Quantity of pollen per plant, pollen sensitivity to high temperature, temperature needs between sowing and female flowering, genotype of GMO: homozygous or heterozygous.

Simulations

This model estimates the rate of varietal impurities due to cross-pollination in maize as well as changes in these rates due to changes in cropping techniques.



An illustration is given of adventitious presence rates for a 6 ha non-GM plot pollinated by a 0.5 ha GMO plot situated within it. This illustration shows the importance of the effect of both distance from the source and the wind, which creates an asymmetric pattern of dissemination.

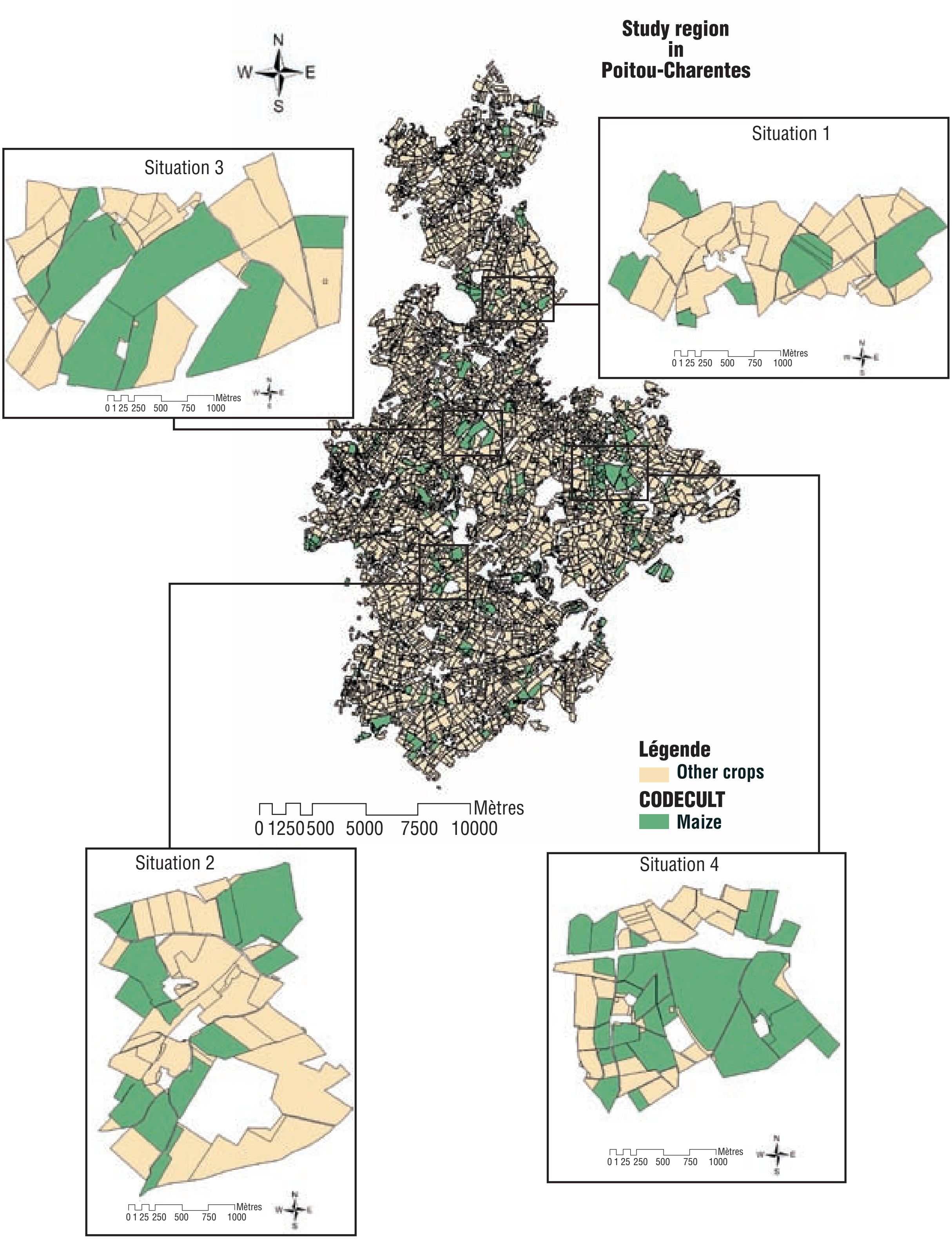
Validation

Three studies were used:

- A field experiment in central France. The aim was to assess the impact of different types of spatial heterogeneity (crops other than maize, for example clover or sunflower) on pollen dispersal (Unpublished results);
- Results of trials for new maize varieties, used to validate the flowering dynamics curves (GEVES, 1997 to 2002, 2 locations);
- Fields of waxy maize located in three different regions of south-west France. The results are for outcrossing between a source field (grain maize) and a sink field (Waxy maize). All input variables were measured along with outcrossing rates at two locations in the sink fields, namely the field borders and the rest of the field (CTPS, 2001-2002).

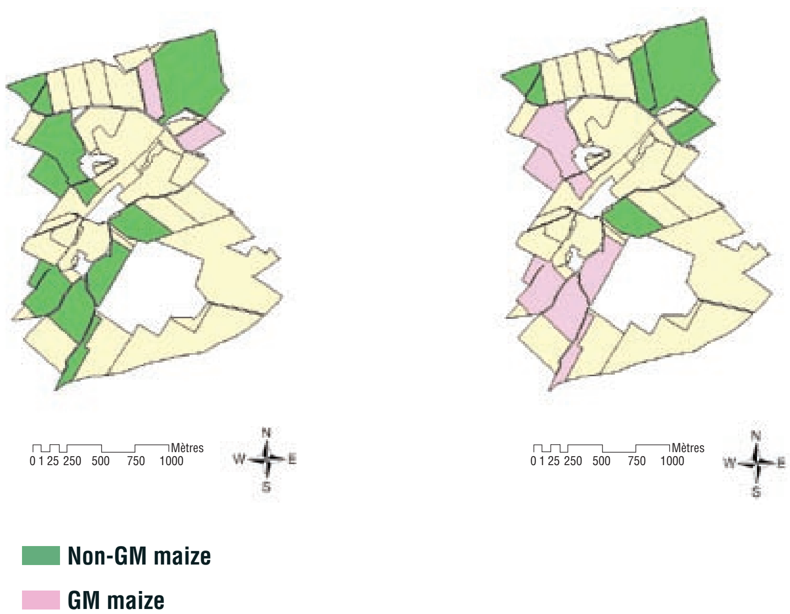
According to preliminary results, the order of magnitude of the simulated rates is correct. Finally, the model was run with various values for the parameters related to the dynamics of pollen release and pollen receptivity during flowering. Though these parameters affect the model predictions, they do not change the conclusion that the model provides reasonable agreement with the observations. Appendix 6 gives more details on gene-flow models.

