Scenarios for co-existence of genetically modified, conventional and organic crops in European agriculture

A synthesis report prepared by

Anne-Katrin Bock, Karine Lheureux, Monique Libeau-Dulos, Hans Nilsagård, Emilio Rodriguez-Cerezo (IPTS - JRC)

in May 2002

on studies conducted by

F. Angevin, N. Colbach, J.-M. Meynard, C. Roturier (INRA, France)
J. Sweet (NIAB, UK)
A. Philp (CEST, UK)
K. Menrad, M. Menrad, S. Wörner (ISI, Germany)
J. Kilpatrick (ADAS, UK)
L. Bonfini, G. Van den Eede (IHCP-JRC, Italy)

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

FOREWORD

The possible increase of commercial production of genetically modified (GM) crops in European agriculture may lead to the adventitious presence of GM crops in non-GM crops. Taking into account the need to keep the two crops separated, the co-existence of GM and non-GM crops in European agriculture presents a challenge.

In May 2000 DG AGRI requested a study on agronomic and economic aspects of co-existence of GM, conventional and organic crops in European agriculture from the Joint Research Centre. The study was initiated as a pan-JRC operation and with external expertise mostly channeled via the European Science and Technology Observatory (ESTO).

This synthesis report presents the results obtained and is based on the six studies performed by different institutes involved:

- *Analysis of potential risks of contamination*
  National Institute of Agricultural Botany (NIAB), Cambridge, UK
  Jeremy Sweet

- *Analysis of necessary adjustments of farming practices*
  Institut National de la Recherche Agronomique (INRA), Paris, France
  Frederique Angevin, Nathalie Colbach, Jean Marc Meynard, Christophe Roturier

- *Overview of existing segregation methods*
  Centre for the Exploitation of Science and Technology (CEST), London, UK
  Alastair Philp

- *Analysis of financial losses in case of contamination*
  Fraunhofer-Institute for Systems and Innovation Research (ISI), Karlsruhe, Germany
  Klaus Menrad, Martina Menrad, Stefan Wörner

- *Farm level monitoring of GMO content in non-GM crops*
  ADAS Consulting Ltd., Wolverhampton, UK
  John Kilpatrick, Simon Turner

- *Review of GMO detection and quantification techniques*
  Institute for Health and Consumer Protection (IHCP), Joint Research Centre
  Guy Van den Eede, Laura Bonfini

This report, the economic analysis and the co-ordination of the study was done by Anne-Katrin Bock, Karine Lheureux, Monique Libeau-Dulos, Hans Nilsagard and Emilio Rodriguez-Cerezo, Institute for Prospective Technological Studies (IPTS), Joint Research Centre.

Whilst IPTS is grateful for the collaboration with the JRC Institutes and for the help and inputs received from other European Commission services (DG AGRI, DG ENTR, DG ENV, DG SANCO), responsibility for the contents rests solely with the IPTS.

Seville, May 2002   Per Sørup

CONCLUSIONS

Consumers, food/feed industry and retailers demand a reasonable degree of choice between GMO- and non-GMO-derived products. But different modes of agricultural production are not naturally compartmentalised. If GM crops increase their share in EU agriculture (which is now minimal) questions arise concerning their possible co-existence with non-GM crops (conventional and organic) at farm level or regional level. Some of these questions are of agronomic and economic nature, and these are addressed in this report:

- *What will be the levels of adventitious presence of GM crops in organic or conventional crops, with current farming practices if the share of GM crops increases to 10% or 50%?*

The study was done for three crops for which GM varieties are available (oilseed rape for seed production, maize for feed production and potatoes for consumption), and for several farm types (both organic and conventional) that were defined to cover the variability present in EU farming infrastructure. For all crop-farm combinations, a hypothetical share of GM crops of 10% or 50% in the region was considered. A share of 50% mimics the situation in countries that adopted GM crops readily (for example the share of GM oilseed rape in Canada is currently 54%), while the 10% figure represents a scenario of slow adoption of GM crops in the EU.

In these scenarios, an estimation of the expected levels of adventitious presence of GM crops in non-GM crops was done with a combination of computer modelling and expert opinion. The estimations have a strong relative value (i.e. they are useful in predicting the effect of a change in farming practices) but the absolute figures obtained have to be taken with care since the models are not yet fully adjusted with field data.

The estimated levels of adventitious presence of GM crops do not change dramatically between the two scenarios of GM crop share (10% or 50%). A practical consequence is that measures to prevent adventitious presence of GM crops (see below) may have to be implemented in the early stages of adoption.

On the other hand, the estimated levels of adventitious presence of GM crops in non-GM crops - assuming the current farming practices specified in the study- vary significantly depending on the crop and farm type (for example, as much as 2.2% for a conventional intensive maize farm or as low as 0.1% for an organic potato farm). In general there is a trend to expect lower levels of adventitious presence of GM crops on organic farms, because of segregation systems already in place, but there are notable exceptions. For example in seed production of rape, organic farms will face higher probability of adventitious presence of GM crops due to problems in controlling volunteers with organic practices.

Sources of adventitious presence of GM crops are well known, and can be divided into four main origins (seed impurities, cross-pollination, volunteers and harvesting-storage practices). The relative importance of each source for the final level depends on the crop and farm type: volunteers are a key source of adventitious presence of GM crops for rape seed farms (especially organic) but are of low importance in maize farms, where seed impurities and cross-pollination account for most of the adventitious presence of GM maize.

- *Can this adventitious presence of GM crops in organic or conventional crops be reduced below certain policy-relevant thresholds with changed farming practices?*

Once again the answer depends on the farm-crop combination. The thresholds used in the analysis are similar to those being discussed in various regulations. These are 0.3% for seed production of allogamous species (rape) and 1% for maize and potato crops (for food-feed uses). All farm types producing oilseed rape seed or conventional maize will be able to meet their thresholds provided they change the set of current farming practices defined in the study. It should be noted that these current farming practices are a compromise, given the diversity of European farms in this regard. Therefore, some of the changes proposed (and the estimated

costs associated) could be already in use in number of farms. In some cases (dependent on farm type) changing farming practices at the individual farm level will be insufficient. In these cases changes may involve co-operation between neighbouring farms. Examples are the introduction of flowering time differences between GM and non-GM varieties, or region-wide border management. In contrast, all potato farm types and some maize farm types (organic) could meet these thresholds with the set of current farming practices defined in the study (with all the reservations already mentioned for the value of absolute figures).

- *Can adventitious presence of GM crops in organic or conventional crops be avoided?*

The possibility of changing practices to meet very low thresholds for all crops, near the analytical limit of quantification (~ 0.1%) is also considered in the report. This reflects the situation in organic farming where the use of GM varieties is not permitted (Council Regulation (EC) 1804/1999), setting a *de facto* threshold. The report concludes that a 0.1% limit will be extremely difficult to meet for any farm-crop combination in the scenarios considered (10% and 50% GMOs in the region), even with significant changes in farming practices. Perhaps some farm types producing seed of oilseed rape could approach such thresholds, but only with significant changes of farming practices.

- *What is the cost of these changes?*

In the analysis all costs are allocated to conventional or organic crop production, including those affecting primarily GMO production in case of co-operation. Compliance with the 1% and 0.3% thresholds through changes in farming practices and introduction of a monitoring system as well as likely insurance needs may result in additional costs of 1% - 10% of current product price for the farm-crop combinations studied (in the 50% scenario). Exceptions are found in the production of seed of oilseed rape, where costs can be much higher in particular farm types (up to 41%). In all cases, monitoring activities account for a large part of the additional costs. Cost reductions might be possible with segregation becoming an integrated part of agricultural practices and with decreasing costs of GMO tests. Generally, organic farms face higher costs (especially indicative insurance costs) per hectare and per tonne than conventional farms. However, when relating costs to product prices, the price premium for organic crops may reduce this difference considerably. Costs have been calculated without taking into account any changes in demand or market prices that would probably accompany an increased level of GM crops in agriculture.

- *Can the different types of production co-exist in a region?*

This question has to be examined case-by-case for each crop. However, it seems clear that co-existence with thresholds in the region of 0.1% is virtually impossible in any of the scenarios considered. When considering the 0.3% (production of seed) and 1% (food-feed production) thresholds, co-existence of GM and non-GM crops in a region (with 10% or 50% GMO share) might technically be possible but economically difficult because of the costs and complexities of changes associated. This is the case exemplified by seed production of rape. For potato the costs are much lower and no significant change of practices is needed, so co-existence could be a reality. The costs and types of adaptation of maize growers put this crop in an intermediate situation, but some types of conventional, intensive maize farms will have difficulties in a co-existence situation.

- *Can the different types of production co-exist on the same farm?*

Finally, cultivation of GM and conventional or organic crops on the same farm might be an unrealistic scenario, even for larger farms. Due to the importance of volunteers, oilseed rape seed producers will exclude growing GM crops on the same farm to avoid adventitious presence of GM seeds in their non-GM seeds. Also for maize and potatoes it would make the handling of the crops rather difficult.

Table of content

List of figures

List of tables

SUMMARY

Background, objectives and scope

1. If genetically modified (GM) crops eventually increase their share in EU agriculture, adventitious presence of GM varieties in non-GM seeds and crops might become an issue. Therefore there is a need to find appropriate measures at the farm level to minimise adventitious presence of GM crops.

2. The objectives of this study, covering three model crops, are to

    - identify sources and estimate levels of adventitious presence of GM crops in non-GM crops at farm level,

    - identify and assess changes of farming practices that could reduce adventitious presence of GM crops in non-GM crops below policy-relevant thresholds,

    - estimate costs of relevant changes in farming practices, costs of monitoring systems and costs of potential insurance systems to cover possible financial losses due to adventitious presence of GM crops in non-GM crops.

3. The study covers three arable crops, with several farm types for each crop in representative production areas of the EU:

    - winter oilseed rape (OSR) for seed production (certified and farm-saved seed) (France, Germany)

    - grain maize for feed production (Italy, France)

    - potato for direct consumption and food processing (UK, Germany)

4. The three model crops have been studied on different conventional and organic farm types, representing the average farm context for each of the different production forms in the selected geographical areas (certified and farm-saved OSR seed, intensive and non-intensive maize cultivation, early and regular potatoes). For a better comparison similar farm and plot sizes have been assumed for conventional and organic farms. Additionally smaller organic farm types have been studied to reflect the actual situation in some Member States.

Basic assumptions and considerations

5. To estimate on-farm levels of adventitious presence of GM crops in non-GM crops and to compare the effects of changing farming practices a combination of expert scientific opinion and computer models was used. The computer models are useful for comparisons of different farming practices. The absolute values provided by the models (e.g. when considering if a particular threshold can be respected) have to be taken with care, since the models are not yet fully validated with field data.

6. A set of farming practices (referred to as "current farming practices" in the study) needed to be defined for each crop, to estimate a "baseline" level of adventitious presence of GM crops in non-GM crops. These current farming practices are obviously a compromise given the variability existing in EU farms in this regard. Therefore, when the results indicate that changes in farming practices are needed to respect a certain threshold (and the costs of these changes are estimated), it could be that a significant number of farms are already applying the proposed or similar agronomic practices (especially in the case of seed production).

7. The estimation of costs arising from the need to reduce the adventitious presence of GM crops in non-GM crops is based on the allocation of all costs to non-GMO production. This reflects the present situation in which there is no particular legal obligation for commercial GM crop production to introduce measures to minimise adventitious presence of GM crops in non-GM crops.

8. For cost calculations market prices for GM crops are assumed to be slightly lower than for corresponding conventional crops. Other changes in market prices or demand due to an increased level of GM crops in agriculture have not been considered. The results of the study cannot be used to forecast neither future market prices nor the demand for GM and non-GM crops.

General Findings

9. Sources of adventitious presence of GM crops in non-GM crops at farm level are seed impurities, spread of pollen and seeds from field to field by wind, insects and machines, overwintering of plants and plants growing from spread seeds as well as mixing of crops after harvest.

10. The percentage of GMOs grown in the region represents an important factor, already a level of 10% GM varieties in the region causes significant levels of GMO content in non-GM crops. Two scenarios of 10% or 50% share of GM crops in the region were analysed. A share of 50% mimics the current situation in countries which adopted GM crops readily (e.g. in 2000, GM soybeans represented about 54% of the American soybean acreage, GM rape seed represented about 50% of the Canadian rape seed acreage) and is the principal scenario examined in the study, while a share of 10% GMOs illustrates an introduction phase of GM crops in EU agriculture.

11. Farming practices such as the treatment of soil, sowing dates, rotation systems and the infrastructure of the farm, as well as farm and plot size may influence levels of adventitious presence of GM crops in non-GM crops.

12. Threshold levels that have been studied here are 1% (for maize and potato crops), 0.3% (for OSR seed production) and 0.1% (for all three model crops). The two first are thresholds that have been integrated in European legislation (for the labelling of GM food) or are being discussed in the context of future legislation (amendment of seed marketing directive). The latter (0.1%) reflects the quantification limit of current analytical methods and mimics the condition of zero GMO content. This corresponds to the situation in organic farming where the use of GM varieties is not permitted according to Council Regulation (EC) 1804/1999, setting a *de facto* threshold. The 1% and 0.3% thresholds can be met in both scenarios studied by changing current farming practices as they have been defined in the study. In certain cases studied, farming practices, involving a co-operation between neighbouring farms, are the most effective ones.

13. The possibilities to meet a very low threshold (0.1%) were analysed for all three model crops. The results show that compliance with this threshold would be difficult in any of the two scenarios considered, even with significant changes in farming practices. Thus, if applying the very low *de facto* threshold currently required in organic production (detection limit), organic production would not be feasible in a region with GM crop production.

14. Compliance with the 1% threshold would result in additional costs (changing farming practices, monitoring system, insurance) of 1% - 9% of current product price for maize and potato. For OSR seed production, the equivalent costs to comply with a 0.3% threshold would be 10% - 41% of current price.

Specific Findings

Winter oilseed rape for seed production

15. For production of certified or farm-saved seed four organic and conventional farm types are studied. Certified seed producers are assumed to grow OSR according to certified seed production standards (e.g. for hybrid seed an isolation distance of 300m and a 6 year rotation, careful post-harvest segregation). The farms using farm-saved seed are assumed to be larger (about three times) with larger plots. The conventional farm applies a short 3 year rotation, exchanges seed and shares machinery with its neighbours or uses contractors (for example for harvesting). It has no dedicated machinery for GM crops and no dedicated

storage facilities. A summary of farm characteristics, predicted levels of adventitious presence of GM OSR in non-GM OSR, recommended changes in farming practices and related costs is shown in Table A of the Annex to this Summary.

16. For the estimation of in-field levels of adventitious presence of GM crops in non-GM crops the computer model GENESYS has been used. It ranks cropping systems according to their probability for gene flow from herbicide tolerant OSR to rape volunteers, both in time (via seeds) and in space (via pollen and seeds). It is suitable for seed as well as for crop production. Expert opinion was used for estimations of post-harvest levels of adventitious presence of GM OSR.

17. Applying current practices as defined in the study, levels of adventitious presence of GM crops are estimated to range from 0.42% to 1.05% for the considered farm types in the presence of 50% GMOs (see Table A). Organic farm types are predicted to have higher levels of adventitious presence of GM OSR mainly because of their lower efficiency in volunteer control compared with conventional farms (see Table A, current practices). All farm types, organic as well as conventional, could achieve a hypothetical 0.3% threshold for GMO content in seed production by changing farming practices.

18. Theoretically, levels of adventitious presence of GM crops could be reduced to very low levels (<0.1%) by changing farming practices. The only exception would be conventional farms using farm-saved seed, where achieving such low levels seems not to be feasible without changing the post-harvest farming strategy completely (see Table A, best change of practices).

19. Levels of adventitious presence of GM crops depend on field sizes (as shown by studying an additional small farm scenario), isolation distances, volunteer control and the farm structure regarding post-harvest handling of the seed crop (possibility to segregate). In addition, for OSR the initial seed purity and the selected crop variety (varietal associations and hybrids with reduced male fertility or – for seed production – with male sterile parent lines are very prone to cross-pollination) play an important role.

20. The model predicted as effective measures:

   - Avoiding *at any time* throughout the rotation cycle cultivation of rape seed within a radius of 300m surrounding the seed production field (costs difficult to estimate due to the need for far-reaching changes of crops and rotations).

   - Changing set-aside management by sowing the field in spring in order to minimise survival of rape volunteers (estimated to 194 €/ha additional costs).

   - Longer rotations with an additional (non-rape) spring crop to control volunteers (no additional costs assumed).

   The selection of measures depends on the type of farm, but in general changing set-aside management and establishing OSR-free zones of 300m around the plot are the most efficient practices, though they are rather costly or require co-operation between farmers. This type of measures might already be applied on some farms in the context of contract obligations from seed companies. The EC Scientific Committee on Plants (SCP), in its opinion from 13 March 2001, recommends an isolation distance of at least 600m for hybrid seed in the year of seed production to avoid cross-pollination.

Maize for grain production

21. For grain maize production seven farm types were studied (conventional and organic, intensive and non-intensive cultivation, large and small organic farms). Main features of intensive maize cultivation are the high percentage of maize grown (50% to 80% of the agricultural area) and varying but generally small isolation distances between different plots. In contrast, farms cultivating maize in non-intensive cultivation regions (maize representing 20% of the agricultural area) are assumed to have larger plots and isolation distances of about 500m. A summary of farm characteristics, levels of adventitious presence

of GM crops in non-GM crops, recommended changes in farming practices and related costs is shown in Table B of the Annex to this Summary.

22. The computer model MAPOD was used to estimate the effects of changing farming practices on the level of in-field adventitious presence of GM maize in non-GM maize via cross-pollination. Post-harvest levels were estimated by an expert panel.

23. Applying current practices, levels of adventitious presence of GM crops in non-GM crops are estimated to range from 0.16% to 2.25% for the considered farm types in the 50% scenario (see Table B).

24. Cross-pollination from GM plants is the main source of in-field adventitious presence of GM maize. The impact depends on relative plot size of the GM source and the non-GM recipient as well as on isolation distances. Small farms or farms with smaller fields would be more affected. Volunteers in maize are not a significant source of adventitious presence of GM crops.

25. Impurities in the certified seeds used for sowing would also be an important source of adventitious presence of GM crops. According to OECD schemes a varietal purity for conventional certified maize seed of 99.0% is required. In the study, adventitious presence of GM seed in conventional maize seeds is assumed to be 0-0.3%. For organic seed lower seed impurities could be expected, reflected in the assumed level of 0.05% in this study.

26. For conventional farms the post-harvest handling of the grains represents another principal source for adventitious presence of GM crops as maize is often cleaned, dried and stored in central facilities, where adventitious admixture could occur.

27. Conventional intensive maize producers may need to change farming practices to comply with a threshold of 1% (in both scenarios of 10% or 50%, and considering an adventitious presence of GM seeds in the seeds used of about 0.3%). Lowering seed impurity would have a big impact but might be difficult to achieve (opinion of the SCP from 13 March 2001). Increasing isolation distances to 100m – 200m, the introduction of varieties for GM and non-GM maize with different flowering times and improving post-harvest management (storage, cleaning and drying facilities dedicated to non-GM maize) would be possible alternatives. The costs of increasing isolation distances and changing post-harvest management have not been determined because of their very complex nature. For a difference in flowering time to be effective, the GM variety has to flower earlier than the non-GM variety. Because of generally lower yields for earlier varieties, this would lead to additional costs of about 45 €/ha (for GMO producers) (see Table B, best change of practices, additional costs).

28. In less intensive maize growing regions, for conventional farms it may be sufficient to change the post-harvest management to meet a threshold of 1% (an adventitious presence of GM seed in non-GM maize seed of 0.3% has been assumed) (see Table B, best change of practices).

29. Organic farms (not growing GM maize on their farms) using organic seed with high purity and having a post-harvest management separated from conventional production, could meet a threshold of 1% without changing current farming practices.

30. A threshold of 0.1% seems to be extremely difficult to achieve for any of the farm scenarios.

Potato for fresh consumption and processing

31. Potato has very different characteristics compared to oilseed rape and maize, as the harvested potato is not the result of a fertilisation event. Therefore it has far less problems regarding pollen flow as a source for adventitious presence of GM crops. In four farm types studied (conventional and organic production of early potatoes and potatoes for direct consumption and processing), the main problems are caused by groundkeepers and post-harvest handling of the crop.

32. Expert opinion alone was used to estimate in-field and post-harvest levels of adventitious presence of GM crops in potatoes. Applying current farming practices including a careful segregation of varieties, the estimated levels of adventitious presence of GM crops in non-GM crops range from 0.1% to 0.54% (see Table C in the Annex to this Summary).

33. All considered farm types would be able to meet a 1% threshold without changing farming practices. Organic farms face levels of adventitious presence of GM crops of less than half of those of the conventional farms. However, even with changes in farming practices, a threshold of 0.1% would probably not be achievable for any farm type. The farm characteristics and results for potato are presented in Table C.

Applicability of existing segregation systems

34. Segregation systems in place (such as those for waxy maize or high erucic acid oilseed rape) are not suitable for the purpose of minimising adventitious presence of GM crops in non-GM crops, without some significant changes. In general the thresholds assured by these systems are less stringent than those being established for GM crops. Also, some of these segregation systems are backed by cheap, fast and easy detection methods (iodine staining for waxy maize) while current methods for detecting and differentiating GM varieties do not yet have these characteristics.

Monitoring adventitious presence of GM crops in non-GM crops on the farm

35. Monitoring systems could be developed adapting the Hazard Analysis and Critical Control Point methodology (HACCP), to define crucial steps in the production process to be controlled. Different degrees of control intensity, adjusted to thresholds and probability of adventitious GMO presence, could be achieved by varying the production steps to be included. At each stage of the cultivation process, steps to assure segregation have to be documented. The scheme would be supported by detection methods (qualitative and quantitative GMO Polymerase Chain Reaction (PCR) analysis).