Appendix 2: Example of field patterns used for the landscape scale study in Poitou-Charentes (France)



Brief description of one of the study cases

Situation with 10% of GM maize in the landscape | **Situation with 50% of GM maize in the landscape**



Source: Courtesy of the Institute for the Protection and Security of the Citizen, Joint Research Centre of the European Union

Appendix 3: Percentage of the area where adventitious GM presence in the-trailer is below 0.1% or 0.9% for non-GM strips of 0, 9 and 18 m

0m		Maximum rate of adventitious GM presence											
Intra-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	65%	59%	12%	9%	0%		96%	97%	95%	95%	91%	90%
	0.1	12%	9%	0%				96%	97%	94%	95%	87%	89%
	0.3	0%						93%	91%	91%	90%	75%	79%
	0.5							87%	89%	84%	84%	12%	9%

9m		Maximum rate of adventitious GM presence											
Intra-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	72%	62%	14%	11%	0%		99%	99%	99%	98%	97%	92%
	0.1	14%	11%	0%				99%	98%	99%	98%	94%	92%
	0.3	0%						99%	96%	97%	92%	86%	81%
	0.5							94%	92%	92%	87%	14%	11%

18m		Maximum rate of adventitious GM presence											
Intra-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	75%	67%	17%	12%	0%		99%	99%	99%	99%	99%	94%
	0.1	17%	12%	0%				99%	99%	99%	99%	99%	92%
	0.3	0%						99%	98%	99%	94%	89%	82%
	0.5							99%	92%	95%	90%	17%	12%

Appendix 4: Effect of difference in flowering time

Appendix 4a: For inter-cluster coexistence

Percentage of the area where adventitious GM presence in the trailer is below 0.1% and 0.9% for flowering time-lags of 30, 60 and 90degree-days

30°days		Maximum rate of adventitious GM presence											
Inter-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	100%	90%	82%	28%	0%		100%		100%		100%	
	0.1	82%	28%	0%									
	0.3	0%										100%	97%
	0.5											82%	28%

60°days		Maximum rate of adventitious GM presence											
Inter-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	100%		100%	49%	0%		100%		100%		100%	
	0.1	100%	49%	0%									
	0.3	0%											
	0.5											100%	49%

90°days		Maximum rate of adventitious GM presence											
Inter-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	100%		100%	81%	0%		100%		100%		100%	
	0.1	100%	81%	0%									
	0.3	0%											
	0.5											100%	81%

Appendix 4b: For intra-cluster coexistence

Percentage of the area where adventitious GM presence in the trailer is below 0.1% and 0.9% for flowering time-lags of 30, 60 and 90 degree-days

30°days		Maximum rate of adventitious GM presence											
Intra-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	66%	71%	13%	15%	0%		100%		100%	99%	98%	97%
	0.1	13%	15%	0%				100%	99%	100%	99%	96%	95%
	0.3	0%						99%	98%	98%	97%	84%	88%
	0.5							96%	95%	95%	91%	13%	15%

60°days		Maximum rate of adventitious GM presence											
Intra-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	87%	90%	21%	27%	0%		100%		100%		100%	
	0.1	21%	27%	0%									
	0.3	0%										98%	97%
	0.5									100%	99%	21%	27%

90°days		Maximum rate of adventitious GM presence											
Intra-cluster co-existence		0.1%						0.9%					
		Trailer 1		Trailer 2		Trailer 3		Trailer 1		Trailer 2		Trailer 3	
Presence of GMOs		10%	50%	10%	50%	10%	50%	10%	50%	10%	50%	10%	50%
Adventitious GM presence in seed	0.01	100%		54%	60%	0%		100%		100%		100%	
	0.1	54%	60%	0%									
	0.3	0%											
	0.5											54%	60%

Appendix 5: Costs of buffer zones for maize crop production at landscape level in France

Field	Area	Area of non-GM buffer zone (ha)						Costs of buffer zones per hectare (€/ha) Gross margin GM > Gross margin non-GM= €43/ha					
Number	ha	10% GM maize, around each field		50% GM maize, around cluster		50% GM maize, around each field		10% GM maize, around each field		50% GM maize, around cluster		50% GM maize, around each field	
		9 m	18 m	9 m	18 m	9 m	18 m	9 m	18 m	9 m	18 m	9 m	18 m
1	8.2												
2	8.1												
3	3.3												
4	1.8												
5	3.6	0.8	1.4					17.27	30.22				
6	12.8												
7	4												
8	5.5	1.2	2					16.95	28.25				
9	2.7												
10	3.8												
11	3.7												
12	5												
13	2												
14	2.8												
15	5.6												
16	2.4												
17	4												
18	12.7												
19	54.3			5.5	9.9	3.4	6.1			2.67	4.80	3.77	6.76
20	27					2.6	4.5					5.79	10.03
21	23.2					2.5	4.4					6.48	11.41
22	17.3	2.1	3.6			2.1	3.6	9.43	16.17			7.30	12.52
23	0.2					0.2	0.2					60.17	60.17
24	0.6					0.5	0.6					50.14	60.17
25	0.5					0.3	0.4					36.10	48.14
26	1					0.4	0.7					24.07	42.12
27	5.2												
28	5												
29	5.5												
30	8.7												

Appendix 6: Review of gene flow models

The purpose of this part of the study is to present a review of models that have been designed to address gene flow between GM and non-GM crops.

Firstly, the main mechanisms involved in this phenomenon are described. Then, the way literature search was conducted is detailed and the criteria used to characterize the different models is presented. This leads to a summary table of the models reviewed, followed by a profile of each individual model (see below). Three models that cover a wide range of mechanisms of gene transfer received particular attention. These are the GeneSys® Oilseed rape, GeneSys® Sugar Beet and MAPOD® maize models. These models are described in detail, including information on how data were used to calibrate these models and the criteria used for evaluation. Some conclusions are also drawn about using these models for prediction.

Role of modelling

Mathematical models present several advantages when studying coexistence between GM and non-GM crops.

Experimentation under field conditions is very difficult. This is true in general in agronomy, where each field trial requires a sizeable investment in space, time and manpower. For instance, in studying crop growth, the results depend on daily climate, soil characteristics, initial conditions and management. The number of possible combinations of input variables is enormous. The situation is even more complicated for interactions between GM and non-GM crops, as several fields and their spatial organization must be considered. To summarize, the number of situations to be studied is huge, and the number of situations that can be studied in practice is very limited.

The cost of a field experiment can be large, when compared with the cost of the computer simulation. Thus, computer simulations allow increasing dramatically the number of contexts studied.

A mathematical model allows also increasing the knowledge of the system in question, beyond the information embodied in the field experiments. What is the origin of this additional knowledge? First, any mathematical model is a way of generalizing experimental results. Expressing relationships in mathematical form allows one to bring out the underlying patterns in the results and to use those for interpolation or extrapolation. Second, the global models that will be discussed here are based on the underlying processes in the system studied, and it is often easier to study the individual processes than the overall system. In the present case, the processes are those that are involved in admixture of non-GM crops and GM crops (for example, by pollen flow). The model provides a way of using the additional experimentation at the process level to draw conclusions about the overall system.

Models can thus potentially aid in predicting system behaviour. Their actual usefulness however depends on how well the model represents the real world. How can one determine whether or not models are sufficiently accurate to be useful? Model evaluation in general involves two sorts of activity. The first concerns the components of the model. How well can one predict the individual processes involved in the systems under study? The second concerns the behaviour of the overall system. How well does the overall model predict system outputs based on inputs? Model evaluation is a major aspect of this study.

A number of different criteria of prediction quality could be of interest, and it is important to specify clearly which criteria are considered. The most demanding criterion would concern the error of prediction of adventitious GM presence for a specific field in a given year and a specific spatial context. Another criterion of major interest is how well the model ranks different management strategies as to their effect on adventitious GM level. Other criteria of interest would be the prediction error of average level of adventitious presence over different spatial contexts, or how this level evolves after a number of years of cohabitation between GM and non-GM crops.

Review of models

22 models were found in the literature (See table below) and described through a common analytical grid:

Calibration is checked if the there is a description of how the model was adjusted to experimental data.

Validation is divided into 4 categories

- I if a sensitivity analysis was conducted;
- II if model descriptive ability was tested;
- III if model predictive ability was tested;
- IV if model ability to rank scenarios was tested.

Crop indicates which plant species is concerned.

Type indicates whether the model is stochastic or deterministic.

Time indicates whether the model is dynamic or static.

Time step indicates the length of the time step (if the model is dynamic): hour, day, year or other.

Space contains N if there is no geographic description of the landscape, S if it is Simply described (*e.g.* only distance between fields) and C if the description is more Complete (*e.g.* description of field shapes and sizes, plus distances). S/C denotes an intermediary level of complexity.

Using GeneSys and MAPOD® models for prediction

GeneSys-rape and MAPOD® models have been tested mainly using two criteria (prediction quality for one field one year and ranking of management strategies). Since models take into account all the major mechanisms of gene flow, it can be tested for any or all of the major management practices that could be employed to limit adventitious presence of GM crops, namely enforcing isolation distances, enforcing temporal isolation through different flowering periods and management of volunteer populations.

Lastly, the validation studies underway have shown that MAPOD® can give reasonable agreement with observed adventitious presence rates (Appendix 1).

The GeneSys-rape model correctly ranks the fields according to their volunteer infestation and predicts volunteer densities accurately, except in spring crops where infestations are frequently underestimated. Post-harvest volunteer densities and genotypes as well as rape harvest genotypes are also correctly predicted. However, the model systematically underestimates gene flow in space and this leads to an error margin of approximately half an order of magnitude.

The numerical predictions of GeneSys Sugar Beet, a new model, have not been validated with field results,. However,,it has been shown that when the parameters are allowed to vary within a range of reasonable values, the effect on the model predictions is appreciable. This suggests that it will be necessary to calibrate the model in order to obtain reliable predictions. There is however information on the general validity of the structure of the model. The general agreement of the model with expected behaviour was tested, and found to be satisfactory. Furthermore, GeneSys Sugar Beet is derived form GeneSys Oilseed Rape. The latter has been quite thoroughly tested and found to give globally reasonable results. Validation of the sugar beet version is mainly a question of assessment of crop specific mechanisms and parameters.

Appendix 6a: Summary of mechanisms considered by each model

Model	Ref.[1]	Pollen						Seeds				
		Vectors		Sources/Sinks				Vectors			Sources/Sinks	
		Diff.[2]	Wind	Poll.[3]	Rel. pl.[4]	Vol.[5]	Oth.[6]	Wind	Anls[7]	Oth.[6]	Rel. pl.[4]	Vol.
Begg	Begg *et al.*, 03											×
Cresswell_DA	Cresswell *et al.*, 95			×	×	×	×					
Cresswell_MC	Cresswell *et al.*, 95			×	×	×	×					
Cresswell_PDM	Cresswell *et al.*, 02			×	×	×	×					
Damgaard	Damgaard *et al.*, 03	×	×	×			×					
GeneScape	Nikolić, 01	×	×		×	×	×					×
GeneSys	Colbach *et al.*, 01	×		×		×	×		×	×	×	×
Giddings	Giddings *et al.*, 97	×	×				×					
Greene	G. & Johnson, 89							×				
Harwood	Harwood *et al.*, 03											
Klein	Klein *et al.*, 00, 03	×	×				×					
Loos_GPM	Loos *et al.*, 03	×	×				×					
Loos_LNF	Loos *et al.*, 03	×	×				×					
MAPOD®	Angevin *et al.*, 01	×	×				×					
RSIM	Maxwell *et al.*, 90	×	×				×					
Meagher	Meagher *et al.*, 03	×	×				×					
Nurminiemi	Nurm. *et al.*, 98	×	×				×					
Pekrun	Pekrun *et al.*, 04											×
Richter	R. & Seppelt, 04	×	×			×	×					×
STEVE	DiFazio, 02	×	×		×	×		×			×	×
Thompson	Thompson *et al.*, 03	×	×	×	×	×	×	×	×		×	×
Walklate	Walklate *et al.*, 04	×	×	×	×	×	×					

1: References; 2: Diffusion; 3: Pollinators; 4: Related plants; 5: Volunteers; 6: Others (for seeds: seed impurity and agricultural machines); 7: Animals.