36. Detection and quantification of GMO content is usually done by analysing the transgenic DNA by PCR or the protein content by immunoassays (Enzyme-linked ImmunoSorbent Assay, ELISA). These tests are rather time-consuming and need laboratory equipment as well as skilled personal. To enable control of GMO content on the farm level, accurate, cheap, quick and easy to use testing methods based on PCR and ELISA need to be developed. Currently, test prices are in the region of 320 € for a quantitative PCR analysis of a single sample or 150 € for a semi-quantitative analysis of a single sample by ELISA. Prices might decrease when larger numbers of samples are tested.

37. Several national and international organisations are involved in developing harmonised guidelines and standards for sampling strategies and GMO detection methods. Validation of testing methods, especially PCR, is undertaken by performing ring trials with different laboratories. The major initiative is this field in the EU is the European Network of GMO Laboratories, organised by the Joint Research Centre /Institute for Health and Consumer Protection (JRC/IHCP). Certified reference materials for PCR and ELISA tests of specific GMOs have been developed by Joint Research Centre /Institute for Reference Materials and Measurements (JRC/IRMM).

Insurance systems

38. If adventitious presence of GM crops in non-GM crops occurs above a set threshold a reduction of income could be expected. Organic farmers would also lose possible organic price premia and subsidies, so their short-term losses would be higher. Indicative insurance costs have been calculated on the basis of short-term losses and an assumed frequency of exceeding the threshold of 3%. In the medium and long-term additional costs for crop management to control GM volunteers, for GMO testing and control might arise. For organic farms, to regain the organic status might take time and imply a further loss of income.

Cost impacts

39. Costs presented below are those needed to meet thresholds of 0.3% for OSR seed and 1% for maize and potato crops, in the 50% scenario.

40. Changing farming practices, where necessary, leads to very different economical burdens for farmers according to crop and farm scenario. Costs of monitoring systems have a high impact on all farms. Monitoring costs include a large part that is fixed per farm unit, therefore total costs would be negatively correlated to farm size. Indicative insurance costs have a large impact on most organic farms due to high price premia, and negligible effects on conventional farms. Differences in yields and prices between crops lead to dramatic differences in economic impact, although the costs per ha may be of similar magnitude. This is illustrated in Figure A of the Annex, which presents total costs as percentage of product price.

41. For OSR, farms producing conventional certified seeds would have additional costs representing 10% of the price, the largest part of the costs being monitoring costs. For the corresponding organic farm, costs would represent more than 20% of the price, the difference being due to higher costs of changing agricultural practices. For seed saving farms, the costs would represent 17% (conventional) or 41% (organic) of the price, the organic farm having to apply a more expensive additional farming practice. These farms would probably be forced to stop saving seed and instead buy certified seed.

42. For maize additional costs for intensive conventional production would correspond to 9% of the price, with almost half the costs originating from yield losses due to change of flowering time. However, costs of necessary changes of the post-harvest management for conventional farms have not been estimated in this study. For an organic farm located in the same area, costs would represent 6% of the price, mainly monitoring costs and indicative insurance costs. In non-intensive maize production (organic or conventional) costs would represent 4% - 5% of the price. In the organic farm, high product prices reduce the economic effect on the total costs, despite rather high indicative insurance costs.

43. Potato is the less affected model crop. There is no need to change agricultural practices for any of the farms and a very high yield as compared to oilseed rape and maize further decreases the costs per tonne. Monitoring and indicative insurance costs would amount to 1% – 3% of the farm gate price.

44. In general organic farms have higher costs per hectare and per tonne compared to conventional farms. This is caused by slightly higher monitoring costs and higher indicative insurance costs as well as, in some cases, higher costs for changing farming practices. However, when relating costs to product prices, the price premia for organic crops reduces this difference considerably.

Future research needs

45. Some of the recommended farming practices could also be employed by farmers growing GM crops. Further studies will be needed to identify and evaluate the effectiveness of practices that these farmers could specifically use to minimise probability of adventitious presence of GM crops in non-GM crops. This could include also specific biological characteristics of GM crops for containment of transgenes.

46. More information on actual levels of seed impurities in the lots marketed in the EU (which is becoming available from some Member States laboratories) is essential for simulations like the ones presented here. Also, a study similar to the one described here for OSR seed could be useful for maize seed, to better understand how co-existence will impact on seed production and to provide information for an adaptation of seed production standards.

47. An exhaustive laboratory survey of the actual presence of traces of GM crops in non-GM crops (in countries where GM crops are widespread) is not available.

48. For a more comprehensive analysis of economical impacts of co-existence a deeper analysis concentrating on the complete economic environment of a farm could be envisaged.

Annex to Summary

Table A: Levels of adventitious presence of GM OSR in non-GM oilseed rape seed production in conventional and organic agriculture with current and with recommended farming practices (50% GMOs in the region, medium-term evaluation)*

	Certified hybrid seed production		Farm-saved seed production	
Farm type	**Conventional**	**Organic**	**Conventional** (50 % GMOs also grown on the farm)	**Organic**
Farm characteristics Farm area Plot size Number of (seed) plots	131 ha 6 ha 1-2	131 ha 6 ha 1-2	351 ha 11 ha 6-7	351 ha 11 ha 6-7
Current practices Total rate of adventitious presence expected	0.42 %	0.61 %	0.59 %	1.09 %
Best change of practices to meet threshold 0.3 % Total rate of adventitious presence expected	To introduce a spring crop in the rotation 0.19 %	Spring sown set-aside 0.04 %	Dedicated machinery, cleaning machinery 0.23 %	Spring sown set-aside 0.11 %
Additional Costs (€ / ha)	~0**	194.3	93.2	194.3
Best change of practices to meet threshold 0.1 % Total rate of adventitious presence expected	Spring sown set-aside 0.03 %	Spring sown set-aside 0.04 %	Not achievable	Combination of practices*** 0.07 %
Additional costs (€ / ha)	194.3	194.3	-	198.6
* The seed bank is assumed to be pure at the beginning of the simulations ** No additional costs compared to current practices *** Combination of practices includes spring sown set-aside, chisel before other crops than rape, region-wide border management, and difference in sowing time				

Table B: Levels of adventitious presence of GM maize in non-GM grain maize production in conventional and organic agriculture with current and with recommended farming practices (50% GMOs in the region)

	Intensive maize cultivation area				Non-intensive maize cultivation area		
Farm type	**Conventional France** (50% of GMOs in and outside the farm)	**Organic large**	**Organic small**	**Conventional Italy** (50% of GMOs in and outside the farm)	**Conventional** (50% of GMOs in and outside the farm)	**Organic large**	**Organic small**
Farm characteristics Farm area Plot size Number of plots	60 ha 3-4 ha 14	60 ha 3-4 ha 14	10 ha 1 ha 1	50 ha 8 ha 3	100 ha 20 ha 1	100 ha 20 ha 1	15 ha 3 ha 1
Current practices Total rate of adventitious presence expected	2.25 % (+/-0.6 %)	0.16 % (+/- 0.07%)	0.58 % (+/- 0.04%)	1.75 % (+/- 0.2%)	0.8 % (+/- 0.5%)	0.17 % (+/- 0.09%)	0.32 % (+/- 0.04%)
Best change of practices to meet threshold 1%	50 °days difference in flowering time + post-harvest management	Current practices	Current practices	Minimum distance 200m + post-harvest management	Post-harvest management	Current practices	Current practices
Total rate of adventitious presence expected	0.66 % (+/- 0.3 %)*			0.69% (+/- 0.3%)*	0.51 % (+/- 0.3 %)*		
Additional costs (€ / ha)	45.4 + n.d.	0	0	n.d.	n.d.	0	0
Threshold 0.1%	Not achievable						

*   It is assumed that the percentage of seed impurities is 0-0.3%. For homozygous GM maize varieties, the effect of seed impurities in the produced crop is doubled. Therefore it is assumed that the effect of the seed impurity is in the interval of 0 – 0.6%, here expressed as 0.3 +/- 0.3%.

n.d. not determined

Table C: Levels of adventitious presence of GM potatoes in non-GM potato production in conventional and organic agriculture with current farming practices (25 to 50 % GMOs in the region)

	Potatoes for direct consumption and processing		Early potatoes	
Farm type	**Conventional** (25 to 50% GMOs also grown on the farm)	**Organic**	**Conventional** (25 to 50% GMOs also grown on the farm)	**Organic**
Farm characteristics Farm area Plot size Number of plots	150 ha 10 ha 3	150 ha 5 ha 5	75 ha 3 ha 5	75 ha 3 ha 5
Current practices Total rate of adventitious presence expected	0.36% (+/- 0.15%)	0.1% (+/- 0.02%)	0.54% (+/- 0.21%)	0.16% (+/- 0.05%)
Best change of practice to meet threshold 1%	Current practices	Current practices	Current practices	Current practices
Additional costs (€ / ha)	0	0	0	0
Threshold 0.1%	Not achievable			
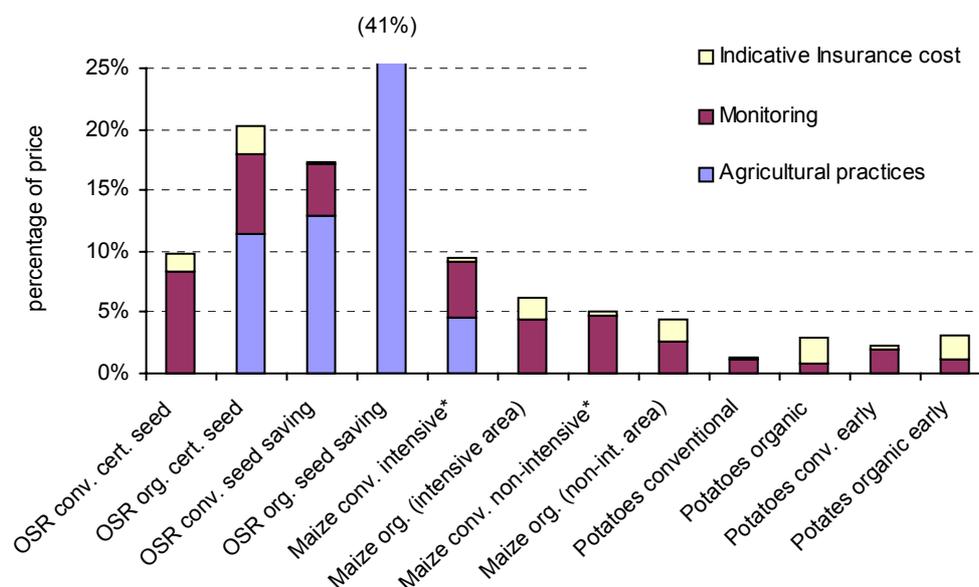
Figure A: Total costs of achieving thresholds for adventitious presence of GM crops in non-GM crops as percentage of farm gate price (targeted threshold 0.3% for oilseed rape, and 1% for maize and potatoes)
*For conventional maize, costs for changes in the post-harvest management are not included.

1 INTRODUCTION

Genetically modified (GM) crops were first commercially planted world-wide to a significant extent in 1996 and since then the acreage has increased rapidly from 2.6 million ha in 1996 to 42.1 million ha in 2000 and is likely to reach 50 million ha at the end of 2001[1]. USA, Canada, Argentina and China share 99% of the area planted with GM crops. The main GM crops grown are soybean, maize, cotton and rapeseed. In the European Union, Portugal, France and Spain grew reduced areas of Bt-maize in 1999 and 2000, with decreasing tendency[2]. This is mainly due to a wide-spread public skepticism against GM crops and GM food products, reflecting concerns about possible adverse effects on the environment and human health.

In June 1999 a *de facto* moratorium on authorisations for placing on the market of GMOs was adopted by the European Council of Environment Ministers, awaiting a revision of Directive 90/220/EEC, which regulates experimental releases and placing on the market of GMOs. In February 2001 the revised directive (Directive 2001/18/EC) was adopted by the European Parliament and the Council of Ministers and will enter into force October 2002. Additionally, in July 2001, two proposals for regulations concerning GM food and feed and traceability and labelling of GMOs have been adopted by the European Commission. An additional proposal concerning GM seed is expected end of 2001. The new directives and regulations close a gap in the legislative framework and answer consumers' concerns regarding the safety of GM products.

Probably the new legislative situation will sooner or later lead to new GM crops being authorised for placing on the market (November 2001: approvals for 14 GM plants are pending). New GM varieties could then be expected on the European market in about 5 years.

The possibility of GM crops mixing with conventional or organic crops is a concern today. Organic farming in 1999 represented 2.6% of the agricultural area of the EU, 1.3% in France, 2.4% in UK, 2.6 % in Germany, 5.5% in Denmark, 6.5% in Italy and 8.5% in Austria[3]. It has rapidly developed world-wide in the last years, and shares of agricultural land as well as number of farms are constantly increasing. The standards for organic farming are strict and cover every step of the production. The utilisation and presence of GMOs is excluded from organic farming.

For conventional food products and food ingredients, the European Union introduced a labelling threshold for adventitious contamination[4] of 1% GMO content at the marketing stage. All food that contains more than 1% GMOs, related to the different ingredients, has to be labelled according to Regulation (EC) 49/2000. The new proposal for a regulation on GM food and feed from July 2001 extends the current labelling provisions to all food (and feed) that has been produced from GMOs, irrespective of the detectability of transgenic DNA or protein. This means that also for example refined oils of GM rapeseed, where no DNA is detectable, will have to be labelled as GM in the future. A 1% threshold is also proposed for adventitious contamination with traces of *unauthorised* GMOs, which have already been subject to a scientific risk assessment by EU institutions and have been found to not pose a risk to human health or the environment. Non-compliance with this latter threshold would render a product unsaleable in the EU. Producers of non-GM crops (conventional farmers) would have to respect these thresholds (legal basis), or, for more stringent production lines (voluntary basis), even lower thresholds would be applied.

---

[1] European Commission, DG Agriculture 2000. Economic impacts of genetically modified crops in the agri-food sector; ISAAA press release 18 October 2001.
[2] Clive James, 2000 ISAAA Briefs No. 21
[3] European Commission, DG AGRI 2001. Organic Farming in the EU facts and figures.
[4] The term "contamination" is used to describe the fact that a conventional or organic crop can be made unsuitable for certain markets or uses by mixing with GM crops above certain thresholds. It does not imply that the presence of genetically modified organisms (GMOs) in conventional or organic crops renders them harmful.

The possible introduction of GM crops on a larger scale into European agriculture will pose the problem of their co-existence with conventional and organic crops. In May 2000 the Agriculture DG requested a study on agronomic and economic aspects of co-existence of genetically modified, conventional and organic crops from the Joint Research Centre (JRC). The study was initiated in September 2000 by the Institute for Prospective Technological Studies (IPTS/JRC). This synthesis report is a summary of the results obtained in the period from October 2000 to July 2001.

The objectives of the study are

- To identify and analyse the causes for, and probabilities of, potential contamination of conventional and organic crops with GM crops on the farm level.

- To identify and propose necessary changes of farming practices in order to minimise gene flow and adventitious mixing of GM and non-GM crops.

- To estimate and analyse the different costs associated with the proposed changes in farming practices.

- To develop a monitoring system needed to confirm that agricultural products, produced in non-GMO based agriculture, do not contain GMOs above certain threshold levels.

- To identify implications of adventitious contamination and estimate the associated financial losses for conventional and organic farms.

The study covers the production of seed, feed and food including the production cycles of the crops as well as the post-harvesting processes up to the first distribution point. Industrial food and feed processing and retailing as well as environmental aspects of gene flow are excluded from the scope of the study.

Three arable crops grown for different purposes were selected as case studies, winter oilseed rape for seed production, grain maize for feed production and potatoes for food production (processed food and direct consumption). These crops represent different biological characteristics and all three are of relevance for GMO-based, conventional as well as organic production. Moreover, for all three crops there are GM varieties developed, including varieties already authorised or pending authorisation at EU level and scientific references are available. Finally, all three are economically important crops in Europe. The crops are studied in their main production areas in the European Union: winter oilseed rape in France and Germany, grain maize in France and Italy and potatoes in UK and Germany.

The study considers for each crop two different contamination threshold levels:
▪ Winter oilseed rape for seed production, 0.1% and 0.3%
▪ Grain maize for feed production, 0.1% and 1%
▪ Potatoes for food production, 0.1% and 1%

The area grown with GM varieties relative to the area grown with conventional varieties influences the need for changed practices. Therefore, the study analyses two potential scenarios of areas grown with GM varieties, namely 10% and 50%. A share of 50% mimics the current situation in countries which adopted GM crops readily (for example in 2000, GM soybeans represented about 54% of the American soybean acreage, GM rape seed represented about 50% of the Canadian rape seed acreage) and is the principal scenario examined in the study. A share of 10% GMOs in the region represents a scenario that assumes a slow introduction of GM crops in EU agriculture.

For all three crops, a number of conventional and organic farm types are studied. Each farm type was set up on the basis of specific criteria established at the beginning of the study to

represent the average farm for each of the selected geographical areas. A set of farming practices, referred to as "current farming practices" in the study, has been defined for each crop to estimate a "baseline" level of adventitous presence of GM crops in non-GM crops. These current farming practices are obviously a compromise given the variability existing in EU farms in this regard.

Finally, the study includes analyses of costs associated with the co-existence of agricultural systems at the farm level. The focus is on conventional and organic farms. All identified costs are borne by the non-GM production, also the costs from changes affecting the GMO-based production. This approach corresponds to a situation with no legal obligation for GM crop farmers to minimise the probability of adventitious contamination of neighbouring non-GM crops. The cost of implementing new measures to minimise contamination, costs for monitoring the farming processes and the GMO content of the product and potential financial losses due to adventitious contamination are covered.

This document is a prospective study, based on assumptions needed to illustrate different scenarios. These assumptions should not be taken as an anticipation of future developments. This applies especially to the selected GMO shares of 10% and 50% and the selected thresholds of 0.1%, 0.3% and 1%. An increased GMO share would certainly require a corresponding demand and would result in a different price structure. These aspects have not been included in the study, the scenarios presented are built on the actual situation and the identified costs cannot be used to predict future prices.

Following this introduction a short overview of existing segregation systems and their applicability to segregate GM and non-GM crops is given in Chapter 2. Chapter 3 provides an analysis of probabilities of contamination for the selected scenarios and estimates the effects of changing farming practices. Information about GMO detection and quantification techniques as well as a proposal for an on-farm monitoring system are presented in Chapter 4, followed by an analysis of potential impacts on conventional and organic farms in case of contamination in Chapter 5. Chapter 6 brings together identified costs and provides a discussion on the total additional costs that probably would be connected with the co-existence and segregation of GM and non-GM crops. Chapter 7 presents the final conclusion. Data on the economic performance of the selected farm types can be found in the Annex.

2   EXISTING SEGREGATION SYSTEMS

In agriculture the segregation of specific crops is a well known issue. There are several segregation systems in place, although most are not dealing with GM crops. In this chapter a brief overview is given on existing or proposed segregation systems and their applicability to segregate GM from non-GM crops.

2.1 Certified seed production

The only area where statutory measures exist to minimise genetic contamination and maximise varietal purity is in the regulation of seeds grown for sale. Legislation to ensure that marketed seed is sufficiently pure exists throughout the world. However it is important to note that the regulation is of seed offered for sale through seed merchants and does not regulate seed which is saved by individual farmers (which may subsequently be transferred to other farmers).

EU seed marketing directives specify separation distances as well as time intervals between the seed crop and any other crop of the same species grown on the plot. National seed inspection and testing agencies back up the regulations. Minimum purity levels have to be achieved. Seed companies often employ even stricter rules. Failure to meet the purity standards will result in the seed not being certified and the seed premium being lost to the grower. Compliance with the varietal purity standards shows that in more than 96% of cases the procedures adopted (isolation, cleaning, rotations, and separation post-harvest) are sufficient to meet the stringent purity standards essential for the seed supply.

However, the purity standards adopted for certified seed are not always strict enough to meet the 0.3% and 0.1% impurity standards used in this study for presence of genetically modified organisms (GMOs). For example the minimum purity for certified hybrid oilseed rape seed is only 90%. Additional safeguards may therefore be required, such as longer isolation distances, more cleaning and/or stipulations that ground used to produce non-GM seed should never before have grown GM varieties. Furthermore, seed production is a small-scale activity with premia to be gained and thus not comparable to bulk production of commodity crops.

The requirements for basic seed production (long separation distances, careful cleaning and vigilant volunteer management) are perhaps the best guide since the purity levels demanded for basic seed (99.9% for conventional basic oilseed rape seed, 99.5% for basic conventional maize seed) approximate the thresholds for GMO content under consideration.

2.2 Supply Chain Initiative on Modified Agricultural Crops

The Supply Chain Initiative for Modified Agricultural Crops (SCIMAC) is a partnership of the British Society of Plant Breeders, the National Farmers Union, the United Kingdom Agricultural Supply Trade Association and the Crop Protection Association. SCIMAC has developed a Code of Practice and Guidelines for the Introduction of GM Herbicide Tolerant (HT) Crops. These UK guidelines[5] specify separation distances to be adopted when growing GMHT varieties. The guidelines also list a range of advice about information transfer and record keeping and make specific suggestions for "good agricultural practice for growing herbicide tolerant (HT) crops". Since GM varieties are currently not commercially grown in the UK these guidelines have only been applied to the series of farm-scale trials currently in progress. Furthermore the separation distances recommended in the SCIMAC code are the subject of a current UK Ministry of Agriculture, Fisheries and Food (MAFF) consultation. The

---

[5] See http://www.cropprotection.org.uk/visitors/content/environment.htm

SCIMAC guidelines have no legal force in criminal law but are the basis for commercial contracts.

There is no data proving the efficiency of this system. Still, the guidelines, reflecting good agricultural practice, might be a useful starting point for minimising contamination.

2.3 Examples of segregation codes

2.3.1 British Retail Consortium / Food and Drink Federation code

The British Retail Consortium and the Food and Drink Federation have produced a technical standard based on current best practice in the sourcing of identity preserved, conventional soya and maize[6]. This code is intended to prevent GM contamination of foodstuffs throughout the supply chain by ensuring identity preservation of soya and maize crops and makes a number of recommendations for farmers, including supply of seed, planting, cultivation as well as harvesting and storage and transport. GM labelling will not be required on products in which these products are incorporated. Suppliers are being encouraged to work to the standard for the supply of both non-GM soya and maize. Those involved in the supply chain are being asked to evaluate the standard and revisions will be made where necessary.

Since the standard has only been finalised recently (published September 2001), the efficiency of the (general) measures proposed for farmers has to be demonstrated. Additionally no threshold has been stated.

2.3.2 Soja de Pays

The scheme was created in spring 1999 in response to a growing call from industry for a quality assured, identity preserved source of soya for animal feed in France. The scheme reaches right through the supply chain to ensure penetrant traceability from field to farmyard feed and is a close partnership among producers, collectors, processors and users of soya in France[7]. The segregation starts with the purchasing and planting of controlled non-GM seeds. At harvest, designated "Soja de Pays" is placed only in identified and reserved silos. The soya beans and derived products are always transported in such a way that they are unable to mix with other materials. This allows for perfect product traceability and endorsement with the Soja de Pays certifying mark. Although the scheme was set up to provide quality assured soya meal for animal feed it also generates a supply of certified non-GM soya oil which is suitable for human consumption.

These requirements are imbedded in the contracts that growers, collectors and processors sign with one another and are monitored (through polymerase chain reaction (PCR) and other spot checks) by an independent organisation mandated to do this by the scheme. The confidence engendered by the identity preservation and traceability aspects of the scheme allows a considerable premium to be garnered by vendors. In 2000 it is estimated that 135000 tonnes of soya (55000 hectares and 6000 producers) will be processed through the scheme.

As one of the first schemes to apply identity preservation methods to GM crop segregation in Europe this is an interesting case study. The current threshold for GM impurity in the Soja de Pays processed products is 1%. When crops such as maize, oilseed rape and potato are

---

[6] See http://www.fdf.org.uk/fdfbrclaunch.html
[7] See http://www.prolea.com/dossiers/index.htm

considered it will be harder to meet a 1% threshold using the procedures in the Soja de Pays scheme because of higher probability of cross-pollination (both maize and oilseed rape) and higher probability of volunteers due to seed spill contributing to the seed bank (in the case of oilseed rape and potato). The post-harvesting procedures will be more applicable but the sizes of maize and oilseed rape seeds are much smaller than soya beans and so the potential for higher level admixing is greater.

2.3.3   High erucic acid oilseed rape (HEAR)

Oilseed rape varieties with high erucic acid (which is not GM) can be used for production of industrial oils. However the erucic acid is an anti-nutrient and so it is important that these crops do not contaminate oilseed rape varieties being grown for human consumption which are low in both erucic acid and glucosinolate (so called double low varieties). Erucic acid levels in oil for human consumption must be below 2% in Europe and in the US.

Contracts governing the growing of oilseed rape for erucic acid production commonly specify:
* Use of only certified seed
* Use of previously cleaned seed drills
* Separation distances of between 100m (UK and Germany) and 400m (France)
* Requirements for cleaning of cultivation and harvesting machinery and
* The importance of post-harvest segregation of oilseeds to prevent admixture.

No industry-wide standard exists within the UK, France or Germany. Prevention of contamination is promoted by contractually mandated testing and strong penalties (up to rejection of the crop) if set parameters for the oilseed fatty acid content are not met.

Compared to the thresholds used in this study the threshold for admixture in the case of HEAR contamination of low erucic varieties is considerably higher (2%). According to a German seed company requesting an isolation distance of 100m, more than 95% of the double low seed lots actually are below 0.2% erucic acid content and only a few seed lots contain about 0.5%, maximum 1% erucic acid. Crossings and contamination in the other direction (double low quality within HEAR) are much more difficult to detect, and all seed lots above 50% erucic acid content are accepted. This illustrates that current industry segregation procedures are competent to deal with a threshold of 1% to 2% but that extra precautions will have to be taken to reduce impurities to less than 1%. All the more so, since a cross-pollination event will not result in the heterozygote seed having full erucic acid production, the 2% limit for erucic acid in the oil will only be broken if there is 4% cross-pollination[8]. Consequently the separation distances for erucic acid do not form a good guide for the more sensitive contamination thresholds that are examined in this project.

2.3.4   Waxy maize

Waxy maize has a high (>99%) proportion of its starch in the branched amylopectin form whereas regular maize contains only around 75% amylopectin and 25% amylose. This makes the waxy maize starch more suitable for uses in processed foods as a stabiliser or thickener and as an emulsifier in salad dressings. It is also used in adhesives and in the paper industry. The waxy maize with high levels of branched starch must be kept separate from conventional maize in order to command the premium from processors. This requires in-field segregation to prevent

---

[8] Ingram, J. (2000). Report on the separation distances required to ensure cross-pollination is below specified limits in non-seed crops of sugar beet, maize and oilseed rape. Commissioned by UK Ministry of Agriculture, Fisheries and Food (MAFF)

cross-pollination as well as separation throughout the growing process to prevent seed/ maize mixing.

Current European production of waxy maize is around 200,000 tonnes, produced essentially in France. 25,000 to 30,000 ha are used to grow waxy maize especially in the south-west of the country, out of a total area of maize production of 1.5 million hectares. This is consequently a minor variety of maize on a national scale but it represents between 1% and 20% of maize collected by participating companies. Production requirements vary according to companies and production areas involved. However there are several common points:

- The minimum threshold of purity of maize is agreed with starch companies to be 96%, a tolerance for contamination of 4%.
- The existence of a simple colourimetric test (using iodine solution) for starch provides an inexpensive way to estimate the proportion of common maize in the waxy maize.
- Growing is under contracts which typically fix the quantity to be grown (hectares or tonnes) and the variety to be used, and which set out rules of segregation (isolation distances, creation of grouped waxy maize fields). Certified hybrid seed must be used. Often also the delivery period is fixed to group the harvesting of waxy maize and to be able to use the maize dryer exclusively for this variety.

Premia of around 9% per tonne can be achieved.

Since the tolerance for impurities in the waxy maize is high (4%), the methods adopted for separation and cleaning do not have to be as stringent as they would be for GM/non-GM. Additionally the existence of a reliable and cheap tool to estimate the purity of the waxy maize will not be easily available for the detection of GM maize.

2.4 Organic farming

EU Council Regulation (EEC) 2092/91 (as amended) sets out the requirements for crops to be sold with a label referring to organic production methods. Council Regulation (EC) 1804/99 specifically stipulates that the product should be produced without the use of genetically modified organisms and/or any products derived from such organisms. Article 13 of Regulation (EEC) No 2092/91 mentions a de minimis threshold for unavoidable contamination which shall not be exceeded, but which has not been defined yet. Seed for organic production should be produced organically, but until 31 December 2003, non-organic seed can be used for organic production with derogation and under restrictive conditions

To minimise mixing of seed and pollen dispersal, certain precautions are deemed necessary by several accreditation organisations such as the UK Soil Association. For example the Soil Association stipulates separation distances for oilseed rape and maize of up to 6 miles (depending on the wind direction, time of flowering and local topology) and individual farm inspections. As outlined in a recent report commissioned by the UK Ministry of Agriculture, Fisheries and Food (MAFF)[9] it will not be possible to guarantee zero GM contamination and it may be difficult to detect low levels of certain types of GM material. This consideration means that if thresholds are set too low they will be unworkable for producers.

An additional source of concern to organic farmers is the potential for the deposition of GM pollen on their crops even if fertilisation does not occur. This is a concern to organic growers since the GM pollen in itself is considered as a contaminant. This may be a more difficult issue to resolve with separation distances since inviable pollen (which would not be of consequence in other circumstances) now has to be considered too and it is likely that pollen can travel further than it can remain viable.

---

[9] Moyes and Dale (1999). Organic farming and gene transfer from genetically modified crops MAFF research project OF0157 Published by John Innes Center, UK May 1999

Since no farms grow GM and organic crops there are few possibilities for admixing on-farm. Measures such as separate storage areas and distinct supply chains, which have already been adopted to minimise mixing of raw materials from organic and non-organic production, will dramatically minimise the potential for post-harvest adventitious mixing with GM crops.

2.5 Conclusion

There are several systems in place to segregate crop varieties. The incentive for segregation is mostly based on price premia for the segregated product. None of these systems can be directly applied to minimise contamination of conventional and organic crops by GM crops. In many cases the threshold that is set by these systems is less stringent than those selected for this study. Another issue is the production scale that might be much smaller than a normal crop production scale, as in the case of certified seed production and the SCIMAC guidelines.

In summary, it seems that presently no working system exists that could be directly adopted for the selected model crops without changes. Instead, it might be possible to combine certain, more general features of the segregation systems and to adapt farming practices accordingly.

3 EFFECTS OF CHANGING FARMING PRACTICES IN THE PRESENCE OF GM CROPS

In this chapter the probabilities of contamination of non-GM crops with GM varieties are analysed. The efficiency of changing farming practices to improve the segregation of non-GM crops is evaluated and corresponding costs are estimated. A combination of expert scientific opinion and computer models (GENESYS, MAPOD) was used to estimate on-farm contamination rates and to evaluate the effects of the analysed changes of practices.

- For oilseed rape the computer model GENESYS was used to estimate the in-field contamination, while contamination during the post-harvest handling of the seed and crop was estimated by a panel of experts in seed certification and agronomy from the UK and France in consultation with colleagues from Germany.

- For maize the computer model MAPOD was used to estimate the in-field contamination, while seed impurity and contamination during the post-harvest handling of the crop were estimated by a panel of experts in seed certification and agronomy from the UK and France.

- For potato, expert opinion alone was used to estimate in-field contamination, seed tuber impurity and contamination during the post-harvest handling of the crop. The panel consisted of experts from the UK and France, in consultation with colleagues from Germany and New Zealand.

3.1 Oilseed rape for seed production

3.1.1 Crop production and use

Three major species of *Brassica* are grown commercially in Europe, *Brassica napus* (eg. oilseed rape, swede rape), *Brassica oleracea* (e.g. cabbage, cauliflower, sprouts) and *Brassica rapa* (e.g. turnip and turnip rape). In Europe *B. napus* is the most widely grown *Brassica* crop and accounts for approximately 95% of current production. Oilseed rape (*B. napus ssp. oleifera*) is sown in both spring and winter forms and is the third most important oil-producing crop in the world, following soya and palm oil. The varieties producing oil suitable for human and animal consumption (containing less than 2% erucic acid and low levels of glucosinolate) are known as double low varieties. These varieties were originally developed in Canada under the brand name canola.

The largest areas of winter oilseed rape in Europe are grown in France and Germany with over 1 million ha grown in each country. These countries and to a lesser extent Britain and the Scandinavian countries are the main countries where plant breeding, the development of new varieties and seed production occurs. France and Germany both had 3000 ha of 2nd and 3rd generation seed production in 2000. Approximately 20% - 25% of the seed used by French farmers is saved from their own crops. Similar proportions of farm-saved seed are used in UK and Germany.

Oilseed rape is typically grown on arable farms and some mixed farms. Certified seed production is usually conducted under contract by specialist growers and by farmers prepared to adopt strict protocols for the production of these crops. According to EU regulation for certified seed production a minimum separation distance of 100m to any other rape crop has to be respected. Additionally the previous cropping on the seed production field should not be incompatible with the seed production. According to OECD Seed Schemes a minimum time lap of 5 years from any previous *Brassica* crop on that field has to be kept. Seed producers in some EU Member States choose longer intervals of e.g. 7 years.

For hybrid seed production, crops are grown with the pollinators sown around the margins and in alternating strips in the field (with ratios of 1: 3 or 1: 4 to the male-sterile plants). For hybrid certified seed production a minimum distance of 300m to any other rape crop is required by EU legislation.

Purity of basic and certified seed, as required by European legislation (Directive 69/208/EEC, Commission Decision 95/232/EEC as extended by 98/173/EEC and 99/84/EEC) is 99.9% for conventional basic seed, 99.7% for conventional certified seed and 90% for certified hybrid seed.

There are no regulations for farm-saved seed production except that the seed sown must be below certain maximum levels of glucosinolate and erucic acid for human and animal consumption. Seed is often taken from the standard crops grown for processing usually in quite short rotations and immediately after another rape crop.

Organic oilseed rape production has recently commenced in Austria, Denmark, Germany, Scotland, Sweden and Switzerland with some crushing plants prepared to segregate organic seed and oil. Most of the crops to date have been spring oilseed rape, because of weed control problems in winter rapeseed and were probably grown from conventional certified seed or from farm-saved organic seed. However organic seed production is commencing in Europe to satisfy the new organic standards, but it consists mostly of farm-saved seed from conventional certified seed grown on organic farms, since few seed companies have adopted organic seed production systems yet.

No GM oilseed rape is grown for commercial production in the EU. The EU has given marketing consent for the cultivation of some male-sterile herbicide-tolerant events, so these varieties are likely to be registered in the future. The import of grain from one GM oilseed rape variety (for processing in the EU) is authorised.

3.1.2   Routes of contamination

GM contamination can occur at different phases through production, harvest and post-harvesting. The most critical sources of contamination are listed below.

3.1.2.1   Pollen-mediated gene flow

B. napus is mainly self-pollinating though it is estimated that out-crossing can occur at levels between 12% - 47%[10]. Cross-pollination occurs primarily through physical contact with neighbouring plants, though pollen is also transferred over longer distances by wind and insects.

The significance of wind and insects as vectors of oilseed rape pollen distribution has been widely researched with contradictory results that are probably influenced by varying environmental and topographical conditions, and the differences in research methodology used[11]. Levels of cross-pollination were recorded at a distance of more than 4 km. Varietal associations are more susceptible to cross-pollination compared to fully fertile rapeseed[12].

---

[10] Becker, H. C., Karle, R. & Han, S. S. (1992) *Theoretical and Applied Genetics* 84: 303-306.

[11] Thompson, C. E., Squire, G., Mackay, G. R., Bradshaw, J. E., Crawford, J. & Ramsay, G. (1999). *Gene Flow and Agriculture: Relevance for Transgenic Crops.* Lutman, P. (ed). BCPC Symposium Proceedings No. 72; Timmons, A. M., O'Brien, E. T., Charters, Y. M., Dubbels, S. J. & Wilkinson, M. J. (1995) *Euphytica* 85: 417-423; Stringham, G. R. & Downey, R. K. (1978) *Can. J. Plant Sci.* 58: 427-434; Downey, R. K. (1999) *Gene Flow and Agriculture: Relevance for Transgenic Crops.* Lutman, P. (ed). BCPC Symposium Proceedings No. 72; Stringham, G. R. & Downey, R. K. (1982) *Agronomy Abstracts* pp136-137.

[12] Simpson, unpublished data

3.1.2.2 Seed-mediated gene flow

Significant seed losses occur in oilseed rape due to natural shedding and crop disturbance by harvesting machinery. Losses of around 50% of total yield are reported in bad harvesting conditions by MacLeod[13] , and losses of around 20% - 25% are not uncommon[14]. In ideal conditions, losses of 2% - 5% have been reported. Rape seeds can persist in the soil for at least five years[15] and very likely for ten years[16], although there is considerable genotypic variation in the development of secondary dormancy.

Large numbers of shed rape seed can result in severe volunteer problems which are difficult to control, particularly in broad-leaved crops, so contamination in subsequent rape crops can become a problem. Volunteer rape is a common and widespread weed in cereal rotations and on field margins, roadsides and soil dumps. Feral rape populations are less common; many die out quickly but others persist in fields and around agricultural land for at least 10 years. The crops and ferals are mainly *B. napus*, accompanied in certain areas by crops and ferals of *B. rapa*, and by wild *B. rapa*[17].

As well as remaining in the cropped field, rape seeds can be inadvertently moved from field to field in machinery, as well as spillage occurring along transport corridors on the farm. Contamination of other crops can occur through gene flow from volunteers or from volunteers being harvested along with the crop.

For the purposes of this study it is important to recognise that certain cruciferous weeds can acquire crop transgenes and act as a reservoir of genes that can transfer back to non-GM crops by hybridisation. In addition some seeds of cruciferous weeds are contaminants of harvested crops and, if they contain transgenes, will increase the levels of GM contamination in non-GM crops. However, it is thought that the frequencies with which this will occur are low and are much less significant than the levels of gene transfer likely from volunteers.

3.1.2.3 Adventitious admixing

Cultivation techniques and the post-harvest handling of the crop play a major role concerning potential contamination. GM contamination of non-GM crops can occur at different phases through the cropping, harvesting, handling, storage and transport of crops. Potential sources of contamination are seed drills, cultivation equipment, harvesting machinery, transporting vehicles and storage, cleaning, drying facilities.

3.1.2.4 Seed purity

Apart from contamination influenced by the biological characteristics of the crop, the purity of the purchased seeds influences considerably the contamination level of the harvest. At present there is no GM rape production in Europe, so it is very unlikely that oilseed rape seed produced in the EU is contaminated. This might change in future when GM crops become more widely commercialized. GM oilseed rape has been grown in several EU countries for research and breeding purposes. In contrast, imported seed from e.g. Canada, might already today be

[13] MacLeod, J. (1981) Oilseed rape book. A manual for growers, farmers and advisors. Cambridge Agricultural Publishing. 107-119.

[14] Price, J. S., Hobson, N., Neale, M. A. & Bruce, D. M. (1996) *J. agric. Engang Res*. 65: 183-191.

[15] Lutman, P. J. W. (1993) *Aspects of Applied Biology* 35, Volunteer crops as weeds, pp. 29-36; Schlink, S. (1994) Őkologie der Keimung und Dormanz von Körnerraps (*Brassica napus* L.) und ihre Bedeutung für eine Überdauerung der Samen im Boden. PhD Thesis, University of Göttingen, Germany; Schlink, S. (1995) *Proceedings 9th European Weed Research Society Symposium*. Challenges for Weed Science in a Changing Europe. Budapest, pp. 65-72.

[16] Sauermann, W. (1993) *Raps*. 11 (2); 82-86.

[17] Squire, G. R., Crawford, J. W., Ramsay, G., Thompson, C. & Bown, J. (1999) Lutman, P. (ed). BCPC Symposium Proceedings No. 72.

contaminated with GM varieties. In May 2000 it became known that oilseed rape seed imported from Canada by the company Advanta had been contaminated with non-EU approved GM varieties. The contaminated seed was sold and planted in several Member States in 1999 and 2000. The contamination level was below 1%. In 2001, services of the "Direction generale de la concurrence, de la consommation et de la repression des fraudes" in France have detected the presence of very low levels (< 0.2%) of GM contamination in seeds distributed in France.

3.1.3 Typical farm types

Winter oilseed rape has been studied in the main production areas in the EU (France and Germany). To assess the effects of a change of farming practices, farm types have been developed. To study certified seed production, a conventional Farm 1 and its organic counterparts Farm 2 (same size) and Farm 2' (small organic farm), situated in South-West France (Tarn-et-Garonne) and Western Germany (Westphalia) have been developed. These farms are specialised in seed production and thus very well equipped with machinery and storage facilities for segregating oilseed rape seed. The staff has considerable experience in handling certified seed production. For all farm types a minimal seed crop management has been assumed as the current practices (e.g. for the set-aside management). Seed companies might have additional requirements in agreements with contracted farmers. Cross-pollination and volunteers present the main sources of contamination for these certified seed production farms. Post-harvest processes are a minor problem because segregation systems are already in place (certified seed production, organic farming).

Farms 3 and 4 represent typical conventional (Farm 3) and organic (Farm 4) farms that save seed from the standard commercial crop. They are situated in Central France (Bourgogne) and Eastern Germany (Sachsen). These farms are larger than Farms 1 and 2 and have also larger plots. The conventional farm exchanges seed and shares machinery with its neighbours or uses contractors (for example for harvesting). It has no dedicated machinery for GM crops and no dedicated storage facilities.

Characteristics of the different farm types are summarised in Table 1.

Table 1: Oilseed rape farm type characteristics

Farm	1		2		2'		3			4	
Production region	Tarn-et-Garonne, France/ Westphalia, Germany						Bourgogne, France/ Sachsen, Germany				
Production	Conventional		Organic		Organic		Conventional			Organic	
Specialisation	Seed production		Seed production		Seed production		Seed[1] & Grain production			Seed[1] & Grain production	
Total area (ha)	633		633		325		633			633	
AUA[2] of the farm (ha)	131		131		13		351			351	
% of rapeseed on the farm	10 – 12		10 - 12		10 - 12		20			20	
Average size of plots (ha)	6		6		1		10 –12			10 – 12	
Number of plots for seed production	1 or 2		1 or 2		1		6-7			6 – 7	
% of GM crops outside the farm	10	50	10	50	10	50	10	50		10	50
	10	50						10	50		
% of GM crops on the farm	0		0		0		0			0	

(1): farm-saved seed
(2): AUA: Agricultural used area

3.1.4　The computer model GENESYS

To assess probable effects of a change of farming practices on contamination rates a computer model, GENESYS, has been used. GENESYS has been developed by INRA to rank cropping systems according to their probability of gene flow from herbicide tolerant winter oilseed rape to rape volunteers both in time via seeds and in space via pollen and seeds. The model is suited for seed as well as crop production. It has been adapted by INRA for simulating hybrid seed production. GENESYS integrates various input variables:

(i)　　　the field plan of the region, comprising cultivated fields and field-edges or waysides (henceforth "borders") consisting of spontaneous vegetation;

(ii)　　the crop rotation of each field;

(iii)　　the cultivation techniques applied to each crop. These techniques include intercrop cultivation, soil tillage for soil bed preparation, sowing date and density, herbicide applications, cutting dates and seed loss at rape harvest,

(iv)　　the type of the transgene, either a dominant allele *A* or a recessive *a*, as well as the genotype of the rapeseed varieties.

The life-cycle of oilseed rape, integrated in the model, concerns both cropped and volunteer rape plants, starting with the seed bank at harvest and determining seedling emergence. Some of these seedlings become adults, flower and produce new seeds, some of which replenish the seed bank at the end of the season. At the end of a simulated year, the model calculates for each stage of the annual rapeseed life-cycle and for each field the number of individuals per m² (number of seeds in the seed bank, of seedlings etc.) and the proportion of the three possible genotypes *AA, Aa* and *aa* (A being the transgene locus)[18].