Appendix 6b: For each model, summary of model characteristics

Model	Ref.[1]	Calibrat.	Validation				Crop	Type	Time	Time step	Space
			I	II	III	IV					
Begg	Begg *et al.*, 03						Oilseed rape	Det	Dyn	Y	N
Cresswell_DA	Cresswell *et al.*, 95	×		×			Oilseed rape	Det	Dyn	0	S
Cresswell_MC	Cresswell *et al.*, 95	×		×			Oilseed rape	Sto	Dyn	0	S
Cresswell_PDM	Cresswell *et al.*, 02	×	×[1]				Oilseed rape	Det	Sta		S
Damgaard	Damgaard *et al.*, 03						Oilseed rape	Det	Sta		S/C
GeneScape	Nikolić, 01		×				Any	Sto	Dyn	Y	C
GeneSys	Colbach *et al.*, 01	×	×	×	×	×	Oilseed rape/ Sugar beet[2]	Det	Dyn	Y/D	C
Giddings	Giddings *et al.*, 97	×					Rye-grass	Det	Sta		S
Greene	G. & Johnson, 89	×		×			Various tree species	Sto	Sta		S
Harwood[3]	Harwood *et al.*, 03	×					Oilseed rape	?	?	Y?	?
Klein	Klein *et al.*, 00, 03	×		×			Maize	Sto	Sta		S/C
Loos_GPM	Loos *et al.*, 03	×		×			Maize	Det	Dyn	H?	C
Loos_LNF	Loos *et al.*, 03	×		×			Maize	Det	Dyn	H?	C
MAPOD®	Angevin *et al.*, 01	×		×	×	×	Maize	Det	Dyn	D	C
RSIM	Maxwell *et al.*, 90	×	×				Weeds	Det	Dyn	Y	S/C
Meagher	Meagher *et al.*, 03	×		×			Creeping bentgrass	Det	Sta		S
Nurminiemi	Nurm. *et al.*, 98	×		×			Grass meadow fescue	Sot	Sta		S
Pekrun	Pekrun *et al.*, 04		×				Oilseed rape	Det	Dyn	Y	N
Richter	R. & Seppelt, 04	×	×				Weeds	Sto	Dyn	Y/D	C
STEVE	DiFazio, 02	×	×	×			Poplar	Sto	Dyn	Y	C
Thompson	Thompson *et al.*, 03		×				*Brassica/ Gossypium*	Det	Dyn	Y	N
Walklate	Walklate *et al.*, 04	×	×	×			Oilseed rape	Det	Sta		S/C

1: comparison of order of magnitude with data of literature, not really a sensitivity analysis; 2: for sugar beet, only calibration; 3: lack of information

Appendix 7: Impact of the amount of pollen produced by both GM and non-GM varieties on the rate of cross-pollination in the case of maize seed production

The relative amount of pollen produced by GM and non-GM varieties affects GM presence in non-GM material, increasing it when the amount of GM pollen emitted increases and decreasing it when the amount of non-GM pollen increases.

In order to assess this effect for maize seed production, a sensitivity analysis has been carried out. Apart from the amount of pollen produced per plant, the protocol for the simulations (form and size of the fields, sowing dates and densities, etc.) is the same as that described in Figure 9. Only situations where the non-GM field is downwind of the GM one are considered here.

From field observations, we have determined that the amount of pollen emitted per plant may vary from 1.2 to 3.4 million grains for seed production and from 6 to 10 million grains for crop production.

Different situations for pollen emission have therefore been simulated:

- A high-risk situation in terms of the cross-pollination rate: the amount of protective pollen emitted by non-GM male parents is low (1.2 million grains per plant) and the amount emitted by GM maize is high (3.4 million grains per plant in the case of a seed production plot and 10 million grains in the case of a crop production plot).
- A favourable situation where cross-pollination is limited: the amount of protective pollen emitted by non-GM male parents is high (3.4 million grains per plant) and the amount emitted by GM maize is low (1.2 million grains per plant in the case of a seed production plot and 6 million grains in the case of a crop production plot).

Type of co-existence	Area of non-GM plot (in ha)	Isolation distance (in m)	Number of extra male parent rows	Adventitious presence (in %) for downwind situation	
				3.4 million non-GM pollen grains and 1.2 million GM pollen grains	1.2 million non-GM pollen grains and 3.4 million GM pollen grains
Seed-Seed	0.5	100	0	0.28	2.16
			2	0.28	2.11
			8	0.25	1.95
			20	0.22	1.73
		200	0	0.12	0.96
			2	0.12	0.91
			8	0.11	0.86
			20	0.10	0.79
		300	0	0.07	0.57
		400	0	0.05	0.37
	1	100	2	0.24	1.83
		200	0	0.11	0.86
		300	0	0.07	0.52
		400	0	0.04	0.34
	2.5	100	2	0.19	1.44
		200	0	0.09	0.69
		300	0	0.05	0.42
		400	0	0.04	0.28
	5	100	0	0.14	1.11
			2	0.14	1.11
			8	0.13	1.04
			20	0.12	0.96
		200	0	0.07	0.54
			2	0.07	0.53
			8	0.06	0.51
			20	0.06	0.48
		300	0	0.04	0.34
		400	0	0.03	0.23

NB: Rows highlighted in gray correspond to current isolation practices in seed production.

Type of co-existence	Area of non-GM plot (in ha)	Isolation distance (in m)	Number of extra male parent rows	Adventitious presence (in %) for downwind situation	
				3.4 million non-GM pollen grains and 6 million GM pollen grains	1.2 million non-GM pollen grains and 10 million GM pollen grains
Crop-Seed	1	100	0	1.64	6.17
		200	0	0.77	3.13
			20	0.66	2.72
		300	0	0.48	2.05
		400	0	0.33	1.46
		500	0	0.24	1.07
		600	0	0.18	0.81
		700	0	0.10	0.48
		800	0	0.11	0.49
		900	0	0.08	0.39
		1000	0	0.07	0.31
	5	100	0	1.06	4.23
		200	0	0.55	2.33
			20	0.49	2.09
		300	0	0.35	1.53
		400	0	0.24	1.09
		500	0	0.18	0.81
		600	0	0.14	0.62
		700	0	0.10	0.48
		800	0	0.08	0.38
		900	0	0.06	0.30
		1000	0	0.05	0.24
	10	100	0	0.79	3.30
			20	0.68	2.88
		200	0	0.43	1.85
		300	0	0.27	1.22
		400	0	0.19	0.87
		500	0	0.18	0.80
		600	0	0.11	0.50
		700	0	0.08	0.39
		800	0	0.07	0.31
		900	0	0.05	0.25
		1000	0	0.04	0.20

NB: Rows highlighted in gray correspond to current isolation practices in seed production.

It is clearly evident from the above tables that the amount of pollen has an important impact on cross-pollination. Indeed, in comparison with favourable situations, the high-risk situation can lead to cross-pollination rates 4 to 5 times higher in the case of "crop-seed" coexistence and 7 to 8 times higher in the case of "seed-seed" coexistence. This provides a rough estimation of the variability that could be observed in a real-life situation.

Appendix 8: Opportunity costs of combining coexistence measures for maize seed production in France

Field size		Additional measures		Rate of adventitious GM presence with additional measures	Flowering time-lag necessary to achieve adventitious GM presence rates below…			Total opportunity costs of additional measures (including isolation distances)			Proportion of gross margin			Total opportunity costs of additional measures (excluding isolation distances)			Proportion of gross margin		
GM seed field	Non-GM-seed	Isolation distance	Extra male rows		0.5 %	0.3 %	0.1 %	€/ha			%			€/ha			%		
ha		m	number		°days	°days	°days	0.5 %	0.3 %	0.1 %	0.5 %	0.3 %	0.1 %	0.5 %	0.3 %	0.1 %	0.5 %	0.3 %	0.1 %
5	0 5	**100**	**2**	**0.77**	Basic			Basic			Basic			Basic			Basic		
		100	0	0.79	90	90	120	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	0	0	0
		100	6	0.71	60			410	n. a.	n. a.	28	0	0	140	n. a.	n. a.	9	0	0
		100	18	0.63				461	n. a.	n. a.	31	0	0	191	n. a.	n. a.	13	0	0
		200	*0*	*0.35*	*0*	*60*	*90*	*643*	*655*	*n. a.*	*43*	*44*	*0*	*0*	*114*	*n. a.*	*0*	*8*	*0*
		200	0	0.33		30		643	691	n. a.	43	46	0	0	447	n. a.	0	30	0
		200	6	0.31				669	716	n. a.	45	48	0	140	575	n. a.	9	39	0
		200	18	0.28		0		720	720	n. a.	48	48	0	191	128	n. a.	13	9	0
		300	0	0.2				0	0	n. a.	0	0	0	0	0	n. a.	0	0	0
		400	0	0.13			60	0	0	n. a.	0	0	0	0	0	114	0	0	8
	1	**100**	**2**	**0.66**	Basic			Basic			Basic			Basic			Basic		
		100	0	0.31	0	30	90	322	568	n. a.	22	38	0	0	447	n. a.	0	30	0
		200	0	0.18		0		643	643	n. a.	43	43	0	0	0	n. a.	0	0	0
		300	0	0.12			60	0	0	n. a.	n. a.	n. a.	0	0	0	114	0	0	8
	2 5	**100**	**2**	**0.52**	Basic			Basic			Basic			Basic			Basic		
		100	0	0.25	0	0	90	322	322	n. a.	22	22	0	0	0	n. a.	0	0	0
		200	0	0.15				643	643	n. a.	43	43	0	0	0	n. a.	0	0	0
		300	0	0.1			60	0	0	n. a.	n. a.	n. a.	0	0	0	114	0	0	8
	5	**100**	**2**	**0.4**	Basic			Basic			Basic			Basic			Basic		
		0	0	0.4	0	60	120	0	114	n. a.	0	8	0	0	114	n. a.	0	8	0
		0	6	0.37				81	195	n. a.	5	13	0	81	195	n. a.	5	13	0
		0	18	0.34				243	357	n. a.	16	24	0	243	357	n. a.	16	24	0
		100	0	0.19		0	90	322	322	n. a.	22	22	0	0	0	n. a.	0	0	0
		100	0	0.19				322	322	n. a.	22	22	0	0	0	n. a.	0	0	0
		100	6	0.18				402	402	n. a.	27	27	0	81	81	n. a.	5	5	0
		100	18	0.17				886	886	n. a.	60	60	0	243	243	n. a.	16	16	0
		200	0	0.12			60	643	643	655	43	43	44	0	0	114	0	0	8
		300	0	0.08			0	0	0	n. a.	0	0	0	0	0	0	0	0	0

The **blue** *figures in the table represent the current situation*

Example for interpretation of the table (in italic format): For a GM seed field of 5 ha and a neighbouring non-GM seed field of 0.5 ha, it is suggested to increase the isolation distance by 200 m in order to achieve a level of 0.35 % of GM adventitious presence. In case a threshold of 0.3 % has to be met, it is necessary to additionally plant maize seed varieties with a flowering lag of 60°days, in case of a 0.1 % threshold with 90°days. If the opportunity costs of increasing isolation distances are taken into account, the opportunity costs of additional measures amount to 643 €/ha (which equals to 43 % of the gross margin of maize seed production) for the 0.5 % threshold, and to 655 €/ha for the 0.3 % threshold (equivalent to 44 % of the gross margin). If opportunity costs of increasing isolation distances are not included in the cost analysis, there are no additional costs in case of a 0.5 % threshold, and opportunity costs of 114 €/ha in case of a 0.3 % threshold (representing 8 % of the gross margin). For the 0.1 % threshold the opportunity costs of the suggested measures cannot be quantified due to lack of information on the yield losses in case of flowering time lags of 90°days.

Appendix 9: Seed production techniques used in beet seed production

The steckling method (south-western France and Italy)

The basic seed is sown in nursery fields in August / September as "mother" and "pollinator" lines. These seeds germinate to produce small plants known as "stecklings", which remain in the field during the winter for vernalisation. This vernalisation causes the plants to push up stems and to produce flowers the following year. Steckling nurseries must be located in fields that have not been used for sugar beet seed production for at least 10 years.

In February/March of the following year, these vernalised stecklings are topped and then lifted and put in boxes. The choice of good, even stecklings makes it possible to ensure the uniform development of seed plants. The stecklings are then transplanted into the final production field by machinery introducing the plants into the soil at regular intervals. Stecklings are transplanted in a precise manner. To maximise pollination and productivity, blocks of 6 rows of female, male sterile plants (no pollen production, genetic monogerms), are alternated with blocks of two rows of multigerm male pollinators. A crop rotation of at least six years is required for sugar beet seed production fields. The stecklings that are not used are destroyed.

Direct sowing method (south-eastern France)

With this method, seeds are sown directly in fields at the end of August (120 000 seeds/ha, to give least 70 000 plants·ha^{-1} at the end of winter), in the desired pattern (8 rows of females, 2 rows of males), usually following a cereal. Plants reach the 12- to 14-leaf stage before winter and are vernalised. Consecutive seed production crops at a given site must be separated by an interval of 10 years.

Major steps in beet seed production

	Steckling method	Direct sowing
August / September	Sowing 1 200 000 s/ha	Sowing 120 000 s/ha
February / March	Stecklings are topped and lifted Sorting Transplanting	
May / June	Stecklings topped by hand	Topped by hand
July	Destruction of pollinators	Destruction of pollinators
August	Harvest	Harvest

In each case, plants are topped manually or mechanically at the end of May or beginning of June, to give uniform flowering, improving seed maturity at harvest time. Irrigation is compulsory, ensuring the maintenance of an adequate water supply for the seed plants. Pollinators are usually destroyed at the end of the flowering period. Seeds are generally harvested at the beginning of August, but harvesting date varies with hybrid and year. The final seed is harvested from the mother lines only. Two harvesting methods are used: either cutting and laying on the swath — from which a combine harvester picks up the seeds a few days later — or chemical desiccation followed by direct harvest. Each producer must possess effective drying and seed storage facilities. Each seed lot from an individual seed producer has a unique identity and will be treated separately in the seed processing phase.

Growers sell basic seeds or stecklings to the producers and decide on the genetic background of the pollinators and male-sterile plants used.