The model is currently being evaluated, using independent data collected either on farmers' fields or on the GMO field trials managed by CETIOM (Centre Technique Interprofessionnel des Oléagineux Métropolitains, France) and other technical institutes[19]. The first comparisons of simulations and trial results show that the rates of contamination of harvested seeds are slightly underestimated but that the orders of magnitude are reliable. GENESYS may therefore be used to compare the effects of different cropping practices or the value of certain varietal characteristics for decreasing the probability of contamination in the field. The inaccuracy has been considered by introducing safety margins when selecting farming practices to minimise in-field contamination.

3.1.5　Assumptions used for simulations

For the simulations, the following input data is supplied:

- The total land area in the region.
- Characteristics of farm types (plot sizes, cropping systems, field pattern; see Table 1).
- The GMO share is 10% or 50% in the region. The conventional farms studied also grow GM crops on the farm.
- The certified seed producers produce hybrid seeds (Farms 1, 2, 2'). The neighbouring farms cultivate fully fertile rape varieties. Standards for the production of certified hybrid seed have been integrated in the simulations (300m isolation distance in the year of seed production, 6 year rotation).
- In the case of farm-saved seeds (Farms 3, 4) fully fertile varieties are grown.

---

[18] Colbach N., Clermont-Dauphin C. and Meynard J.M., 2001a. *Agric. Ecosyst. Environ.*, 83, 235-253 ; Colbach N., Clermont-Dauphin C. and Meynard J.M., 2001b. *Agric. Ecosyst. Environ.*, 83, 255-270.

[19] Champolivier J., 1997. Etude de l'impact de colzas résistants aux herbicides dans les systèmes de culture. 1ère année d'expérimentation. Synthèse des essais inter-instituts-Campagne 1995-96. *CETIOM*, 22 p; Champolivier J., Messéan A. and Gasquez J., 1997. *Bull. GCIRC*, 14, 63-66; Berl M., 2000. Rapport DAA–INA P-G, 69 p. + annexes.

- The GM oilseed rape is assumed to have a dominant allele for herbicide tolerance (A), the genotype for the transgenic variety is AA, and aa for the non-GM variety.
- The minimum distance between plots for certified seed production and other rapeseed plots is 300m (hybrid production). For farm-saved seed (Farms 3 and 4) no isolation distance is required by legislation.
- The seed bank is pure at the beginning of the simulation and for the first sowing pure seed is used.
- For conventional Farms 1 and 3 the proposed farming practices change also on the surrounding farms. In the case of organic farms, changes only apply to them.
- In the case of farm-saved seed (Farms 3 and 4) all farms in the region use farm-saved seed.

3.1.6   General interpretation of simulation results

For the interpretation of the modelling results, it is important to note that the results presented in this study reflect mid-term effects and average values. For Farms 1, 2, 2' and 4, which have a 6 year rotation system, this means that results for regular rapeseed refer to the second round of rotation (year 7 to 13) and to year 13 for the certified seed production fields. For Farm 3 the results refer also to the second round of rotation, but as the rotation is shorter, this means year 4 to 6.

Additionally it should be kept in mind, that the model provides relative results, which do not take into account any unfavourable circumstances like adverse weather conditions and accidents on the farm etc. Moreover, the assumptions used for the simulations, presented in Chapter 3.1.5, also limit the possibility to generalise the results.

3.1.7   Measures to reduce in-field contamination evaluated by GENESYS

For oilseed rape the main ways by which in-field contamination could occur are
- seed impurity (especially for farm-saved seed);
- cross-pollination;
- volunteers.

Several cropping techniques are known to minimise the probability of contamination through these sources. Most of the techniques are already employed to control feral populations and volunteers by:
- improving the efficiency of weed control by herbicides (simulations 2, 3);
- decreasing the importance of seed bank (several kinds of soil tillage are tested) (simulations 5, 6);
- managing populations in field borders by cutting or use of selective herbicide (simulations 10, 11, 12);
- sowing set-aside in spring and thus avoiding the development of volunteers (simulation 13). Even if ploughing of set-aside is sometimes already practiced today, sowing the set-aside in spring is assumed to be more efficient in reducing volunteers;
- rape free rotations in the radius of 300m surrounding the seed production field (simulation 18);
- lengthening the rotation by introducing a spring crop in which volunteers cannot flower (simulation 15).

The techniques can also be combined to improve their effects on contamination rate (simulation 14).

Other techniques are tested to limit cross-pollination:
- difference in the dates of sowing non-GM and GM rape in order to avoid cross-pollination during flowering (simulations 7, 8, 9); delaying sowing time of non-GM rape could additionally allow destruction of volunteers before sowing of non-GM rape (simulations 8, 9)
- situation of the seed production field in the landscape and type of field pattern (simulations 16, 17).

Concerning seed purity, the effect of using commercial seeds instead of farm-saved seeds (Farms 3 and 4) is simulated (simulation 19).

3.1.8   Farm 1: Conventional certified seed production

Table 2 shows the current crop management on Farm 1. The following rotations are in use on the farm and in the region:
- R/WW/WW/SA/WW/SC
- SC/WW/WW

R = rape; SA = set-aside; SC = spring crop; WW = winter wheat

Concerning the seed production field, the farm operates long crop rotations with cereals and spring crops so that weeds and volunteers are kept to a minimum. Rape represents 10% of the agricultural used area (AUA), so there is at least another rotation on the farm. Generally, this kind of rotation in this region begins with a spring crop followed by one or two cereals. These two rotations are randomly distributed over the region to obtain the overall rape proportions and the GM rape proportions required for the various simulations. When a field is grown for seed production, all other rape crops of the same year are more than 300m away.

Table 2: Current crop management on Farm 1

Crop	Stubble breaking	Soil tillage	Sowing date	Sowing density (seeds/m²)	Cutting	Herbicides (sowing + spring)		Harvest loss
						Type	Volunteer mortality	
Border					none			
GM rape	yes	chisel	30 Aug.	70		selective	95%	5%
NGM rape	yes	chisel	30 Aug.	70				5%
Seed rape	yes	chisel	30 Aug.	70				5%
Winter wheat	yes	chisel	3 Oct.	350		non-selective	95%	
Spring crop	yes	chisel	1 March	350		non-selective	95%	
Set-aside					Mid-April			

The field pattern of Farm 1 in the region is shown in Figure 1. Forests surround this field pattern and neither pollen nor seeds can enter the region. The fields of Farm 1 (gray color) are distributed over the whole region (Figure 1, left). The field used for rape seed production every 6 years is at the center of the region. The black lines represent roads along which the borders are located (Figure 1, right).
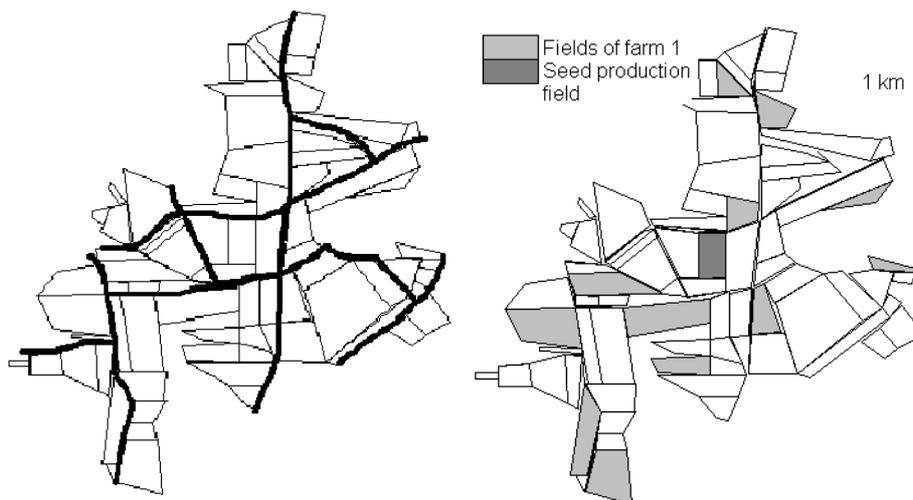
Figure 1: Map of the region surrounding Farm 1 considered in the model
(left: dispersed field pattern; right: disposition of borders)

Farm 1 grows each year 1 plot (6 ha) for certified seed production of winter oilseed rape and another plot (6 ha) with conventional oilseed rape. The situation with current farming practices in the presence of different GMO shares in the region and on the farm (10%, 50%) is presented in Table 3. It is obvious that post-harvest practices do not pose a problem. In-field contamination via pollen or seeds could become a difficulty, depending on the GMO share. The GMO share on the farm does not increase the contamination level for the seed production, the GMO share in the region seems to be decisive.

Table 3: Potential contamination levels to be expected with current farming practices on Farm 1

Farm 1	Proportion of GM rape on / off the farm			
	0% / 10%	10% / 10%	0% / 50%	50% / 50%
	Current practices			
In-field contamination (%) (1)	0.2	0.2	0.4	0.4
Other routes of contamination (%) (2)	0.02	0.02	0.02	0.02
Total contamination expected (%)	0.22	0.22	0.42	0.42
(1): Results based on simulation 1 (Table 4); (2): Includes drilling, cultivation equipment, harvesting, transport from field to farm, storage and cleaning, transport from farm.				

3.1.8.1 Simulations with GENESYS for Farm 1

Table 4 describes simulations 1 to 15, used to calculate changes in the crop management and the rotation system (see also Chapter 3.1.7), Simulation 1 presenting current practices. Simulations 16 to 18 (see below) describe changes in the field pattern and isolation distances.

Table 4: Description of proposed changes in cropping techniques for Farm 1
(Simulated with the GENESYS model, dispersed field pattern)

Simulation	Rotation	Crop management								
		W herbicide-volunteer mortality	Soil tillage		Sowing date		Borders		Set-aside	GMR harvest loss
			W+Sc	R	GMR	NGMR	cutting	herbicide	sowing	
1	RWWSaWSc	0.95	chisel	chisel	30/8	30/8	none	none	none	5%
2	RWWSaWSc	**0.8**	chisel	chisel	30/8	30/8	none	none	none	5%
3	RWWSaWSc	**0.99**	chisel	chisel	30/8	30/8	none	none	none	5%
4	RWWSaWSc	0.95	chisel	chisel	30/8	30/8	none	none	none	**10%**
5	RWWSaWSc	0.95	chisel	**plough**	30/8	30/8	none	none	none	5%
6	RWWSaWSc	0.95	**plough**	chisel	30/8	30/8	none	none	none	5%
7	RWWSaWSc	0.95	chisel	chisel	**14/9**	**15/8**	none	none	none	5%
8	RWWSaWSc	0.95	chisel	chisel	**15/8**	**14/9**	none	none	none	5%
9	RWWSaWSc	0.95	chisel	chisel	30/8	**14/9**	none	none	none	5%
10	RWWSaWSc	0.95	chisel	chisel	30/8	30/8	**Mid-April**	none	none	5%
11	RWWSaWSc	0.95	chisel	chisel	30/8	30/8	**Mid-May**	none	none	5%
12	RWWSaWSc	0.95	chisel	chisel	30/8	30/8	none	**selective**	none	5%
13	RWWSaWSc	0.95	chisel	chisel	30/8	30/8	none	none	**spring**	5%
14	RWWSaWSc	**0.99**	chisel	**plough**	**15/8**	**14/9**	**Mid-May**	none	**spring**	5%
15	**RWWSaWScSc**	0.95	chisel	chisel	30/8	30/8	none	none	none	5%

R=rape, W=wheat; Sa=set-aside; Sc=spring crop; GMR=GM rape; NGMR=non-GM rape
NB: bold represents the change; Simulation 1 presents the current farming practices

Simulation 16: The field pattern is changed from dispersed to clustered (Figure 2). The seed production field (dark gray field) is exposed to non-farm fields at the edge of the cluster.

Simulation 17: The field pattern is changed from dispersed to clustered (Figure 2). The seed production field (black field) is protected from non-farm fields being situated at the opposite edge of the cluster and at the edge of the region.

Simulation 18: Rotations with oilseed rape are further than 300m away from the seed production field. So even in those years where the field is not used for seed production, there are no rape crops in the vicinity.
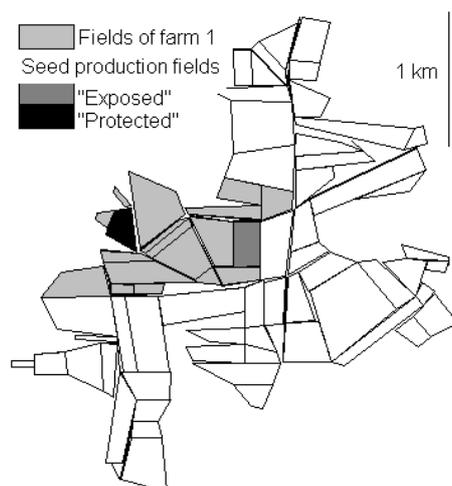
Figure 2: Clustered field pattern for Farm 1
(Field distribution in simulations 16 and 17)

The results of running the GENESYS model for Farm 1 under each simulation are summarised in Table 5. The results are expressed as (%) of GM seeds in the harvest of the non-GM seed production field in the mid-term (year 13). It should be kept in mind that these are the result of a simulation, based on certain assumptions. Additionally the model used for the calculation does not give correct absolute values. The results presented can be used to rank the different farming practices referring to their efficiency in reducing contamination.

Below the results obtained for each simulation are commented:

The contamination rates are generally higher with 50% GM oilseed rape in the region than with 10%. There is not much influence of the share of GM oilseed rape grown on the farm. The main factor seems to be the GMO share in the region.

Simulations 2, 3: Herbicide efficiency in winter wheat has little effect because the level of volunteers is too high.

Simulation 4: Increase of harvest loss of GM rape increases contamination rates, because more GM seeds remain in the fields and lead to volunteers.

Simulation 5: Ploughing before planting rape crops decreases contamination in conventional rape, because seeds are buried too deeply for successful emergence in the rape crops. For the seed production field the effect is small, because it is situated at a distance of 300m from any GM rape crop.

Simulation 6: Ploughing before winter and spring crops increases non-GM contamination because burial of seeds increases seed survival. Many seeds are still alive when the field is tilled for a new rape crop and tillage brings the buried seeds back to soil surface. Taking this result into account, this simulation was not carried out for other constellations.

Table 5: Estimated contamination rates in oilseed rape for seed production on Farm 1

Farm 1	GM seeds in non-GM oilseed rape seed production (%)*			
	- Seed production field -			
	Proportion of GM oilseed rape on / off farm			
Simulation	0% / 10%	10% / 10%	0% / 50%	50% / 50%
1	0.20	0.20	0.40	0.40
2	0.21	0.20	0.41	0.41
3	0.20	0.20	0.41	0.41
4	0.26	0.25	0.46	0.46
5	0.20	0.15	0.3	0.3
6	0.57	--	--	--
7	0.49	--	--	--
8	0.06	0.06	0.10	0.10
9	0.06	--	--	--
10	0.19	0.19	0.25	0.25
11	0.20	0.20	0.20	0.20
12	5.4	5.4	6.0	6.0
13	0.01	0.01	0.02	0.01
14	< 0.01	< 0.01	< 0.01	< 0.01
15	0.03	0.08	0.17	0.17
16	< 0.01	0.20	0.01	0.31
17	< 0.01	< 0.01	< 0.01	0.02
18	< 0.01	< 0.01	< 0.01	< 0.01
* For hybrid seed production, values for year 13 of the rotation cycles are presented				

Simulation 7: Trying to dissociate GM and non-GM oilseed rape flowering periods by delaying GM oilseed rape sowing and advancing non-GM oilseed rape sowing increases contamination. The simultaneous flowering period is indeed shorter, but volunteer emergence inside the non-GM crop is favoured by the early sowing. Furthermore, the non-GM oilseed rape flowering now overlaps more with rape volunteer flowering along the borders and in set-aside, thus increasing the probability of gene flow. Taking this result into account, this simulation was not carried out for other constellations.

Simulations 8, 9: Delaying only non-GM oilseed rape sowing (simulation 9) or combining it with a simultaneous advancement of GM oilseed rape sowing (simulation 8) considerably decreases contamination, because rape volunteer emergence in non-GM oilseed rape is decreased. Flowering overlap with GM oilseed rape and volunteers in borders and set-aside seems not to have much effect as there is next to no difference between the two simulations.

Simulations 10, 11: Border cutting only slightly decreases contamination rates. Cutting is beneficial because it either delays flowering (early cutting) or makes seed production impossible (late cutting) for rape volunteers on borders. Regarding the situation with 50% GM oilseed rape in the region, border cutting is more efficient than for the 10% situation because of more volunteers. Late cutting is the better choice because it prevents volunteers from producing seeds.

Simulation 12: Treating borders with glyphosate in the case of GM glyphosate-tolerant varieties increases contamination considerably. Glyphosate only destroys the non-GM volunteers and thus favors both pollen and seed production by the remaining GM volunteers. The negative effect is much stronger when the general volunteer level is lower. The effect of glyphosate is better, if already 50% of oilseed rape in the region is GM and thus the share of GM volunteers is higher.

Simulation 13: Improving set-aside management by sowing the field in spring is optimal for reducing contamination as volunteers can produce neither pollen nor seed in spring sown crops because of insufficient vernalisation and lack of time before crop harvest.

Simulation 14: The combination of spring sown set-aside, increased herbicide mortality of volunteers in winter wheat, ploughing before rape crops, delayed non-GM rape sowing decreases contamination even more, but the impact is small for on-farm rape compared to the increase in the work load.

Simulation 15: Longer rotations are also a good way for limiting on-farm and off-farm contamination because less seeds survive from the previous rape crop after 7 than after 6 years of non-rape crops. Furthermore, the supplementary crop is a spring crop where neither pollen nor seed production is possible, thus leading to a considerable decrease in seed bank for the future rape crop. If the supplementary crop were one favoring volunteer reproduction, the lengthening of the rotation would not have been beneficial. A longer rotation is less beneficial if the share of GM crops raises to 50%. In that case the depletion of the seed bank is less important for the contamination level.

Simulations 16, 17: Grouping the farm fields in a single cluster protects the farm rape crops from contamination. Placing the hybrid seed production field far away from the off-farm fields reduces contamination slightly more (simulation 17). Regarding the situation with GM oilseed rape also grown on the farm (10%/10%, 50%/50%), clustering the fields increases the probability of contamination of the certified seed field via the GM rape fields on the same farm (simulation 16). A decrease in contamination level in this situation could be achieved by positioning the seed production field near the edge of the region, where there is less pollen flow from the center (simulation 17).

Simulation 18: Even when farm fields are dispersed in the region as it is usually the case in France, contamination levels can be drastically reduced by assuring that the fields surrounding

the seed production fields are never grown with rape crops, even in those years when there is no seed production. However, this demands a considerable co-operation from neighbouring farmers.

Except for simulation 18, effects are usually considerably smaller for the hybrid seed production field which is located at more than 300m from any GM rape field, than for the other non-GM rape fields on the farm (results not shown).

3.1.8.2 Evolution of contamination levels over time

A long-term simulation using current practices for Farm 1 in the presence of 10% and 50% GMOs in the region shows that contamination levels increase continuously until reaching the maximum sill value after 80 to 90 years (Figure 3). These possible developments should be kept in mind when considering the medium-term simulation results presented above.
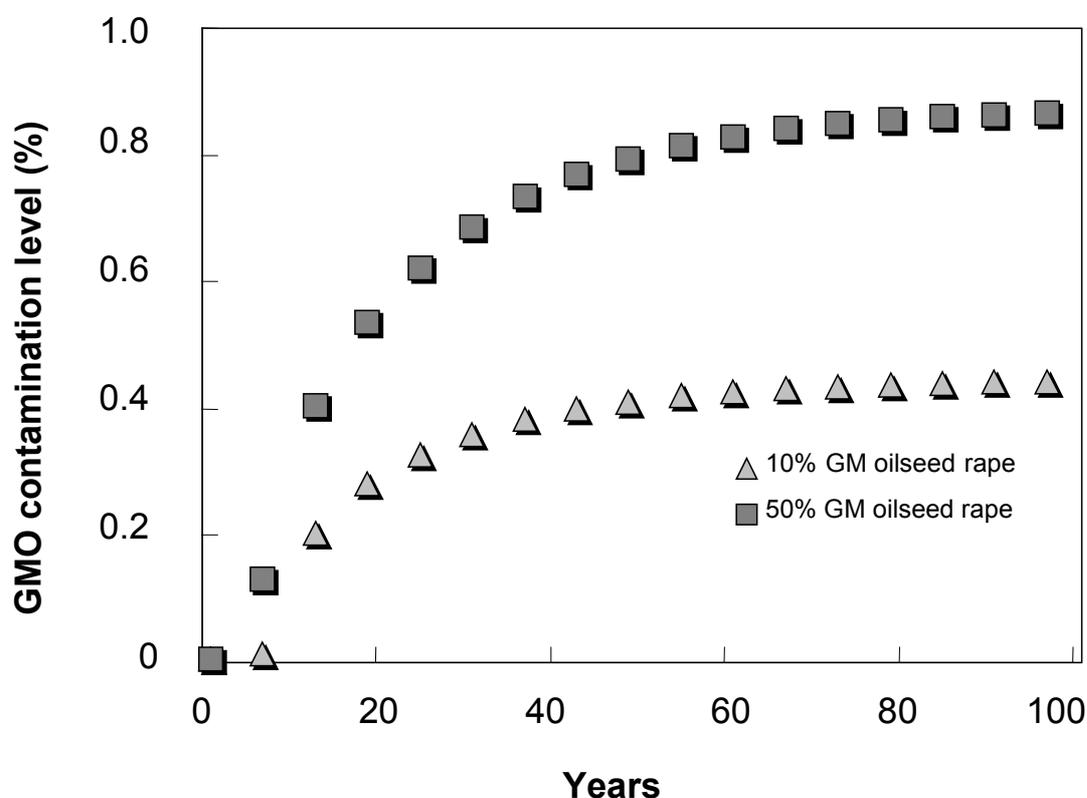
Figure 3: Evolution of contamination levels of hybrid seed production over time on Farm 1 (in the presence of 10% or 50% GM oilseed rape off-farm)

3.1.8.3 Conclusions for Farm 1

At this point it should be stressed again that the model GENESYS is suited for comparing contamination levels between simulated practices. The absolute values obtained are less precise (although they are accurate in the order of magnitude) and according to preliminary experiments to adjust the model, may be underestimating the contamination levels. The results, therefore, are best for ranking the effects of different farming practices in reducing contamination.