Appendix 10: Summary of expert opinion on each of the specific practices used to limit admixture levels to 0.1%, 0.3% and 0.5% in sugar beet seeds and the feasibility of these measures

This table is derived from the GNIS report in the "study of the production of GM seeds tolerant to a non-selective herbicide" (Collectif, 2002) and the FNAMS results (Sicard, 2003), as supplemented by expert opinion.

Current practices	Additional measures	Threshold	Feasibility	Time	Who?
Nursery plot management					
Minimum 5 years between two nurseries	Informing farmers about specific production conditions for GM crops	All	No difficulty		Company
Field pattern precisely defined on map	Map of the region with location of fields with GM seed production	0.1% and 0.3%	See measures below for isolation distance management"		Farmer & Company
Sowing					
Treated basic seeds	Specific labelling of GM basic seeds	All	Apply regulation		Company
Drill adapted to limit seed losses	None				
Careful cleaning of the drill between two plots and at the end of the nursery phase	Careful checking of drill cleanliness	0.10%	Drill selected to facilitate washing	0.5 h / variety plot	Farmer
Separation of varieties in the nursery fields	None				
Steckling harvest					
Steckling labelling and distribution by the technical service of the seed growing company	None				Company
Preparation and conditioning of stecklings on the nursery plot	Careful supervision	0.1% and 0.3%	Quality assurance		Farmer
Packaging in adapted containers to limit losses	Sealed and labelled containers	All	Quality assurance		Farmer & Company
Plot monitoring during subsequent years	Supervision of potential re-growth for several years + destruction (hand pulling or use of selective herbicide)	All		2h/year/ha	Farmer
Destruction of excess stecklings					
Supervision of total destruction of stecklings	None	All			Farmer
Spray of non-selective herbicide after lifting	Change to selective herbicide	All	No difficulty	No additional time	Farmer
Deep burial of nursery residues in the case of soil tillage	None				
Rotation favouring the destruction of volunteers (wheat or maize after steckling crops)	None				
Mechanical management in the case of bare soil the year after crop	None				
Seed production					
One production area per beet type (sugar, fodder, beetroot)	Define an area specific to GM seed production	0.10%			Company
One variety per seed production farm	None				
Field identification to ensure correct intervals between two seed crops	Map of the region indicating the location of fields with GM seed production	0.1% and 0.3%	See measures below for isolation distance management		Company & Farmer
Rotation ensuring destruction of volunteers	Information on field history in the event of the transfer of a farmer from one seed production company to another	All		No additional time required	Farmer

Current practices	Additional measures	Threshold	Feasibility	Time	Who?
Isolation distances					
Between pollinators of the same ploidy level: 300 m	1000 m isolation distance if the gene is borne by the pollinator	All			
Between pollinators of different ploidy levels: 600 m	Map of the region showing the location of fields with GM seed production	0.1% and 0.3%		0.5 h/ha/year	Company & Farmer
Between sugar beet seed production and other types of beet: 1000 m	Common management of production area by seed companies	0.1% and 0.3%			
	Increase the size of the area managed	0.50%		5 h/ha/year for supervision and hand pulling	Company & Farmer
Global management of the seed production area by mechanical or chemical destruction	Increase the size of the area managed	0.30%		10 h/ ha/year for supervision and hand pulling	Company & Farmer
	Increase the size of the area managed	0.10%		25 h/ ha/year for supervision and hand pulling	Company & Farmer
Planting					
Destruction of excess stecklings	Destruction of excess stecklings on the seed production plot	All	No difficulty	No additional time	Farmer
Field management					
Careful technical management by farmer	None				
Crops are controlled by seed company technicians	No intervention by the contractor without the agreement of the seed company	0.10%	No difficulty		
Supervision of the surroundings during the flowering period	None				
Pollinator destruction					
Separation of pollinators, sterile male and female plants	None				
Pollinator crushing	Special attention if the transgene is in the male line	All	No difficulty		Farmer
Burial underground	None				
Soil tillage to speed up emergence of re-growth (e.g. “false sowing”)	Very careful “false sowing” (period of intervention just after harvest)	0.30%			Farmer
	One additional “false sowing” with the use of rotary harrowing or Danish cultivator	0.10%		0.5 h/ha/year	Farmer
Machine cleaning in the field	In-field cleaning of the mowing machine used for pollinator destruction	0.1% and 0.3%	Need for water tank in the field	0.5 h/ha/year	
Harvest					
By farmer or company (50 / 50)	Harvest must be organised according to transgene cultivation area	All			Farmer and Company

Current practices	Additional measures	Threshold	Feasibility	Time	Who?
Combine harvesters cleaned in the field	Combine harvesters must be cleaned before leaving each field (transportation losses) and carefully cleaned on the farm (admixture between fields)	All	Very time-consuming Need for water tank on the plot	3 to 4 h for each cleaning	Farmer and/or Company
	Systematic control of combine harvester cleanliness	All			Farmer and /or Company
Transport and storage					
Limitation of seed losses during transport (inform farmer)	Complete organisation of transportation by seed companies	All			Company
Trailer cleaning and securing of canvas cover	Labelling of GM seed lots (traceability)	All			Company
Drying on farm	Most farmers own their own dryer	All	When shared, dryers are ventilated trailers, easy to clean		Farmer
Cleanliness of storage silo and dryer	Control of dryer cleanliness by seed company technician	All			Company
Cleaning of elevator and handling machinery before and after operation	Control of trailer cleanliness by seed company technician	All			Company
Post-harvest					
Superficial soil tillage to speed up seed germination	None				
Control of re-growth the following year	Control of re-growth during the next three years (2-3 times per year)	0.30%		1 h/ha	
Control of re-growth the following year	Control of re-growth during the next three years (2-3 times per year)	0.10%		3h/ha	
Mechanical or chemical destruction of volunteers	If current practice is chemical control with glyphosate and the GM beet is tolerant to this herbicide: use selective herbicide or other total herbicide (glufosinate)	All	No difficulty	No additional time	Farmer
Following crop: a cereal is preferred (easy volunteer control by herbicide)	Control of weed control program the following year				Company
Minimum soil tillage before the following crop (avoid deep burial of seeds with high longevity)	None				
Seed cleaning and processing					
Limitation of seed losses during farm-factory transport	Processing in factories with official agreement				Company
Particular attention in factory to avoid seed lot admixture	Total traceability of seed lots	All	Apply regulation		Company
Seed lot testing (quality)	Seed lot testing (herbicide tolerance)				Company
Distribution					
Seeds in sealed bags with official certificate	Specific labelling for GM		Apply regulation		

Appendix 11: Description of the GeneSys®-beet model (Sester *et al*, 2003)

GeneSys®-beet is an adaptation of GeneSys®-rapeseed (Colbach *et al*, 2001a & b). Its aim is to quantify the effect of cropping systems on gene escape from sugar beet to weed beet.