Considering a GM oilseed rape share of 10% in the region, current farming practices for seed production may allow to achieve a 0.3% threshold. It should be kept in mind that this is based on an estimation of mid-term effects, assuming that the seed bank is pure. Additionally, contamination rates (0.22% for current practices) are already close to the threshold. These practices may become a commercial risk for the farmer in the following rotations, when the general contamination rate increases in the longer run.

When the GM oilseed rape share in the region is 50%, best suited practices to achieve the 0.3% threshold are:

- To cut borders mid April or mid May (simulations 10 & 11). The feasibility of these solutions depends on the good will of the neighbours and the administration (for the road borders) to be really efficient. Another incentive for farmers to adopt these practices is that it is a way to destroy relays of pests and diseases.
- To have a longer rotation with an additional spring crop (simulation 15) to control volunteers.
- To sow GM rape one month before the non-GM rape in order to have a difference in flowering time and to destroy emerging volunteers before sowing non-GM rape (simulations 8, 9). However, it should be noted that the effect of advancing the sowing date of GM rape could be significantly reduced by unfavourable weather conditions (e.g. dryness at sowing time resulting in later germination of the seeds), rendering this measure impracticable.

The model identified the best suited practices to reduce contamination rates below 0.1%:
- To manage the set-aside step of the rotation differently by sowing a spring crop (simulation 13);
- To combine several proposed practices (simulation 14);
- To have a clustered field pattern (simulations 16 & 17). This is certainly not always possible;
- To introduce rape-free rotations in the 300m width surrounding the seed production field (simulation 18). This requires good collaboration between farmers (and perhaps contracts). It should be noted that the Scientific Committee on Plants in its opinion from 13 March 2001[20] recommends a minimum of 600m isolation distance for hybrid seed in the year of seed production to miminise cross-pollination;
- In the case of 10% GM oilseed rape share sowing GM rape one month before the non-GM rape in order to have difference in flowering time and to destroy emerging volunteers before the sowing of non-GM rape (simulation 8). This measure is however impracticable for the reasons given above.

To have a seed production field in a clustered field pattern is efficient to reduce the probability of contamination but it depends on the characteristics of the farm and of the agricultural landscape (variable according to the region). In summary, the most feasible measures appear to be introducing a spring crop in the rotation (to meet 0.3%) or to sow a spring crop on set-aside (to meet 0.1%). In both cases, it allows to control volunteers. These values are based on the assumption (apart from others) that all farms in the area change their farming practices, although sowing the set-aside seems to be effective also when applied to the certified seed producing fields only. Especially in the case of a dispersed field pattern, this is the most efficient way to reduce contamination.

---

[20] Scientific Committee on Plants, opinion from 13 March 2001 available at
 http://europa.eu.int/comm/food/fs/sc/scp/out93_gmo_en.pdf

3.1.9   Farm 2: Organic certified seed production

Farm 2 is identical to Farm 1, except for being an organic farm with a different seed crop management (Table 6). Organic farms have rotations with legumes and pulse, such spring crops were introduced in both rotations on Farm 2:

- R/WW/SC/SA/WW/SC
- SC/WW/SC/SA/WW

R = rape; SA = set-aside; SC = spring crop; WW = winter wheat

The surrounding farms in the region are conventional farms, which use rotations and crop management similar to Farm 1. The rotations are randomly distributed over the region to obtain the overall rape proportions and the GM rape proportions required for the various simulations. Borders are managed by state or city administrations or a subcontractor and may be treated with herbicides even when adjacent to organically managed plots. Concerning current practices as defined in the study, borders are not cut.

Table 6: Current crop management on Farm 2

Crop	Stubble breaking	Soil tillage	Sowing date	Sowing density (seeds/m²)	Cutting	Mechanical weed control (seedling stage) Volunteer mortality	Harvest loss
NGM rape	yes	plough	30 Aug.	70			5%
Seed rape	yes	plough	30 Aug.	70			5%
Winter wheat	yes	plough	3 Oct.	350		40%	
Spring crop	yes	plough	1 March	350		40%	
Set-aside					Mid-April		

As Table 7 shows, the contamination levels for organic Farm 2 are generally higher than for conventional Farm 1. The reason for this might be the lower volunteer control efficiency in winter wheat (assumed 40% efficiency, only mechanical control). Post-harvest contamination is very low, as no GM crops are grown on the farm and the farm is well equipped and specialized for seed production. With current practices, it seems that on Farm 2 neither the 0.3% nor the 0.1% threshold can be met.

Table 7: Potential contamination levels to be expected with current farming practices on Farm 2

Farm 2	Proportion of GM rape on / off the farm	
	0% / 10%	**0% / 50%**
	Current practices	
In-field contamination (%) (1)	0.4	0.6
Other routes of contamination (%) (2)	0.01	0.01
Total contamination expected (%)	0.41	0.61
(1): Results from simulation 1 (Table 8) (2): Includes drilling, cultivation equipment, harvesting, transport from field to farm, storage and cleaning, transport from farm.		

3.1.9.1 Simulations with GENESYS for Farm 2

Changes in cropping system elements will only concern the farm fields, in contrast to Farm 1 where changes were also operated off-farm. The only change off-farm concerns the rape harvest loss, which is often more related to climatic conditions rather than to crop management. It is assumed that the organic farmer was able to maintain a minimum isolation distance of 300m between his seed production field and all other rape fields of the region according to certified seed production standards.

Table 8: Description of proposed changes in cropping techniques for Farm 2 (Simulated with the GENESYS model, dispersed field pattern)

Simulation	Rotation	Crop management							
		W mechanical weed control efficiency	Soil tillage		NGMR Sowing date	Borders		Set-aside sowing	GMR harvest loss
			W+Sc	R		cutting	herbicide		
1	RWScSaWSc	0.40	plough	plough	30/8	none	none	None	5%
2	RWScSaWSc	**0.20**	plough	plough	30/8	none	none	None	5%
3	RWScSaWSc	**0.60**	plough	plough	30/8	none	none	None	5%
4	RWScSaWSc	0.40	chisel	chisel	30/8	none	none	None	**10%**
5	RWScSaWSc	0.40	**chisel**	plough	30/8	none	none	None	5%
8/9	RWScSaWSc	0.40	chisel	chisel	**14/9**	none	none	None	5%
10	RWScSaWSc	0.40	chisel	chisel	30/8	**Mid-April**	none	None	5%
11	RWScSaWSc	0.40	chisel	chisel	30/8	**Mid-May**	none	None	5%
12	RWScSaWSc	0.40	chisel	chisel	30/8	none	**selective**	None	5%
13	RWScSaWSc	0.40	chisel	chisel	30/8	none	none	**Spring**	5%
14	RWScSaWSc	**0.60**	**chisel**	plough	**14/9**	**Mid-May**	none	**Spring**	5%
15	**RWWSaWScSc**	0.40	chisel	chisel	30/8	none	none	None	5%

R=rape, W=wheat; Sa=set-aside; Sc=spring crop; GMR=GM rape; NGMR=non-GM rape
NB: bold represents the change

Simulations 16 to 18 are identical to those used for Farm 1.

Compared to the results for Farm 1, there are only a few differences for the organic counterpart (Table 9).

Simulations 2, 3: Changes in volunteer control efficiency do not lead to any changes in contamination rates of non-GM oilseed rape seed production, and this despite larger variations in efficiency than were simulated for Farm 1. However, the volunteer control performed on the organic farm is not very efficient because it is carried out at the seedling stage without killing sufficient seedlings to reduce adult volunteer populations.

Simulation 5: Chisel before crops other than rape is more efficient in limiting contamination rates of non-GM rape harvest on the farm as rape crops are always preceded by ploughing on the organic Farm 2, in contrast to Farm 1 where chisel was the usual tillage mode.

Simulation 15: Increasing the rotation length leads to more contamination in the hybrid seed production field in contrast to Farm 1. This result is unexpected, but can be explained by the fact that only the rotations on the farm were lengthened while the off-farm fields kept their original rotation. This lead to an unfavourable situation where in the year before the seed production, the production field was next to a GM rape. This proximity was the cause of an increase of the GM seed bank in the seed production field.

The results of simulations 15 and 18 show clearly that the isolation of the seed production fields not only in the year of actual seed production is an important issue concerning contamination levels.

Table 9: Estimated contamination rates in organic oilseed rape for seed production on Farm 2

Farm 2	GM seeds in non-GM oilseed rape seed production (%)*	
	Seed production field	
	Proportion of GM rape on / off farm	
Simulation	**0% /10%**	**0% / 50%**
1	0.40	0.6
2	0.42	0.59
3	0.42	0.58
4	0.54	0.71
5	0.18	0.31
8	0.13	0.17
9	0.13	0.17
10	0.41	0.46
11	0.46	0.47
12	4.42	4.9
13	0.02	0.034
14	0.01	0.014
15	2.9	2.9
16	< 0.01	< 0.01
17	< 0.01	< 0.01
18	< 0.01	< 0.01
* For hybrid seed production, values for year 13 of the rotation cycles are presented		

3.1.9.2 Conclusions for Farm 2

For an organic farm with the features of Farm 2, a 0.3% threshold could be met employing the following measures:
- To chisel before crops other than rape instead of using a plough with 10% GM rape in the region (simulation 5). However, it should be noticed that, due to climatic conditions, it is not always feasible to employ this measure.
- To manage the set-aside step of the rotation differently by sowing a spring crop (simulation 13).
- To sow non-GM rape later than GM rapeseed (simulations 8, 9). As mentioned before, climatic conditions could significantly interfere in the duration of flowering and limit the expected difference of flowering between GM and non-GM varieties. Sowing GM rape in mid August may also imply sowing in dry conditions (depends on the region) and following difficulties in emergence. Therefore this practice is not reliable enough as a tool to minimise cross-pollination.

To achieve a contamination level below 0.1% the same farming practices as identified for Farm 1 would be efficient, except for sowing GM rape earlier, which has too little effect on the organic farm.

3.1.10 Farm 2': Organic certified seed production on a small organic farm

To obtain information on the effect of farm and plot size as well as trying to better reflect reality of organic farming in some European regions, a small organic farm (Farm 2') was included in the study. This farm has only 10% of the farm size of Farms 1 and 2, and the plots have only a size of 1 ha. Crop management as well as the simulations calculated are the same as for Farm 2. The field pattern of the farm changes according to the different farm characteristics (Figures 4, 5). For the simulations regarding a clustered field pattern (16, 17) only the exposed position of the seed production field was possible because of the smallness of the farm (Figure 5). Accordingly only simulation 16 was calculated.
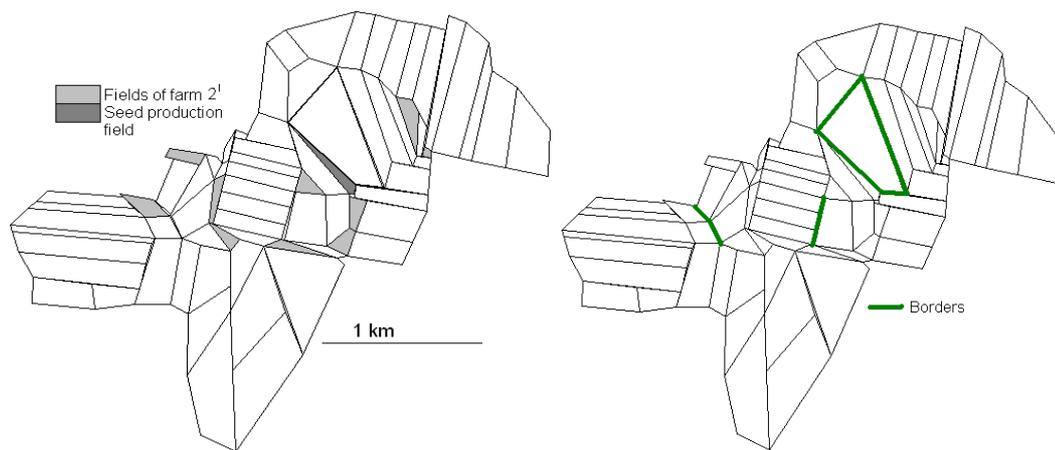
Figure 4: Map of the region surrounding Farm 2' considered in the computer model (left: dispersed field pattern, right: disposition of borders)
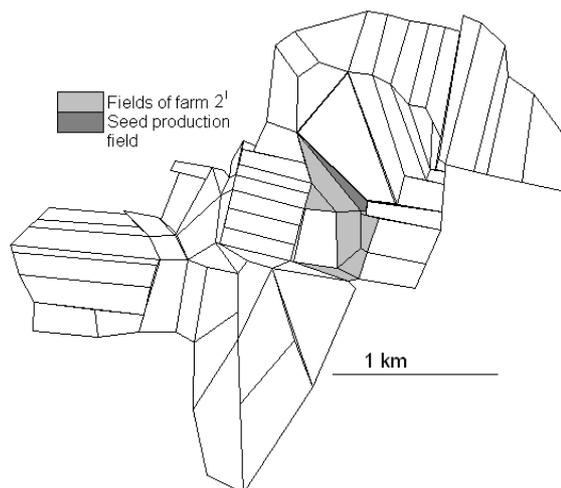
Figure 5: Clustered field pattern for Farm 2'

Concerning current practices (Table 10) the contamination levels to be expected are much higher than on Farm 2. The difference in plot size shows a huge effect on contamination via pollen flow and seed dispersal from GM crops and GM volunteers. Neither of the two considered thresholds could be met on this farm.

Table 10: Potential contamination levels to be expected with current farming practices on Farm 2'

Farm 2'	Proportion of GM rape on / off the farm	
	0% / 10%	**0% / 50%**
	Current practices	
In-field contamination (%) (1)	2.0	9.0
Other routes of contamination (%) (2)	0.01	0.01
Total contamination expected (%)	2.01	9.01
(1) Results from simulation 1 (Table 11) (2) Includes drilling, cultivation equipment, harvesting, transport from field to farm, storage and cleaning, transport from farm.		

The simulation results are presented in Table 11.

Table 11: Estimated contamination rates in organic oilseed rape for seed production on Farm 2'

Farm 2'	GM seeds in non-GM oilseed rape seed production (%)*	
	Seed production field	
	Proportion of GM rape on / off the farm	
Simulation	**0% / 10%**	**0% / 50%**
1	2.0	9.0
2	2.2	9.4
3	2.2	9.4
4	2.	11.1
5	0.9	6.4
8	0.7	2.7
9	0.7	2.7
10	2.4	7.5
11	3.2	3.4
12	15.0	18.5
13	0.1	0.33
14	0.05	0.23
15	9.2	10.6
16	4.3	7.6
18	< 0.01	< 0.01
* For hybrid seed production, values for year 13 of the rotation cycles are presented		

Simulations 10, 11: Border cutting favours contamination of the seed production field. This field is one of the few close to a border, as the number and area of borders is very small on Farm 2' compared to Farm 2. On the other side of the border next to the seed production field is a field grown every 6 years with non-GM rape. The field on the other side of the seed production field is grown every six years with GM rape. In this particular situation, reducing the number of volunteers on the border means decreasing the number of non-GM volunteers helping to dilute the effect of GM pollen and seed imports from the GM field. Regarding the situation with 50% GMO share, border cutting leads to a reduction of contamination levels, because borders are largely infested with GM volunteers.

Simulations 15 and 16: In both cases the random attribution of rotations and crops leads to an unexpected increase in contamination, because a set-aside field was situated near the seed production field in the year of seed production. This result again shows the importance of an isolation of the seed production fields during all years. In the case of 50% GMOs in the region, even a low number of GM-free fields near the seed production field have a beneficial effect.

The only simulations that show a considerable reduction of contamination rates are 13, 14 and 18.

3.1.10.1 Conclusions for Farm 2'

Farm 2' has very high *in-field* contamination levels employing current practices compared to the larger organic farm type. Because of severe problems with volunteer control and cross-pollination, this farm most probably would not be contracted as a certified seed producer, nor would the seed with such a high contamination level be accepted and certified. Nevertheless, this farm type illustrates nicely the effect of farm and field size on contamination levels.

Considering 10% GMOs in the region, spring sown set-aside (simulation 13) could reduce contamination levels below 0.3%. In the case of 50% GMO share, this measure alone would not be enough. A combination of spring sown set-aside, increased volunteer control efficiency in winter wheat, border cutting, later sowing of non-GM rape and chiselling before other crops than rape could reduce contamination levels closely below 0.3%.

A combination of measures could reduce the contamination level below 0.1% in case 10% GMOs are grown in the region (simulation 14). A very efficient measure would be to keep a minimum distance of 300m to any rape field throughout the whole rotation (simulation 18).

3.1.11 Farm 3: Conventional farm-saved seed production

Farm 3 is a comparatively large farm with large plots. Approximately 20% of the farm is covered with oilseed rape at one time. In contrast to Farm 1, the rotation is very short and simple, only consisting of rape and winter wheat. The second rotation shown below is used on the remaining fields. Both rotations are distributed randomly over the region to obtain the overall rape proportions and the GM rape proportions required for the various simulations.

- R/WW/WW
- SC/SA/ WW/WW/SC/WW/WW

R = rape; SA = set-aside; SC = spring crop; WW = winter wheat

Farm-saved seed is used for non-GM rape on- and off-farm. The crop is managed as detailed in Table 12.

Table 12: Current crop management on Farm 3

Crop	Stubble breaking	Soil tillage	Sowing date	Sowing density (seeds/m²)	Seed origin	Cutting	Herbicides (sowing + spring) Type	Volunteer mortality	Harvest loss
Border						none			
GM rape	yes	chisel	30 Aug.	70	Commercial		selective	95%	5%
NGM rape	yes	chisel	30 Aug.	70	Farm				5%
Winter wheat	yes	chisel	3 Oct.	350			non-selective	95%	
Spring crop	yes	chisel	1 March	350			non-selective	95%	
Set-aside						Mid-April			

If the transgene codes for glyphosate tolerance, glyphosate will be a selective herbicide killing only non-GM rape volunteers. Non-selective herbicides are any active substances killing GM and non-GM volunteers without distinction. The volunteer mortality rate applies only to sensitive volunteers.

The field pattern of Farm 3 is presented in Figure 6.
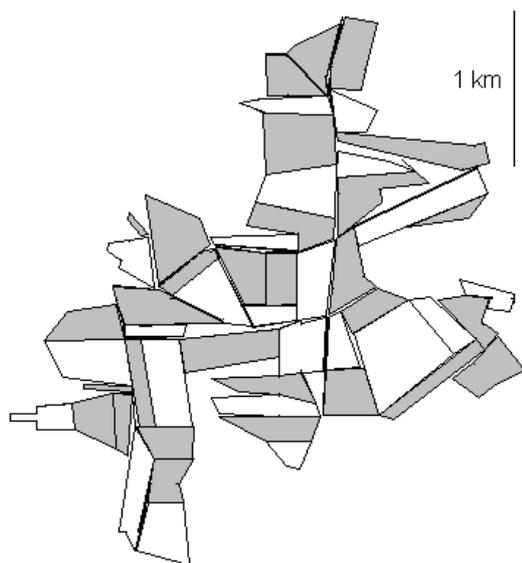
Figure 6: Map of the region surrounding Farm 3 considered in the computer model

The contamination rates obtained with current farming practices are presented in Table 13. In-field contamination is rather low on Farm 3, compared to Farm 1, despite the fact that farm-saved seed is used. The reason for this is the large field size of 10 ha - 12 ha. The effect of plot size could also been shown for Farms 2 and 2'. Additionally the rotation system on Farm 3 is different. It is much shorter, only a 3 year rotation, but does not include a set-aside step. In contrast to this the handling of the crop during drilling, cultivation, harvest and post-harvest processes leads to a rather high contamination level (0.5%) because of shared machinery with neighbours who grow GM crops, employment of contractors, no dedicated storage facilities etc. It should be noted that the values for other than in-field contamination have been estimated by several experts from the participating institutes. They are not the result of a simulation.

Table 13: Potential contamination levels to be expected with current farming practices on Farm 3

Farm 3	Proportion of GM rape on / off the farm			
	0% / 10%	**10% / 10%**	**0% / 50%**	**50% / 50%**
	Current practices			
In-field contamination (%)* (variation)	0.002 (0.0017 – 0.003)	0.004 (0.003 – 0.005)	0.05 (0.04 – 0.07)	0.09 (0.06 – 0.12)
Other routes of contamination (%) (1)	0.5	0.5	0.5	0.5
Total contamination expected (%)	0.502	0.504	0.55	0.59
* The values for in-field contamination present an average of the second rotation round (year 4 to 6). The variations are given in brackets. Results from simulation 1 (Table 14) (1) Includes drilling, cultivation equipment, harvesting, transport from field to farm, storage and cleaning.				

On Farm 3, the handling of the crop poses the highest probability of contamination. To decrease this probability several measures could be taken:
- to invest in storage facilities and to design silos for GMOs and non-GMOs;
- to use only the own combine of the farm;
- to clean carefully the transport vehicles;
- to stop exchanges of seeds with neighbouring farmers.

An alternative to the investment in storage facilities would be to deliver directly the harvest to a collecting and storage organisation (CSO) and to keep the existing storage for farm-saved seed. This might not always be possible due to the distance from the closest co-operative (depends on the region and the country) and the farmer's strategy to sell his products.

The other propositions imply mainly changes on-farm. It is difficult to limit sharing of cultivation equipment (due to the cost of investment) but despite the difficulties of cleaning a combine, it should be done properly and in general, more time should be spent in cleaning the machinery. The use of an external company for harvesting is also a major contamination factor that it is almost impossible to control.

Table 14 shows the different simulations for Farm 3 that have been calculated. The main way in which contamination is likely to occur is the handling of the crop on the farm, farming practices aiming at in-field contamination reduction are of minor importance. Nevertheless, the results provide some interesting information (Table 15).