Model structure

The input variables are the regional field pattern, the crop successions, the cultivation techniques for each crop and some aspects of the climate. Output variables are, for each field and year, adult plants, newly produced seeds and the density and genotype proportions of the seed bank.

The model is based on the life-cycle of sugar and weed beet (see above). Cultivated sugar beet is biennial and accumulates sucrose during the first year. Annual plants are either weed beets or prematurely bolting cultivated sugar beet. Groundkeepers are small sugar beet roots lost during harvest which flower in the following crop. Each day, the density and genotypes are calculated for every life-stage in each field, depending on cultivation techniques and crop environment. Herbicide-resistant and -sensitive plants differ only in their response to the herbicide against which the transgene confers resistance. During flowering, pollen is dispersed between fields depending on field areas, shapes and distances as well as on flowering dates.

Choice of parameter values

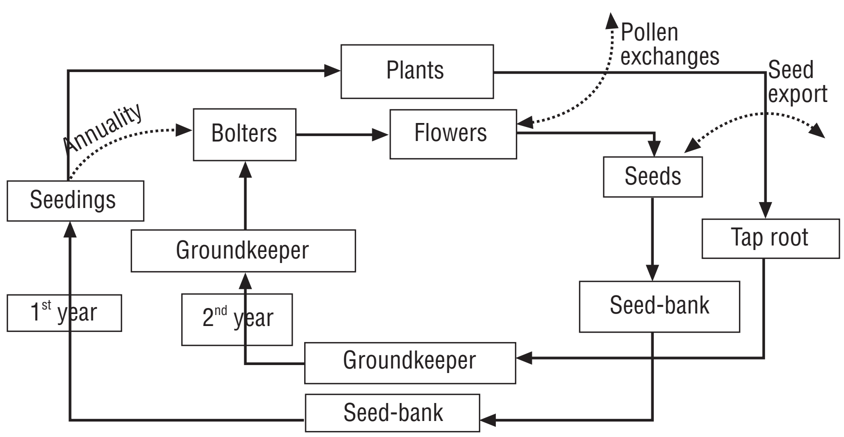
Parameters describing cultivated sugar beet are found in the literature. Processes specific to weed beet are often unknown, e.g. seed survival in soil, the evolution of germination ability with seed age, or the competitive effects of crops on the flowering and seed production of weed beet and of groundkeepers. Field experiments were set up to study these processes and their results used to estimate model parameter values.

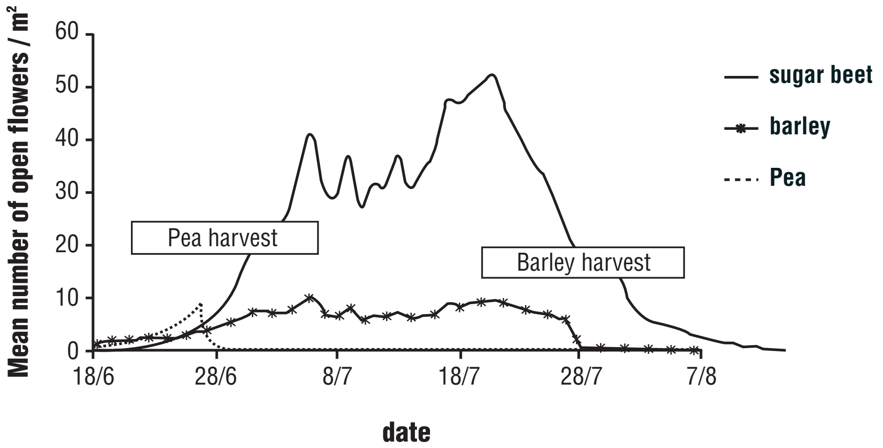
Simulations

Simulations carried out with the model allow an *a priori* evaluation of the advantages and disadvantages of innovative cropping systems. For example, the figure below shows the dates and intensity of weed beet flowering in different crops and therefore the likelihood and volume of gene flow via pollen.

Simulation of the impact of the crop (spring barley, pea and sugar beet) on the flowering

Life-cycle for annual plants (weed beet or prematurely bolting cultivated sugar beet) and biennial plants (cultivated sugar beet)





dynamics of weed beet in fields originally infested by 0.5 weed beet seedlings per m^2

Using the model for prediction

The quantitative validation of the GeneSys - sugar beet model is on-going.

There is, however, information on the general validity of the structure of the model. The general agreement of the model with expected behaviour was tested, and found to be satisfactory. Furthermore, GeneSys Sugar Beet is derived from GeneSys Oilseed Rape. The latter has been quite thoroughly tested and found to give reasonable results overall. Validation of the sugar beet version is mainly a question of assessing crop-specific mechanisms and parameters.

Appendix 12: Farm types in the sugar beet study

Picardie case study

- France = 22% of European sugar beet production area, 35 000 farms, 32 sugar companies
- Picardie: area of intensive sugar beet production, with 10% of European production
- No organic sugar beet

The French Chambers of Agriculture have set up a system for classifying agricultural holdings into types (called ROSACE). Several farms corresponding to each major farm type are regularly followed up from a technical and economic standpoint. The accuracy of the classification was checked in Picardie based on data from the 2000 agricultural census. Recent data were therefore available to determine representative, conventional farm types in Santerre (one small region of Picardie).

- **Farm 1**: type "Potato grower"
  - Clustered fields (176 ha)
  - SB / P / Wheat / Leg / Wheat / P / wheat
  - SB / Wheat / Pea / Wheat (no irrigation)
- **Farm 2**: type "Sugar beet grower", medium quota
  - Dispersed fields (164 ha)
  - SB / Wheat / Set aside / Pea / Wheat
- **Farm 3**: Cereal grower
  - Dispersed fields (46 ha)
  - SB / Wheat / Pea / Wheat
- **Farm 4**: Organic
  - Dispersed fields (20 ha)
  - Luc. /Luc. /Luc. / Fodder beet / Wheat / Spring Barley / Oats / Triticale

Bavaria case study

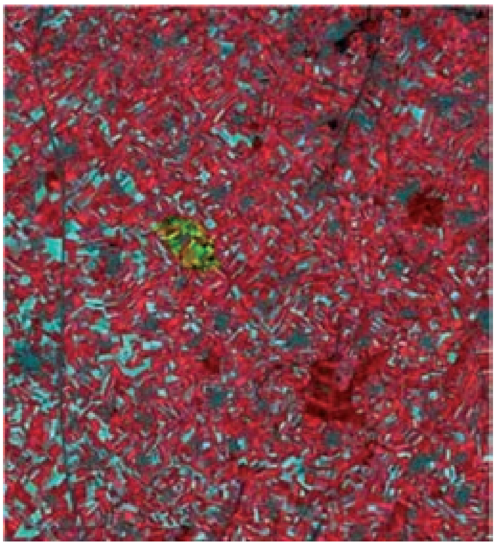
- 71 557 ha sugar beet
- 34% of farms are 2 to 10 ha
- 26% are 10 to 20 ha (Average: 23.3 ha/farm)
- 1 595 ha fodder beet
- Organic: 3 386 farms, average area: 28.1 ha
- Organic sugar beet production exported to Switzerland
    > Situation contrasts with Santerre (sizes of farms and fields)