Table 14: Description of proposed changes in cropping techniques for Farm 3
(Simulated with the GENESYS model, dispersed field pattern)

Simulation	Rotation	Seed origin for non-GM rape	W herbicide-volunteer mortality	Soil tillage W+Sc	Soil tillage R	Sowing date GMR	Sowing date NGMR	Borders cutting	Borders herbicide	Set-aside sowing	GMR harvest loss
1	RWW	farm	0.95	chisel	Chisel	30/8	30/8	none	none	none	5%
2	RWW	farm	**0.8**	chisel	Chisel	30/8	30/8	none	none	none	5%
3	RWW	farm	**0.99**	chisel	Chisel	30/8	30/8	none	none	none	5%
4	RWW	farm	0.95	chisel	Chisel	30/8	30/8	none	none	none	**10%**
5	RWW	farm	0.95	chisel	**Plough**	30/8	30/8	none	none	none	5%
8	RWW	farm	0.95	chisel	Chisel	**15/8**	**14/9**	none	none	none	5%
10	RWW	farm	0.95	chisel	Chisel	30/8	30/8	**Mid-April**	none	none	5%
11	RWW	farm	0.95	chisel	Chisel	30/8	30/8	**Mid-May**	none	none	5%
12	RWW	farm	0.95	chisel	chisel	30/8	30/8	none	**selective**	none	5%
13	RWW	farm	0.95	chisel	chisel	30/8	30/8	none	none	**spring**	5%
14	RWW	farm	**0.99**	chisel	**plough**	**15/8**	**14/9**	**Mid-May**	none	**spring**	5%
19	RWW	**commercial**	0.95	chisel	chisel	30/8	30/8	none	none	none	5%
20	**RWWSaWSc**	farm	0.95	chisel	chisel	30/8	30/8	none	none	none	5%

R=rape, W=wheat; Sa=set-aside; Sc=spring crop; GMR=GM rape; NGMR=non-GM rape
NB: bold represents the change

Simulation 16: The field pattern is changed from dispersed to clustered. The seed production field is exposed to non-farm fields at the edge of the cluster.

Table 15: Estimated contamination rates in oilseed rape for food and feed production on Farm 3

Farm 3	GM seeds in non-GM oilseed rape production (%)*			
	Proportion of GM rape on / off the farm			
Simulation	0% / 10%	10% / 10%	0% / 50%	50% / 50%
1	0.002	0.004	0.05	0.09
2	0.003	0.0046	0.056	0.1
3	0.0024	0.004	0.055	0.09
4	0.0025	0.004	0.063	0.11
5	0.0024	0.004	0.055	0.09
8	0.0014	0.0026	0.041	0.04
10	0.0015	0.0028	0.053	0.07
11	0.0015	0.0027	0.052	0.05
12	0.13	0.15	0.25	0.34
13	0.0023	0.004	0.054	0.09
14	0.002	0.0024	0.04	0.03
16	0.001	0.04	0.008	0.22
19	0.0004	0.0006	0.006	0.01
20	0.1	0.02	1.3	3.0

* The values for in-field contamination present an average of the second rotation round (year 4 to 6).

Compared to Farm 1 the following differences could be noted:

Simulations 2, 3: Variations in herbicide efficiency had a stronger effect on farm contamination levels than for Farm 1. The reason is the low volunteer level on Farm 3. In this case, variations in mortality rates are more noticeable than on Farm 1 where the general volunteer density was such that herbicide efficiency had little impact.

Simulation 4: Increases in harvest loss in GM rape off-farm did not affect non-GM rape crops. The size of the fields protects the non-GM crops better against influxes of foreign pollen and seeds.

Simulation 5: Ploughing before rape crops did not decrease contamination rates. The seed bank is too small for soil tillage to have much impact.

Simulation 8: Similarly changing sowing dates had much less impact than on Farm 1. Because of the smallness of the seed bank, delaying non-GM sowing has little effect on seed survival. Furthermore, because of the field size, decreasing the overlapping of flowering periods had also less impact on pollen flows.

Simulations 10, 11: Border cutting is more efficient on Farm 3. Because of the field sizes, the rape crops are more concentrated than on Farm 1. Therefore, borders play a more important role in gene flow and their management is crucial. On Farm 1, rape crops were more homogeneously distributed over the whole region, as fields were smaller.

Simulation 12: Glyphosate spraying leads to an increase in contamination rates by providing GM volunteers a selective advantage. This effect is becoming smaller when the GM volunteer rate rises (10% GMO share on- and off-farm).

Simulation 13: Set-aside management is less important than on Farm 1, because of the differences in rotations. As the rape rotations do not comprise any set-aside on Farm 3, the avoidance of seed production on set-aside fields is less important for gene flow than on Farm 1.

The decrease in contamination rates observed for Farm 3 is entirely due to a decrease in pollen flow from set-aside neighbour fields to simultaneous non-GM fields.

Simulation 16: Clustering the farm fields has also less impact because the fields are bigger than on Farm 1. This situation changes when the GMO share on the farm rises. In that case the clustering of the fields leads to a considerable increase in contamination on the farm.

Simulation 19: Using commercial seed (which is assumed to be not contaminated) instead of farm-saved seed decreases contamination rates considerably. However, as the contamination levels are already quite low, this has less importance in this situation.

Simulation 20: Introducing set-aside into the rape rotation makes contamination very likely, even if the rotation is lengthened and the rape crops are only grown every 6 instead of every 3 years. In the case of 10% GMOs on- and off-farm the introduction of set aside has less effect. Other contamination routes are more important. Regarding a GMO share of 50% on- and off-farm the potential contamination level is much higher. The set-aside permits renewal of the seedbank during those years where no rape is grown on the field. Because of the high GMO proportion, this renewal amplifies GMO spread even more than with 10% GMO share. In the latter case, set-aside also permits renewal of non-GM seeds, thus helping to dilute the GM contamination.

3.1.11.1 Conclusions for Farm 3

On Farm 3 the handling of the oilseed rape during cultivation and post-harvest is the crucial factor that influences contamination rate. The 0.3% threshold could be met by changing the handling of the crop by investing in dedicated machinery or at least by cleaning machinery used for non-GM oilseed rape thoroughly. By doing this the post-harvest contamination level could probably be reduced from ~0.5% to ~0.14%.

Regarding the case with 50% GM rape on the farm and in the region, additional measures to reduce the in-field contamination could be taken. Either a combination of different measures (simulation 14) would be effective or abandoning the saving of seeds and using commercial seed (which was assumed to be pure in the simulation) (simulation 19). The latter would consequently lead to a situation, in which the 0.3% threshold for seed production would no longer be applicable for Farm 3, which would have switched to food and feed production completely. A threshold of 1% would then seem appropriate.

A 0.1% threshold cannot be met. Investing also in dedicated storage facilities would reduce the probability of contamination further but this would be very costly and in the end would change the whole farm strategy. Additionally in-field contamination rates will increase over time, as contaminated farm-saved seed is used, so changing farming practices would only delay reaching the threshold value. These results stress the importance of seed purity.

3.1.12   Farm 4: Organic farm-saved seed production

Farm 4 represents the organic counterpart of Farm 3, having the same features except for the crop rotation system, which is identical to that of organic Farm 2. The surrounding conventional farms use the same crop rotations as conventional Farm 3. All farms use farm-saved seeds for non-GM oilseed rape production. Changes of farming practices do only apply to the organic Farm 4. The only change off-farm concerns harvest losses.

The contamination rates to be expected using current farming practices are presented in Table 16.

Table 16: Potential contamination levels to be expected with current farming practices on Farm 4

Farm 4	Proportion of GM rape on / off the farm	
	0% / 10%	**0% / 50%**
	Current practices	
In-field contamination (%)* (variation)	0.2 (0.009 – 0.6)	1.0 (0.58 – 1.43)
Other routes of contamination (%) (1)	0.09	0.09
Total contamination expected (%)	0.29	1.09
* The values for in-field contamination present an average of the second rotation round (year 7 to 13). The variations are given in brackets. Results from simulation 1 (Table 17) (1) Includes drilling, cultivation equipment, harvesting, transport from field to farm, storage and cleaning.		

Farm 4 has a much higher in-field contamination level as compared to the conventional counterpart. In-field contamination is increased because Farm 4 employs a rotation system with a set-aside step in contrast to Farm 3, which had only a very short rotation without set-aside. Additionally volunteer control is less effective. The handling and post-harvest contamination level stems from sharing the combiner with neighbours who grow GM rape. Current farming practices may not allow to meet a 0.3% threshold. Compared to Farm 2, which is managed similarly, the contamination rates are lower, because of the larger field sizes, which protect non-GM rape more efficiently against GM pollen and seed influxes. For Farm 4 simulations identical to Farm 2 have been calculated. The results are presented in Table 17.

Table 17: Estimated contamination rates in organic oilseed rape for food and feed production on Farm 4

Farm 4 Simulation	GM seeds in NGMR seed production (%)* Proportion of GM rape on / off the farm	
	0% / 10%	**0% / 50%**
1	0.20	1.0
2	0.21	1.0
3	0.21	1.0
4	0.21	1.34
5	0.22	0.9
8/9	0.06	0.3
10	0.18	0.9
11	< 0.01	0.36
12	1.26	2.5
13	0.03	0.06
14	< 0.01	0.02
16	< 0.01	0.02
19	0.09	0.23
* The values for in-field contamination present an average of the second rotation round (year 7 to 13).		

Compared to Farm 3 the use of commercial seed instead of farm-saved seed is less effective, because the GM seed bank on the farm is larger so that there is a rather important contamination source in any case. Additionally, commercial seeds are only used on Farm 4, the surrounding farms continue to use farm-saved seeds.

3.1.12.1 Conclusions for Farm 4

First, a reduction of contamination via the harvesting process needs to be achieved. This could be done by not sharing machinery with the neighbours. Post-harvest contamination levels could then be reduced from 0.09% to 0.05%.

In the case of 10% GMOs in the region, in order to keep contamination levels below 0.3%, it would be appropriate to sow the set-aside in spring (simulation 13). Another efficient measure would be to sow GM rape earlier than non-GM rape and thus reduce overlapping of flowering (simulations 8, 9). Nevertheless, the possibility of using this measure depends on favourable weather conditions and can vary from year to year. Thus it is not reliable enough to minimise cross-pollination. Also, the use of commercial seed would be an option (simulation 19). Regarding a GMO share of 50% in the region, spring sown set-aside (simulation 13) or a combination of measures (simulation 14) could lead to contamination levels below 0.3%.

In the case of 10% GMOs in the region, border cutting is an efficient measure to reduce contamination levels below 0.1% (simulation 11). Still, this measure depends on the good will of neighbours and administration to reach its full effect. A combination of different measures to reduce volunteers (simulation 14) could also be used to reduce contamination levels below 0.1%. The clustering of the farm fields also showed positive effects (simulation 16).

3.1.13 Costs of changed farming practices

Additional costs that could arise because of changed farming practices have been estimated as follows. For some efficient measures costs could not be determined, because these measures either require a reorganisation of agricultural land (clustering of fields, simulations 16, 17) or co-operation between farmers, including comprehensive changes of the used crops and rotations (isolation distance of 300m during the whole rotation cycle, simulation 18).

- Chiselling before other crops than rape (Farm 2, simulation 5).
  As chiselling is cheaper than ploughing (44.5 €/ha instead of 80.5 €/ha) there are no additional costs assumed.

- Changing sowing time for GM and non-GM rape (simulations 8, 9).
  As there are no additional working steps required, no additional costs are assumed.

- Border management (simulations 10, 11).
  Assumptions: - Border management is carried out by the farmer,
      - it includes 1 crushing per year with a 40cv DIN to 60 cv DIN tractor
        and a mower of 2m width used on 30 to 100 ha per year,
      - the 2 sides of the paths or roads are considered with a width of 1m

   For estimation of costs see Table 18.

  For Farm 4, 2.34 ha of paths and roads have been estimated, extrapolated to 4.2 ha for the whole region of 633 ha. If 4.2 ha of borders have to be cut to minimise contamination on 70 ha oilseed rape grown on Farm 4, the additional costs amount to 4.3 €/ha oilseed rape. This corresponds to 0.5% of the gross margin plus subsidies achievable with organic oilseed rape by Farm 4.

Table 18: Cost estimation for border management
(Source: Calculations according to Teyssier 1999[21])

	Cost (€/ha)
Tractor	7 – 9.14
Mower	9.9 – 25
Man power	45.73
TOTAL COSTS	**62.63 – 79.87**
TOTAL AVERAGE COSTS	**71.25**

- Spring sown set-aside (simulation 13).
  Assumptions: - Set-aside is sown with Italian rye-grass or hybrid clover,
  - Mechanical operations are: 2 stubble cultivation, sowing, rolling, and 1 crushing (minimal management) or 2 crushings (maximal management),
  - Costs of seed are calculated according to ITCF advice concerning sowing density (ITCF, 1994),
  - Operating costs include machinery maintenance, fuel and lubricant
  - Machinery costs include amortization of new machines (Gembloux method),
  - In addition, nitrogen fertilizer can be applied for rye-grass.

Table 19: Cost estimation for sowing a set-aside with hybrid clover or Italian rye-grass
(Source: Perspectives agricoles, July-August 1994)

	Hybrid Clover	**Italian Rye-grass**
Seeds (€/ha)	25.9 – 34.68	34.5 - 46
Operating costs (€/ha)	45.73	45.73
Machinery costs (€/ha)	99.8 (1) – 136.74 (2)	99.8 (1) – 145.27 (3)
TOTAL COSTS (€/ha)	**171.43 – 217.15**	**180 - 237**
(1) Minimal management including 1 crushing; **(2)** Maximal management including 2 crushings **(3)** Maximal management + nitrogen fertilizer application		

For the calculation of additional costs the average cost for sowing hybrid clover (194.3 €/ha) has been selected. This corresponds to about 20% of oilseed rape gross margin plus subsidies for Farms 1 and 2 and to 24% for Farm 4. The costs vary according to the intensity of management that is chosen (1 or 2 crushings, application of fertilizer). In the farm types selected in this study, sowing the set-aside is not a practice in place. It should be noted that in some Member States, ploughing the set-aside is done when farmers are confronted with serious weed problems. In that case, costs of sowing the set-aside with hybrid clover or Italian rye-grass would be reduced to the cost of buying and sowing seeds and fertilizer application. Presented contamination levels are based on sowing of set-aside of *all* oilseed rape fields, either on the farm (organic farms) or in the region (conventional farms). However, simulation results indicate that the effect of sowing set-aside *only* on the concerned seed production field (Farms 1, 2 and 2') would be similar. Therefore costs are calculated for the sowing of set-aside of the corresponding fields only.

---

[21] Teyssier, Daniel 1998-1999. Index des prix et des Normes agricoles (14 ème édition). Synthèse agricole, Bordeaux.

- Combination of measures (simulation 14).
  In the combination of measures one measure (enhanced weed control efficiency) is included which did not show any positive effect on contamination levels and was therefore not included in this cost calculation. For later sowing of non-GM rape and chisel before crops other than rape no additional costs have been assumed. The only measures with corresponding costs are spring sown set-aside (see above, 194.3 €/ha) and border cutting (see above, 4.3 €/ha for Farm 4; 6.2 €/ha for Farm 2'). For Farm 4 this adds up to additional costs of 198.6 €/ha (corresponding to 27% of gross margin plus subsidies), for Farm 2' additional costs of 200.5 €/ha arise (corresponding to 20% of gross margin plus subsidies).

- Introduction of an additional spring crop in the rotation (simulation 15)
  No additional costs are assumed. Prolonging the rotation by adding an extra spring crop to the rotation could potentially increase short-term profitability, since the relative time the plot is not used (set-aside) is lowered. However, long-term effects would probably include increased application of fertilizer (to avoid reduced land productivity) and negative environmental effects.

- Dedicated machinery (Farm 3).
  No data for additional costs were available. To indicate possible additional costs, an increase of present machinery costs of 50% was estimated. This corresponds to additional cost of 93.2 €/ha.

3.1.14 General conclusion for oilseed rape

The following Tables 20 & 21 summarise the results for oilseed rape seed production in the presence of GM crops. The "best change of practice" was selected as the cheapest or best applicable farming practice to produce below the targeted thresholds of 0.3% and 0.1%.

Table 20: Summary of contamination rates in oilseed rape seed production in conventional and organic agriculture with current and with recommended farming practices (10% GMOs in the region, medium-term evaluation)*

Farm type	Conv. 1	Conv. 1 (10% GMOs also grown on the farm)	Organic 2 large	Organic 2' ** small	Conv. 3	Conv. 3 (10% GMOs also grown on the farm)	Organic 4 large
Current practices Total rate of contamination expected	0.22 %	0.22 %	0.41 %	2.01%	0.5 %	0.5 %	0.29 %
Best change of practice to meet threshold 0.3%	Current practices	Current practices	Chisel before other crop than rape	Spring sown set-aside	Dedicated machinery, cleaning machinery	Dedicated machinery, cleaning machinery	Spring sown set-aside
Total rate of contamination expected			0.19 %	0.11 %	0.14 %	0.14 %	0.08 %
Additional costs (€ / ha)	0	0	~ 0***	194.3	93.2		194.3
Best change of practice to meet threshold 0.1 %	Spring sown set-aside (1)	Spring sown set-aside (1)	Spring sown set-aside	Combination of practices (3) or Rape-free rotations in the 300m surrounding the field	Global change of post-harvest management	Global change of post-harvest management	Combination of practices (3) or regional border management
Total rate of contamination expected	0.03 % (2)	0.03 % (2)	0.03 % (2)	0.06 % or 0.02 %			0.06 % or 0.06 %
Additional costs (€ / ha)	194.3	194.3	194.3	200.5 / n.d.	-	-	198.6 / 4.3

*   The seed bank is assumed to be pure at the beginning of the simulations
**   Organic Farm 2' is a small farm with very small plots, which does not represent a typical certified seed producer.
***   No additional costs compared to current practices.
 (1)   On all set-aside of the studied area (especially when the field pattern of the seed production farm is dispersed)
 (2)   Considering all kinds of field pattern (dispersed or clustered) in the case of a clustered field pattern, to choose a "protected position" for the seed production field is sufficient
 (3)   Combination of practices includes spring sown set-aside, chisel before other crops than rape, region-wide border management and difference in sowing time
n.d.   not determined

Table 21: Summary of contamination rates in oilseed rape seed production in conventional and organic agriculture with current and with recommended farming practices
(50% GMOs in the region, medium-term evaluation)*

Farm type	Conv. 1	Conv. 1 (50 % GMOs also grown on the farm)	Organic 2 large	Organic 2' ** small	Conv. 3	Conv. 3 (50 % GMOs also grown on the farm)	Organic 4 large
Current practices Total rate of contamination expected	0.42 %	0.42 %	0.61 %	9.01 %	0.55 %	0.59 %	1.09 %
Best change of practice to meet threshold 0.3%	To introduce a spring crop in the rotation (3)	To introduce a spring crop in the rotation (3)	Spring sown set-aside	Combination of practices (4)	Dedicated machinery, cleaning machinery	Dedicated machinery, cleaning machinery	Spring sown set-aside
Total rate of contamination expected	0.19 %	0.19 %	0.04 %	0.23%	0.19 %	0.23 %	0.11 %
Additional costs (€ / ha)	~ 0***	~ 0***	194.3	200.5	93.2	93.2	194.3
Best change of practice to meet threshold 0.1%	Spring sown set-aside (1)	Spring sown set-aside (1)	Spring sown set-aside	Rape-free rotations in the 300m surrounding the field	Impossible to achieve	Impossible to achieve	Combination of practices (4)
Total rate of contamination expected	0.03 % (2)	0.03 % (2)	0.04 % (2)	0.03 %			0.07 %
Additional costs (€ / ha)	194.3	194.3	194.3	n.d.	-	-	198.6

*   The seed bank is assumed to be pure at the beginning of the simulations
**   Organic Farm 2' is a small farm with very small plots, which does not represent a typical certified seed producer.
***   No additional costs compared to current practices
(1)   On all set-aside of the studied area (especially when the field pattern of the seed production farm is dispersed)
(2)   Considering all kinds of field pattern (dispersed or clustered) in the case of a clustered field pattern, to choose a "protected position" for the seed production field is sufficient
(3)   Has environmental consequences (bare soil in winter, risk of nitrate leaching), which are difficult to estimate
(4)   Combination of practices includes spring sown set-aside, chisel before other crops than rape, region-wide border management and difference in sowing time
n.d. not determined

From the simulation results the following important factors, influencing in-field contamination, can be identified:

- Seed purity. In the case of farm-saved seeds seed impurity can be an important source for contamination.

- Variety. Varietal associations and hybrid production with a high share of male sterile plants are more susceptible to cross-pollination than fully fertile varieties.

- Volunteer control. The efficiency of volunteer control, which is higher in conventional than in organic farming, strongly influences contamination rates.

- Rotation / set-aside (management). The characteristics of the rotation system used, containing a set-aside step or not, is a very important issue regarding contamination. Set-aside plots allow volunteers to grow and spread pollen and seed, thus also increasing the seed bank for the following years. If the set-aside step is sown with a spring crop, this effect can be avoided.

- Full isolation of seed production field. The isolation of the seed production field from other rape crops in all years is important to avoid building up a seed bank and a volunteer problem.

- Plot distribution in landscape (clustered / dispersed). The clustering of fields allows the farmers to have more influence on the fields that are near the seed production field and enables the protection of the field. This effect is dependent on the size of the farm, and on the exact localization of the seed plot.

Several measures to reduce in-field contamination have been tested with the help of GENESYS. Few measures involve changes that take place only on the studied farm. Most require at least a partial co-operation between the neighbours and these are generally the most effective measures (e.g. changed field pattern, 300m isolation distance throughout all years). Regarding the simulation results it is obvious that for the farm types tested, in-field contamination can be minimised to a certain extent, enabling a production with potentially very low contamination levels. It should be noted that for an efficient isolation of certified hybrid seed production the Scientific Committee on Plants in its opinion from 13 March 2001[22] considers a distance of at least 600m in the year of seed production necessary to minimise cross-pollination. This recommendation is not reflected in the simulation results.

The economic aspects of changing farming practices were partly not determinable, but in cases where data were available, figures show that achieving low contamination levels could have a rather high cost.

Regarding certified seed production (Farms 1, 2, and 2'), which is supposed to use pure basic seed for seed production and to have a well functioning segregation system running on farm, current practices as defined in this study may not be sufficient to keep the contamination level below the studied thresholds. The only exception is Farm 1 in the presence of 10% GMOs, where contamination levels could be below 0.3%. In all cases measures were available which could reduce contamination levels efficiently below 0.1%. The easiest measure to employ seems to be spring sown set-aside, which would be in the responsibility of the farmer, but accounts for about 20% of the gross margin plus subsidies.

---

[22] Scientific Committee on Plants, opinion from 13 March 2001 available at
http://europa.eu.int/comm/food/fs/sc/scp/out93_gmo_en.pdf

The results also indicate that organic farms might be more affected by the presence of GM oilseed rape in the region than a conventional farm, mostly because of volunteer problems. If the organic farm were smaller (example Farm 2') the contamination problem would be aggravated considerably. This farm certainly would not be eligible for certified seed production. Only close co-operation with the neighbouring conventional farms could probably help in minimising contamination.

Simulation results showed little difference between GM crops only being cultivated in the region or also on the farm. However, certified seed producers probably would avoid growing GM oilseed rape on their farm in any case to reduce the likelihood of contamination.

In the case of conventional farm-saved seed (Farm 3), the farm structure and resulting crop handling influences contamination levels considerably. Minimising contamination would need dedicated and cleaned machinery or even a restructuring of the post-harvest processes with investments for example in storage facilities as well as stopping the exchange of seeds with neighbouring farmers. As estimations suggest, to reduce contamination levels below 0.1% would be very difficult or even impossible. Farm 4, as an organic farm, has less problems with segregation but higher in-field contamination levels. Without giving up using farm-saved seed, contamination levels could be minimised below 0.1%. Again, the costs could hinder an implementation.

The results obtained with GENESYS are based on certain assumptions used for the simulations. For all simulations, it was assumed that the seed bank was pure at the beginning of the rotation. This assumption contrasts the postulation for some of the simulations that 10% or 50% of the oilseed rape grown on the conventional farms is GM. Taking this into account, it is rather unlikely that very low contamination levels could be achieved if GM and non-GM oilseed rape are grown on the same farm. Additionally, the results present medium-term results. The contamination level, as the long-term simulation showed, could increase considerably with time.

Summarising the results, it seems to be difficult for the farm types considered in the study, to achieve contamination levels below 0.3% employing current practices. A considerable reduction of in-field contamination could be achieved to the extent that even levels below 0.1% could be reached. Problems regarding the handling of the crop and the logistics of the farm (Farm 3) could be more difficult to solve. For this farm type, very low contamination levels of 0.1% could be impossible to accomplish.

3.2 Grain maize for feed production

3.2.1 Crop production and use

Cultivated maize (*Zea mays*) is presumed to have derived from teosinte (*Z. mexicana*), a native of Central America, and was introduced into Europe in the sixteenth century. Maize is cultivated worldwide and represents a staple food for a significant proportion of the world's population[23], as well as being grown as a livestock fodder crop in parts of Europe and elsewhere.

Maize is a tall annual grass. The functional staminate flowers are borne in male tassels located terminally on the stems, and the female cobs are borne in the axils of the middle leaves. Pollen is produced entirely in the staminate inflorescence, and is released from the tassels in large quantities. It has been estimated that for each ovule developing into a kernel an individual plant delivers from 9,000 to 50,000 pollen grains, often over a period of 2-14 days, though more usually over a shorter period of 5-8 days. Assuming an average ear of maize grows approximately 500 kernels, a plant will yield between 4.5 and 25 million pollen grains. The pollen grains are large (90-125 μm), and when compared with other anemophilous species have a high terminal velocity and therefore a higher comparative deposition. Maize is considered to be a protandrous species although there is usually some overlap of pollen shedding and silk emergence on the same plant that can account for up to 5% self-pollination.

Grain maize is grown for its dry seed, which is processed into a range of animal feed and human food. In Europe grain maize is produced mainly in France (1.7 Mio ha, 43% of EU production 1999) and Italy (0.9 Mio ha, 23% of EU production 1999).

GM maize accounted for about 27% of total GM crop area worldwide in 1999. This represents about 8% of the world total maize area. Most of GM maize is grown in the USA, Argentina and Canada. In Europe, France grew 2000 ha in 1998 and only 100 ha in 1999. Spain and Portugal grew small areas in 1999 (10.000 ha to 25.000 ha and 1000 ha, respectively)[24]. All GM maize planted to date is insect-resistant Bt-maize, expressing toxins from the soil bacterium *Bacillus thuringiensis*.

3.2.2 Routes of contamination

3.2.2.1 Pollen-mediated gene flow

Maize is primarily wind pollinated. Most of the pollen falls within 5m of the field's edge, 98% of the pollen remains within a 25m – 50m radius of most of the maize field[25]. However, outcrossing can be detected up to a distance of 800m[26]. Pollen dispersal and pollen flow between GM and non-GM maize crops seems to be dependent on the scale of pollen release and on the distances between source and recipients. Also the depths of the recipient fields in the direction of the source of contamination plays a role. It appears that "depth of the field" is of greater importance than total acreage in reducing contamination. The percentage of outcrosses occurring in successive rows indicates that the first five rows adjacent to the source of

---

[23] Anon (1994b) The Regulatory Directive Dir 94-11 Plant Biotechnology Office, Plant Health and Production Division, Canadian Food Inspection Agency

[24] European Commission, DG Agriculture 2000. Economic impacts of genetically modified crops in the agri-food sector. ENDS Daily 09/05/00 (www.environmentdaily.com)

[25] Sears, M. K. & Stanley-Horn, D. (2000) Fairbairn, C., Scoles, G. & McHughen, A. (Eds.) Proceedings of the 6th International Symposium on The Biosafety of Genetically Modified Organisms. University Entension Press, Canada; Pleasants, J. M., Hellmich, R. L. & Lewis, L. C. (1999) Pollen deposition on milkweed leaves under natural conditions (presentation at the Monarch Butterfly Research Symposium, Chicago).

[26] Salamov, A. B. (1940) Sel. I. Sem., 3. (Russian translation by Michael Afanasiev in 1949).

contamination function as a barrier to the dispersal of contaminating pollen. Additional border rows serve only to dilute the contaminating pollen[27]. Overall the percentage of cross breeding with other maize crops in the vicinity will depend on factors such as separation distance, local barriers to pollen movement and local climate and topography.

If introgression between GM and non-GM varieties were to occur, the probability of a volunteer weed problem occurring is low because its reproductive capacity is limited due to characteristics such as its inability to shed seed naturally. It seems unlikely that any shed maize seed would remain viable for prolonged periods under European conditions due to lack of dormancy and the inability of seed to survive low temperatures[28].

In Europe there are no known relatives with which maize can hybridise. Therefore there appears to be no probability of gene flow from GM maize to wild plants and back to maize.

3.2.2.2 Adventitious admixture

Contamination via drilling, cultivation equipment and harvesting is considered to be low. Seed admixture is likely to occur post-harvest during grain handling, storage and transport, largely due to lack of adequate facilities for segregation and due to poor management and quality control.

3.2.2.3 Seed purity

The minimum separation distance in the EU is currently 200m for all categories of seed production and this is deemed sufficient to maintain inbred lines at 99.9% purity[29]. Seed from certain sources may contain adventitious GM material. Most likely to be contaminated are seeds produced in regions where GM crops are extensively grown and seed from merchants who also produce seeds of GM varieties. In 2000, seed lots imported from North America contained low amounts of GM seeds and controls done at Member State level (France) have shown that a high proportion of maize seed tested (41%) contained low levels of GMO contamination (< 0.2%)[30]. At present there is little commercial GM grain maize production in Europe, except in Spain (2% to 4.3% of maize cultivation area) and some East European countries. Hence it is unlikely that seed produced in Europe will be contaminated. However this situation could change if GM crops become widely grown.

3.2.3 Typical farm types

Grain maize production has been studied in two main production areas, France and Italy. Two different farm types have been developed to reflect different cultivation methods. Farms 1 and 5, situated in Southern France (Pau valley) and Italy (Po plain), respectively, grow maize mainly in continuous culture and belong to regions where maize is the main production crop (up to 80% of the area is in continuous maize production). Late-maturing hybrids are grown and seed is imported from the USA. The harvested grain is transported to a central grain handling facility, where it is cleaned, dried and stored. The organic counterparts to Farm 1 (Farm 2 and 2') grow maize in long rotations.

---

[27] Jones, M. D. & Brooks, J. S. (1952) Effect of tree barriers on outcrossing in corn. Oklahoma Agricultural Experimental Station, *Technical Bulletin No. T-45*.

[28] Scientific Committee on Plants, opinion from 13 March 2001 available at
http://europa.eu.int/comm/food/fs/sc/scp/out93_gmo_en.pdf

[29] Ingram, J. (2000) Report on the separation distances required to ensure cross-pollination is below specified limits in non-seed crops of sugar beet, maize and oilseed rape. *MAFF Project No.: RG0123*. MAFF.

[30] http://www.finances.gouv.fr/DGCCRF/actualites/index.html

Farm 3 represents a conventional farm that grows maize in long rotations on just 20% of the farm area. It is situated in Central France (Beauce region). Field sizes are large (20 ha) and distances to other maize fields are on average 500m. The farm grows early and semi-early varieties, and dries the grain in a central continuous process dryer. Farms 4 and 4' (smaller) represent the organic versions of this farm type.

Farm characteristics are summarised in Table 22.

Table 22: Maize farm type characteristics

Farm	1	2	2'	5	3	4	4'
	Conventional	Organic	Organic	Conventional	Conventional	Organic	Organic
Region	Pau Valley			Po-Plain (Italy)	Beauce		
	Intensive maize cultivation				Non-intensive maize cultivation		
Rotation	continuous maize: 95 %	Maize in long rotations		Continuous maize: 60 % Maize in rotation: 40 %	Maize 20 % / Cereals 60 %		
Maize/AUA	80 % (Valley)	10%		Maize 40-55%	10-20 %		
Farm size	60 ha		10 ha	40-60 ha	100 ha		15 ha
Plot size	3-4 ha		1-4 ha	6-10 ha	20 ha		3 ha
Sowing dates	20/04 to 01/05			15/04 to 15/05	10/04 to 01/05		
Drill ownership	85 % individual				Individual		
Flowering dates	14/07 to 01/08			15/07 to 15/08	4-5 days between varieties total flowering period about 10 days		
Distance between maize plots	0.80 - 100 m			2 - 6 m	500 m		
Combine harvester ownership	85 - 90 % by companies			60 % individual 40 % companies	50 % individual - 50 % collective		
Drying	95 % storage organisation; 5 % farm			100 % farmers' organisations for specific plants	90 % storage organisation - 10 % farm		
Storage	90 % storage organisation; 10 % farm			55-60 % storage organisation or feed industry 40-45 % farm	90% storage organisation, 10% farm		
Segregation	YES, already for Waxy, Sweet, Plata			/	Difficult (continuous process of drying, fast harvest)		
Maize use on farm	YES (for ducks and geese)			YES (cattle)	NO		

3.2.4   The computer model MAPOD

To estimate the effects of changing farming practices on the levels of in-field contamination, a computer model developed by INRA was used. The model MAPOD (Matrix based Approach to POllen Dispersal) takes into account several parameters:

- Field plan:
    Form and size of the fields
    Location of GM plants
- Climate (daily data):
    Temperature; rain; wind: speed and direction
- Parameters for the pollen dispersal function:
    Tassel height of each variety
    Cob height of the 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 the GMO: homozygous or heterozygous

With the help of MAPOD, the dynamics of male and female flowering can be simulated, making it possible to estimate the amounts of pollen produced by GM and non-GM varieties 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.

The results provided are expressed as the mean frequency of GM seeds in the harvest. The variation of the mean value is +/- 10%.

MAPOD is a very recently developed model[31]. It is less sophisticated than the model GENESYS used for oilseed rape. Validation of MAPOD is in progress, based on independent results obtained in trials not used in the development of the model. The first comparisons of simulations and trial results show that the rates of contamination of harvested grains are slightly underestimated but that the orders of magnitude are reliable. MAPOD may therefore be used best to compare the effects of different cropping practices or the value of certain varietal characteristics for decreasing the probability of contamination in the field.

3.2.5   Assumptions used for simulation

For the simulation the following input data is supplied:

- Characteristics of model farms (plot sizes, field pattern, cropping system)
- The GMO share in the region (10% or 50%). In the case of conventional farms, this reflects also the GM maize share on the farm.
- The GM maize variety grown in the region is assumed to be homozygous for the transgene. This is a worst case scenario, since all GM varieties developed so far are heterozygous.
- Seed lots used are assumed to be pure. Potential seed impurities are considered in an additive manner, taking into account the threshold proposal for maize seed (0.3%) that was discussed in the opinion of the Scientific Committee on Plants of 13.03.01[32]. A simulation of a random distribution of GM plants (0.3%) in a non-GM maize field would give rise to an impurity of 0.6% in the harvest, if the GM variety is homozygous. Based on these findings a safety margin of 0.3% is introduced for seed purity (0.3% +/- 0.3%).
- Wind speed is considered to be constant at 4 m/s, blowing north to south.
- In the region investigated there are no natural barriers.
- All maize varieties have the same flowering dates.

---

[31] Angevin F., Klein E., Choimet C., Meynard J. M., de Rouw A. and Sohbi Y., 2001. Rapport du groupe 3 « Isolement des collectes et maîtrise des disséminations au champ » du programme de recherche *"Pertinence économique et faisabilité d'une filière 'sans utilisation d'OGM' "*. INRA – FNSEA, 55 p, *in press* (pp 21-36); Klein E., 2000. *Estimation de la fonction de dispersion du pollen. Application à la dissémination de transgènes dans l'environnement*. Thèse de l'Université Paris XI – Orsay, 80 p + annexes.

[32] Scientific Committee on Plants, opinion from 13 March 2001 available at
 http://europa.eu.int/comm/food/fs/sc/scp/out93_gmo_en.pdf

- Discontinuities that exist in an agricultural landscape like roads or other crops are represented in the model as sterile maize plants.

3.2.6   Evaluated measures to reduce contamination levels

3.2.6.1   Management of in-field contamination

Increasing isolation distances would be an effective measure to decrease contamination via cross-pollination. However, it might be difficult to realise, depending on the farm structure and the neighbouring farms.

Harvesting the field margins separately from the center of the field, and discard the margin harvest. A discard width of 6m can reduce the contamination level about 20%. Because of the loss in yield, this measure can be rather costly. Several simulations were carried out with MAPOD, to quantify the effect of this measure (Table 23). These data were used to determine the effect of discarding for the different farm types (see below).

Table 23: Effect of discard width on the mean contamination rate
(For a field of non-GM maize adjacent to a field of GM maize of same size (2 ha)*)

Discard width	Rate of contamination (%)	Estimation of rate decrease
0 m	9.6	
6 m	7.7	- 20 %
10 m	7.2	- 25 %
12 m	6.5	- 32 %
20 m	5.7	- 41 %
*Studied case: GM & non-GM fields are adjacent (distance 0.8 m), wind: north to south; speed: 4 m/s throughout flowering, non-GM crop is "downwind" of the GM crop, the two varieties have the same flowering time		

Clustering of fields for GM maize varieties in a "production island'. Compared to dispersed fields of the same acreage, contamination levels can be reduced considerably. This measure requires co-operation between farmers and perhaps contracting by a collection and storage organisation (CSO).

Introduction of a time-lag of flowering time between GM and non-GM varieties. Due to maize protandry, the time-lag is more effective, if the GM variety flowers earlier than the non-GM variety (Figure 7).
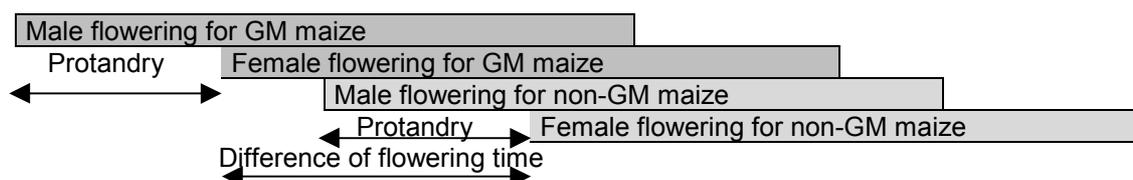
Figure 7: Protandry and differences in flowering time of maize

Differences in flowering time are expressed in degree days (^{o}days), calculated based on air temperature. For maize, the rate of development and the duration of the various growth stages are well defined in degree days and are genetic characteristics. A difference of 50 ^{o}days represents in Southern France approximately 3 days.

Several simulations were carried out with MAPOD to assess the effect of difference of flowering time (Table 24). The results of this simulation are applied also for the other farm types investigated.

Table 24: Effect of a difference in flowering time on the mean rate of contamination

Flowering time of non-GM maize:	The rate of contamination reduced by a factor of
25°days after that of the GM variety	1.5
50°days after that of the GM variety	5
75°day after that of the GM variety	50
Studied case: Italian context (Farm 5); 50% GM varieties in the landscape	

Selecting varieties so as to have a range of flowering times may have consequences for yield. Early varieties are less productive than late varieties. This yield loss accounts for the GM maize variety. Thus, a co-operation has to be established between GM maize growers and non-GM maize growers. Late varieties are more productive than early varieties but are subject to another type of commercial risk: in cold and/or rainy years, harvesting of late varieties may be difficult (potential losses).

3.2.6.2 Management of post-harvest contamination

Based on the analysis of existing segregation practices of different maize varieties, three different possibilities to segregate GM and non-GM maize can be envisaged:

- Separate collection of GM and non-GM varieties by the CSO. Harvested maize grains will be dried and stored on the farm and GM and non-GM maize will be delivered at different times to the CSO. Maize batches will be tested directly on the farm regarding the contamination level. This approach could be expensive, because of possible costs for drying and storage facilities and testing.

- Strategy of isolation by contracts between farmers and CSO. Isolation can be achieved by obliging farmers per contract to respect isolation distances, to use GM and non-GM maize varieties with different flowering times and, additionally fix the delivery dates of the crop. The latter would enable to dry GM and non-GM varieties separately. Alternatively the central dryer could be cleaned carefully between different maize varieties.

  The safest approach would be to create production islands around a dedicated silo. This would grant a relative high level of isolation and facilitates traceability of origin.

- The strictest measure would be to create GMO-free regions.

MAPOD simulation results are presented in the following sections for a situation in which 50% of the maize grown in the region and on the conventional farms is GM.

3.2.7   Farm 1: Intensive maize production in France

Farm 1 produces grain maize in continuous culture on about 80% of the farm area. The plots are comparatively small (3 ha - 4 ha). As maize is the main crop produced in this region, distances between plots are small (0.8m – 100m). Farmers use late flowering varieties. Table 25 shows the contamination levels for Farm 1 with 50% GM maize in the region and on the farm. Results are presented for current practices and the effects of different measures to minimise contamination are simulated. The main contamination sources are seed impurities, cross-pollination and the post-harvest handling of the crop. The results are expressed as % of the harvested grains.

Table 25: Estimation of contamination levels for Farm 1
(50% GMOs in the region and on the farm)*

Farm 1		Changes introduced to limit cross-pollination					
	Current practices	Discard width 6 m ***	Minimum distance 100 m	Minimum Distance 200 m	Difference in flowering time (25 °days)	Difference in flowering time (50 °days)	Difference in flowering time (75 °days)
Seed	0.5 (+/- 0.2)	**0.3 (+/- 0.3)**	**0,3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**
Drilling / Cultivation equipment	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cross-pollination	1.5	**1.2**	**1**	**0.5**	**1**	**0.3**	**0.03**
Harvesting / Transport from field to storage facility / Transport from farm	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Storage / Cleaning/ Drying	0.2 (+/- 0.15)	**0.01 ****	**0.01 ****	**0.01 ****	**0.01 ****	**0.01 ****	0.2 (+/- 0.15)
Total contamination expected	2.25 % (+/- 0.35 %)	**1.56 % (+/- 0.3%)**	**1.36 % (+/- 0.3%)**	**0.86 % (+/- 0.3%)**	**1.36 % (+/- 0.3%)**	**0.66 % (+/- 0.3%)**	**0.58 % (+/- 0.45%)**

*   Results are expressed in % of GM grains in harvest;
**   If the material is fully dedicated;
*** Case where fields are adjacent;
Changes are in bold.

For current practices, the values for seed impurities are based on data from France, stating that seeds for late maize varieties imported from the USA, show varying degrees of contamination with GM maize. In all other cases an average seed impurity of 0.3% was assumed.

Discarding a 6m margin is not enough to reduce contamination below a threshold of 1% (when GM and non-GM fields are adjacent). The same is true for a distance of 100m between the fields. Even a minimum distance of 200m only reduces the contamination level just below 1%, even if post-harvest handling of the crop is improved simultaneously. The most effective measure seems to be using varieties with a difference in flowering times of at least 50 °days. This reduces cross-pollination levels considerably. If additionally the post-harvest handling is changed to minimise contamination, the results are well below 1% impurities. Since the waxy maize production is currently segregated in this region, the existing system could be adapted to GM maize. Using a time-lag of flowering of 75 °days, post-harvest handling does not need to be changed to achieve a contamination level below 1%.

Even in the case that GM-free seed is used, impurities would be above 0.1% in all cases simulated.

At this point it should be stressed that these are the result of a simulation, based on certain assumptions. Additionally the model used for the calculation does give relative values. The results presented can be used to rank the different farming practices referring to their efficiency in reducing contamination via cross-pollination.

3.2.8   Farm 5: Intensive grain maize production in Italy

This farm is located in Northern Italy in the plain of the river Po. Farms 1 and 5 have many features in common. The conditions of use and possession of equipment are similar, as are the conditions of drying and storage. Storage is distributed between farms and co-operatives and there are possibilities for segregating the different types of production.

The principal differences between the two farms are:
- larger plot sizes (6 ha – 10 ha) for the Italian farm (Farm 5);
- maize grown also in rotation (only 60% of maize grown in continuous culture);
- smaller proportion of maize in the local environment of the Italian farm (40% - 55%).

The probability of cross-pollination on Farm 5 is lower compared to Farm 1, whereas the probability of post-harvest contamination is similar to Farm 1 (Table 26). A minimum distance of 200m and additional post-harvest changes could reduce contamination levels below 1%. In contrast to Farm 1, in the agricultural landscape of Farm 5, this would probably be feasible. Differences in flowering time are effective if greater than 25 $^\circ$days, even without changing post-harvest practices.