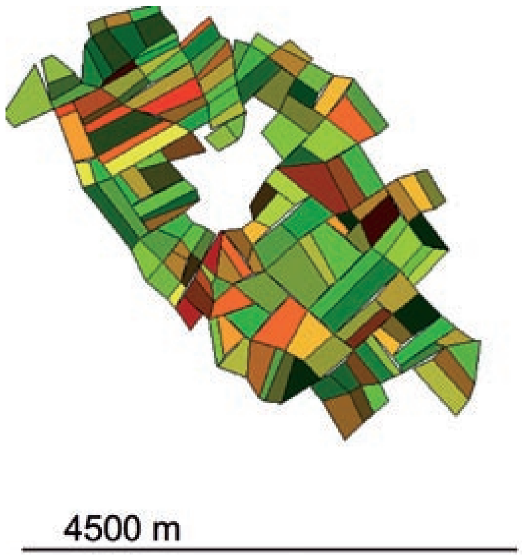
Bavarian farm type

This type is determined on the basis of expert opinion.

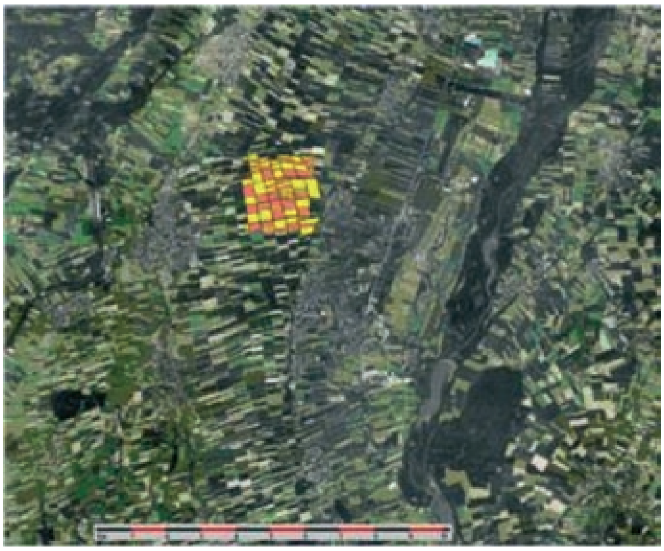
- Average plot size: 2.5-3.35 ha
- Rotations:
    - Wheat / SB/ wheat / maize / barley
    - Wheat / SB / wheat / potatoes
- Sugar beet sowing after *Sinapis alba* (intercropping) and stubble mulching or,
- Sugar beet sowing after conventional soil preparation (ploughing + 2 pre-sowing tillages)
- Hoeing between rows: 2-3 times
- Hand uprooting of weed beets

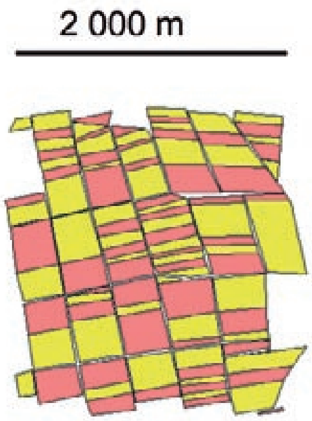
Appendix 13a: Location of the agricultural area chosen for simulation in Santerre and layout of the 149 chosen fields around a village





Appendix 13b: Location of the agricultural area chosen for simulation in Bavaria and layout of the 100 chosen fields





Source: Courtesy of the Institute for the Protection and Security of the Citizen, Joint Research Centre of the European Union

Appendix 14: Scenarios used for sugar beet simulations

Summary of the basic simulated situations (current practices - good management of weed beets)

Farm	Rotation	Situation of the farm	Management of bolters in sugar beet crops	Initial seed bank	Ploughing	Set-aside treatment
Type 1	Sugar beet / potato/ wheat / vegetable / wheat / potato / wheat	Without GM sugar beet	Two rounds of hand pulling	0 seeds/m²	Each year	
		With GM sugar beet	No hand pulling	300 seeds/m²	Only before sugar beet and potato	
Type 2	Sugar beet / wheat / set aside / pea / wheat	Without GM sugar beet	Two rounds of hand pulling	0 seeds/m²	Each year	Treated with non-selective herbicide
		With GM sugar beet	No hand pulling	300 seeds /m²	Only before sugar beet	Treated with non-selective herbicide
Type 3	Sugar beet / wheat / pea / wheat	Without GM sugar beet	Two rounds of hand pulling	0 seeds/m²	Each year	
		With GM sugar beet	No hand pulling	300 seeds /m²	Only before sugar beet	
Type Bavaria	Wheat / sugar beet / wheat / maize / barley	Without GM sugar beet	Two rounds of hand pulling	0 seeds/m²	Each year	
		With GM sugar beet	No hand pulling	300 seeds /m²	Only before sugar beet	

Summary of worst-case scenarios

Several situations were tested to investigate various particularly high-risk cases, i.e. "worst-case scenarios". The impact of the following points was tested:

- The quality of bolter management in non-GM sugar beet crops;
- The presence of organic farming in the neighbourhood;
- Variations in soil tillage (ploughing vs. simplified practices);
- The use of total herbicide during set-aside (selection pressure).

We then carried out simulations with the same regional map. However, some of the fields around GM sugar beet crops were managed as described above, some had the same cropping system but without bolter management in sugar beet crops, some had an organic cropping system and some had a system without ploughing. These simulations were carried out for each of the four types of farm, but, for farm type 2, the fields with no ploughing were replaced by fields with no glyphosate management of set-aside land, which was cut twice.

Adjustments to GM crop grower practices

Then, for the high-risk situations described above, we tested the impact of several changes to the cropping system in fields with transgenic sugar beet in their rotation.

Case study	Change in fields with GM sugar beet
Farm 1	1 round of hand pulling 2 rounds of hand pulling Variety with the transgene in the pollinator
Farm 2	1 round of hand pulling 2 rounds of hand pulling Variety with the transgene in the pollinator
Farm 3	1 round of hand pulling 2 rounds of hand pulling Variety with the transgene in the pollinator Ploughing each year No ploughing
Farm 4	1 round of hand pulling 2 rounds of hand pulling Variety with the transgene in the pollinator

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