Even in the case that GM-free seed is used, impurities would be above 0.1% in all cases simulated.

Table 26: Estimation of contamination levels for Farm 5
(50% GMOs in the region and on the farm)*

Farm 5		Changes introduced to limit cross-pollination					
	Current practices	Discard width 6 m ***	Minimum distance 100 m	Minimum distance 200 m	Difference of flowering time (25 $^\circ$days)	Difference of flowering time (50 $^\circ$days)	Difference of flowering time (75 $^\circ$days)
Seed	0.5 (+/- 0.2)	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**	**0.3 (+/- 0.3)**
Drilling / Cultivation equipment	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cross-pollination	1.0	**0.8**	**0.66**	**0.33**	**0.66**	**0.2**	**0.02**
Harvesting / Transport from field to storage facility / Transport from farm	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Storage / Cleaning / Drying	0.2	**0.01 ****	**0.01 ****	**0.01 ****	**0.01 ****	0.2	0.2
Total contamination expected	1.75 % (+/- 0.2%)	**1.16 % (+/- 0.3%)**	**1.02 % (+/- 0.3%)**	**0.69 % (+/- 0.3%)**	**1.02 % (+/- 0.3%)**	**0.75 % (+/- 0.3%)**	**0.57 % (+/- 0.3 %)**

*   Results are expressed in % of GM grains in harvest;
**   If the material is fully dedicated;
*** Case where fields are adjacent;
Changes are in bold.

3.2.9 Farms 2 and 2': Organic grain maize production in Southern France

The organic Farms 2 and 2' are situated in the same region as Farm 1. Maize is grown in rotation and accounts for only 10% of the crops. As a result of this rotation, the farmer cannot always avoid having to cultivate fields with maize at the edge of the farm. The probability of contamination is therefore chiefly associated with cross-pollination with plants in neighbouring fields. Post-harvest contamination is low, because machinery is cleaned if shared with neighbours. Farm 2' operates a farming system identical to that of Farm 2, but has a smaller total area and is made up of smaller plots of land (see Table 22). It is therefore more vulnerable to gene flow via pollen.

Tables 27 and 28 summarise the situation for Farms 2 and 2'.

Table 27: Estimation of contamination levels for Farm 2
(50% GMOs in the region)*

Farm 2		Changes introduced to limit cross-pollination					
	Current practices	Discard width 6 m **	Minimum distance 300 m	Difference of flowering time (25 °days)	Difference of flowering time (50 °days)	Difference of flowering time (75 °days)
Seed***	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)
Cross-pollination	0.08 % (+/- 0.03)	**0.06 %**	**0.04 %**	**0.05 %**	**0.02 %**	**0.01 %**
Harvesting / Transport from field to storage facility / Storage, cleaning, drying / Milling / Transport from farm	0.03	0.03	0.03	0.03	0.03	0.03
Total contamination expected	0.16 % (+/- 0.07)	**0.14 %** (+/- 0.04)	**0.12 %** (+/- 0.04)	**0.13 %** (+/- 0.04)	**0.1 %** (+/- 0.04)	**0.09 %** (+/- 0.04)
* Results are expressed in % of GM grains in harvest							
** Case where fields are adjacent							
*** Values for seed impurity are estimations							
Changes are in bold.							

Compared to Farm 1 the contamination level is much lower, because seed impurity is lower as well as the cross-pollination level because of larger isolation distances. The contamination at post-harvest level is low, because a segregation system is in place for storage, cleaning and drying (organic production). The estimated values are in all cases well below 1%, but above 0.1%. Even with a lag in flowering time of 75 °days the overall contamination level is still close to 0.1%.

Table 28: Estimation of contamination levels for Farm 2'
(50% GMOs in the region)*

Farm 2'		Changes introduced to limit cross-pollination				
	Current practices	Discard width 6 m **	Minimum distance 300 m	Difference of flowering time (25 °days)	Difference of flowering time (50 °days)	Difference of flowering time (75 °days)
Seed***	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)	0.05 (+/- 0.04)
Cross-pollination	0.5 %	**0.4 %**	**0.25 %**	**0.33 %**	**0.1 %**	**0.01 %**
Harvesting / Transport from field to storage facility / Storage, cleaning, drying / Milling / Transport from farm	0.03	0.03	0.03	0.03	0.03	0.03
Total contamination expected	0.58 % (+/- 0.04)	**0.48 %** **(+/- 0.04)**	**0.33 %** **(+/- 0.04)**	**0.41 %** **(+/- 0.04)**	**0.18 %** **(+/- 0.04)**	**0.09 %** **(+/- 0.04)**
* Results are expressed in % of GM grains in harvest ** Case where fields are adjacent *** Values for seed impurity are estimations Changes are in bold.						

The contamination level of the smaller Farm 2' is, as expected, much higher than for Farm 2. Still the levels are below 1% without the need to change farming practices. Introducing a time lag of flowering time of 75 °days reduces cross-pollination levels considerably, the overall contamination rate is still very close to 0.1%.

3.2.10 Farm 3: Non-intensive conventional grain maize production

Farm 3 is situated in Central France (Beauce). Maize is grown in rotation with other crops and accounts for about 20% of the farm area each year, actually one field per year. GM and non-GM might be grown alternately, but not in the same year. Machinery is shared with neighbours and a central continuous drying facility is used.

The average distance between maize fields is already 500m. To reduce cross-pollination further only a time-lag between GM and non-GM flowering dates would be a possible measure. That time-lag will be limited by the varieties used (early to mid-early), 25 degree days and 50 degree days. Results are presented in Table 29.

With current farming practices contamination levels are near 1%. To ensure a harvest below 1% contamination post-harvest handling of the crop has to be changed. Here the "isolation by contract" strategy and fully dedicated material seem the most suitable (total contamination expected 0.51% +/- 0.3%). Additional reduction of in-field contamination by introducing a lag in flowering time would not help to achieve a 0.1% threshold.

Table 29: Estimation of contamination levels for Farm 3
(50% GMOs in the region)*

Farm 3	Current practices	Changes introduced to limit cross pollination.	
		Difference of flowering time (25 °days)	Difference of flowering time (50 °days)
Seed***	0.1 (+/- 0.05)	**0.3 (+/- 0.3 %)**	**0.3 (+/- 0.3 %)**
Drilling / Cultivation equipment	0	0	0
Cross-pollination	0.15 (+/- 0.05)	**0.1**	**0.03**
Volunteers / Harvesting / Transport from field to storage facility / Transport from farm	0.05	0.05	0.05
Storage -Cleaning Drying	0.5 (+/- 0.4)	**0.01****	**0.01****
Total contamination expected	0.8 % (+/- 0.5 %)	**0.46 %** **(+/- 0.3 %)**	**0.39 %** **(+/- 0.3 %)**
* Results are expressed in % of GM grains in harvest ** If the material is fully dedicated *** Values for seed impurity are estimations Changes are in bold.			

3.2.11 Farms 4 and 4': Organic grain maize production in Central France

Farm 4 is similar to Farm 3, except that it is an organic farm. Farm 4' represents a smaller version of Farm 4 to test for the influence of farm and plot size (15 ha and 3 ha, respectively). As expected the overall contamination level is much lower than for Farm 3 and well below 1% (Farm 4: 0.17%; Farm 4': 0.32%). Cross-pollination presents the main source of contamination. A difference in flowering time of 50 °days reduces cross-pollination, but a 0.1% threshold still cannot be met with sufficient security (Farm 4: 0.13%; Farm 4': 0.09%).

3.2.12 Contamination levels with 10% GMOs in the region

Simulations considering a GMO share of 10% in the region show as expected a lower cross-pollination level for all farms. The resulting contamination levels are presented in Table 30 in comparison to a GMO share of 50%. Other contamination sources apart from cross-pollination have not been changed.

Apart from Farms 1 and 5, where maize is intensively cultivated, all farms are well below 1% contamination in the case of 10% GM maize in the region. The contamination levels are always above the 0.1% threshold. However, it should be noticed that the estimated post-harvest contamination levels have not been adapted to the 10% situation. To reduce contamination levels the same measures as proposed in the case of 50% GM maize in the region can be applied (results not shown).

Table 30: Comparison of contamination rates on farm types for GMO shares of 10% and 50% in the region

	Farm type	1	2	2'	3	4	4'	5
10 % GMOS in landscape	**Current practices** **Cross-pollination (%)***	0.25	0.02	0.1	0.03	0.04	0.05	0.2
	Total rate of contamination expected** (%)*	1 (+/- 0.35)	0.1 (+/- 0.07)	0.18 (+/- 0.04)	0.68 (+/- 0.5)	0.09 (+/- 0.09)	0.12 (+/- 0.04)	0.95 (+/- 0.2)
50 % GMOS in landscape	**Current practices** **Cross-pollination (%)***	1.5	0.1	0.5	0.15	0.15	0.25	1.0
	Total rate of contamination expected (%)*	2.25 (+/- 0.35)	0.16 (+/- 0.07)	0.58 (+/- 0.04)	0.8 (+/- 0.5)	0.17 (+/- 0.09)	0.32 (+/- 0.04)	1.75 (+/- 0.2)

*   Results are expressed in % of GM grains in harvest
**   The rate of contamination via cross-pollination has been changed to take into account the 10% GMO
        share in the landscape. The estimations of other routes of contamination have been kept.

3.2.13   Costs of changed farming practices

Following the results of the different simulations, discarding part of the harvest has been shown to be a rather inefficient solution to the problem of cross-pollination, at least when the fields are adjacent to each other as was assumed in the calculation. In contrast, increasing isolation distances and introducing varieties with different flowering times seem to be efficient measures. Additionally, depending on the farm type, post-harvest handling of the grain needs to be changed.

Increasing isolation distances is difficult to assess in economic terms. This measure is connected with a restructuring of the farm or a good co-operation between farmers. An estimation of these costs would need additional economic analysis that was not in the scope of this study. The same is true for the creation of production islands.

The additional costs of an introduction of maize varieties with differing flowering times can be estimated. Later varieties are generally higher yielding but have also the commercial risk of yield losses due to adverse weather conditions later in the year. As the GM variety would be the earlier variety, the yield loss connected to the generally lower yield has to be borne by the GM maize grower. The cost calculation is based on the yield difference between the earlier and the later variety (Table 31).

Table 31: Yield losses and costs due to change of flowering time (Farm 1)

Change of flowering time from	very late to late	late to mid early
Difference in flowering time (°days)	25 – 50	50
Yield of very late / late variety (t/ha) (1)	15.48	13.40
Yield of late / mid early variety (t/ha) (1)	13.40	12.94
Yield losses (t/ha)	2.08	0.46
Prices of maize(€/t) (2)	98.7	98.7
Cost of losses (€/ha)	205.3	45.4
Cost of losses (€ / t)	15.3	3.5
Source: (1): AGPM trials 1999 & 2000 [33]; (2): Les quatre saisons Sud-Adour – n° 83. Averages of 3 years (1997 to 1999)[34]		

The yields of the different maize varieties refer to non-GM varieties, assuming that there are no significant yield differences between GM and non-GM varieties. Data are from small-scale field trials with optimisation of plant protection. Thus, yields are higher (10 to 15 %) than those achieved in normal conditions in a farmer's plot. However, using these data is the best way to have a proper comparison of yields (no climate or soil differences, same management for the whole trial).

Regarding Farm 1, in the case of a time-lag of flowering of 50 °days changing the GM maize variety from late to mid-early, potential losses account to about 45.4 €/ha (5% to 6% of the gross margin plus subsidies). These costs refer to the earlier GM variety. Changing the GM maize variety from very late to late (time-lag 25 to 50 °days), yield losses are much higher and this is reflected in the costs: 205.3 €/ha, which represents 20% to 25% of the gross margin plus subsidies. Thus costs are variable and might even become higher, if we assume a time-lag of 75 °days. As the study is based in the hypothesis that GM crop farmers are not requested to use measures to minimise contamination, any costs that might arise are assumed to be incurred by the non-GM crop farmer. Probably a combination of the GM crop farmer growing an earlier variety and the non-GM crop farmer growing a later variety could minimise additional costs. For the calculation of additional costs for Farm 1 using late varieties, the change from late to early variety was used (45.5 €/ha).

Changes of farming practices concerning post-harvest require a restructuring of the farm and/or investments in drying and storage facilities, including partly the other farms and CSO. An estimation of the costs would have gone beyond the scope of this study due to its complexity.

3.2.14 General conclusion for maize

Tables 32a and 32b provide an overview of proposed practices for each farm to achieve the assumed thresholds of 1% and 0.1%. At this point it should be stressed that the model MAPOD is suited for comparing contamination values of simulated practices. The absolute values obtained are less precise (although they are accurate in the order of magnitude) and according to preliminary experiments to adjust the model, may be underestimating the contamination values. The results, therefore, are best for ranking the effects of different farming practices in reducing contamination.

---

[33] AGPM, 2000. Valeur culturale des variétés inscrites en 2000 au catalogue officiel et disponibles en France en 2000 ; AGPM, 2000. Etude des coûts de production et évolution.
[34] Les 4 saisons Sud-Adour - Printemps 2000. N°83.

Table 32: Summary of contamination levels in grain maize production in conventional and organic agriculture with current and with recommended farm practices
(10% GMOs in the region)

Farm type	Conv. 1 (10% GMOs also grown on the farm)	Organic 2 large	Organic 2' small	Conv. 3 (10% GMOs also grown on the farm)	Organic 4 large	Organic 4' small	Conv. 5 (10% GMOs also grown on the farm)
Current practices Total rate of contamination expected	1 % (+/- 0.6 %)	0.1 % (+/- 0.07 %)	0.18 % (+/- 0.04%)	0.68 % (+/- 0.5 %)	0.09 % (+/- 0.09 %)	0.12 % (+/- 0.04 %)	0.95 % (+/- 0.2 %)
Best change of practices to meet 1% threshold	Isolation distance 200m	Current practices	Current practices	Post-harvest management (2)	Current practices	Current practices	Isolation distance 100m
Total rate of contamination expected	0.63% (+/- 0.3 %) (1) (3)			0.39% (+/- 0.3 %) (1)			0.68% (+/- 0.3%) (1) (3)
Additional costs (€ / ha)	n.d.	0	0	n.d.	0	0	n.d.
Best change of practices to meet 0.1 % threshold	Impossible to achieve						

(1)   Assuming that the percentage of seed impurities is 0.3 % (+/- 0.3 %)
(2)   Changes consist of dedicating a silo or systematically declassifying the batches dried after emptying the drying unit between two kinds of maize.
(3)   An alternative measure would be to introduce a difference in flowering time of 50 ^{o}days with additional costs of 45.5 €/ha (0.6 % +/- 0.45%). This would require GM maize producer to change the variety they grow and probably be more difficult to implement.
n.d.   not determined

The main factors influencing local levels of contamination seem to be
- seed impurity
- the relative proportion of maize in the agricultural landscape
- the relative size of fields (pollen emitter and receptor) and field pattern
- the process of collecting, drying and storage of the harvested grain.

Under the conditions selected for studying grain maize production, a very low threshold of 0.1% cannot be achieved, neither with current nor with changed practices, neither for organic nor for conventional farms, even if the GMO share in the region is only 10%. Potential seed impurities as well as post-harvest admixtures because of farm logistics render a very strict segregation impossible.

The conventional farms in this study would have to change practices for complying with a threshold of 1%, even if only 10% of maize grown in the region would be GM. For Farms 1 and 5 an increase in isolation distances would present a solution, however, considering the regional structure and the intensive cultivation of maize, this might not be easily feasible. The introduction of different flowering times for GM and non-GM varieties would probably be an alternative solution, which also would require co-operation.

Table 32 cont.: Summary of contamination levels in grain maize production in conventional and organic agriculture with current and with recommended farm practices (50% GMOs in the region)

Farm type	Conv. 1 (50% of GMOs also grown on the farm)	Organic 2 large	Organic 2' small	Conv. 3 (50% of GMOs also grown on the farm)	Organic 4 large	Organic 4' small	Conv. 5 (50% of GMOs also grown on the farm)
Current practices							
Total rate of contamination expected	2.25 % (+/-0.6 %)	0.16 % (+/- 0.07%)	0.58 % (+/- 0.04%)	0.8 % (+/- 0.5%)	0.17 % (+/- 0.09%)	0.32 % (+/- 0.04 %)	1.75 % (+/- 0.2%)
Best change of practices to meet 1 % threshold	50 ° days difference in flowering time + post-harvest management	Current practices	Current practices	Post-harvest management (2)	Current practices	Current practices	Minimum distance 200m + post-harvest management
Total rate of contamination expected	0.66 (+/- 0.3 %) (1)			0.51 (+/- 0.3 %) (1)			0.69% (+/- 0.3%) (1)
Additional costs (€ / ha)	45.4 + n.d.	0	0	n.d.	0	0	n.d.
Best change of practices to meet 0.1% threshold	Impossible to achieve						

(1)   Assuming that the percentage of seed impurities is 0.3 % (+/- 0.3 %)
(2)   Changes consist in dedicating a silo or systematically declassifying the batches dried after emptying the drying unit between two kinds of maize.
n.d.   not determined

The results are strongly influenced by the assumed seed impurity of at least 0.3% for conventional farms. The Scientific Committee on Plants considered in its opinion on adventitious presence of GM seeds in conventional seeds from 13 March 2001[35], that the threshold of 0.3% discussed for maize will only be achieved under ideal conditions. Following that opinion, a certain contamination level had to be considered also in this study. But even if seed is assumed to be pure, other sources of contamination prevail, which still render 0.1% very difficult to achieve.

The organic farms in this study, even the small ones, have no difficulties in achieving a threshold of 1%. This is based on the assumption that the used (organic) seed is comparatively pure and that the post-harvest segregation is working well. Still, also organic farms have difficulties in achieving with some security a stricter threshold like 0.1%.

---

[35] Scientific Committee on Plants, opinion from 13 March 2001 available at
http://europa.eu.int/comm/food/fs/sc/scp/out93_gmo_en.pdf

3.3 Potato for food production

3.3.1 Crop production and use

Potato (*Solanum tuberosum*) is a perennial grown for its tubers, which develop at the roots of the plant and are thus a clone of the mother plant. Potatoes are grown as an annual crop from vegetative tubers, known as seed tubers or seed potatoes, which can persist in the soil when the plant dies back each autumn. Concerning true seed production, the degree to which flowering occurs, the duration of flowering and the response of flowering behaviour to environmental conditions are greatly influenced by the different cultivars. Flower development does not ensure fruit set, and pollen sterility is frequently encountered under field conditions in parts of Europe.

The EU is currently the second largest producer of potatoes in the world after China (16% and 19% of world production, respectively). Certified seed tubers are produced by specialist growers on farms isolated from the main crop production areas and in zones such as Scotland where virus infection can be minimised. Some farmers also save small tubers from healthy crops grown from certified seed tubers and use these for their own seed (UK 27% of potatoes planted).

In 1999 virus- and insect-resistant GM potatoes were grown on about 40,000 ha world-wide (USA 30,000 ha, Canada 10,000 ha, Romania and Ukraine 1,000 ha each)[36]. In the European Union no GM potato has yet been approved for placing on the market (November 2001), although one application is pending for a GM potato with altered starch composition. GM potatoes seem not to be as successful as other GM crops, widely used mainly by farmers in the USA and Canada, since Monsanto is said to reduce research activities and marketing of GM potatoes[37].

Potatoes are predominantly used for direct human consumption today. First early and second early potatoes are grown to give the slightly sweeter, less starchy 'new potatoes' in June, July and August. These potatoes are usually boiled. They represent about 8.4% of the overall potato production in the EU. Main crop potatoes are lifted at the end of the summer either for direct marketing, processing or storage. They are more versatile and can be baked, fried or boiled. Particular varieties are grown for certain culinary or processing requirements.

3.3.2 Routes of contamination

3.3.2.1 Pollen-mediated gene flow

Potato is mainly self-pollinating, with estimates of the rates of cross-pollination under field conditions ranging from 0 to about 20%[38]. Wind is considered a more important vector than insects in effecting cross-pollination. Field trials showed minimal dispersal of pollen beyond the immediate vicinity of potato fields (5m to 10m). Pollen dispersal from a GM potato field is unlikely to affect the receiving crop directly as the process of fertilisation and seed production does not affect the harvested product. Since the crop is planted with seed tubers rather than true seed, a GM contaminant would not be transmitted to progeny crops.

---

[36] European Commission, DG Agriculture 2000. Economic impacts of genetically modified crops in the agri-food sector.
[37] ESA Newsletter May 2001. http://www.entsoc.org/newsletter/2001/May/window.htm
[38] Plaisted, R. L. (1980) Potato. In: Fehr, W. R. & Hadley, H. H. (eds.) Hybridisation of crop plants. American Society of Agronomy, Madison, pp. 483-494.

3.3.2.2 Seed-mediated gene flow

Many potato cultivars can produce true potato seed, which can survive in field conditions for at least eight years. Being the product of cross-pollination, these seeds could potentially contaminate subsequent potato crops.

Volunteer potatoes (groundkeeper) are a serious weed problem on farms. True seed, unharvested tubers, and damaged tuber pieces can survive in the ground and sprout the following year to produce weed plants in subsequent crops. These in turn will produce small tubers, which can persist to contaminate crops in subsequent years. Potato volunteers are hard to control with herbicides in broad-leaved crops e.g. peas, beans, sugar beet, and are difficult to remove by hand. Failure to control volunteers can allow potato plant numbers to be maintained or increased through a rotation so that they subsequently contaminate the next potato crop.

Feral plants present little or no probability of acting as either a GM pollen source or recipient. Data show that natural gene flow from potato to its wild relatives *S. nigrum* and *S. dulcamara* is highly unlikely.

3.3.2.3 Adventitious admixing

Probability of contamination during cultivation and harvesting is considered to be rather low. In contrast, post-harvest handling of the crop (storage, grading, washing and packing) could be a major source of contamination.

3.3.2.4 Seed tuber purity

Certified seed tubers are generally produced on specialist farms in isolated sites with high standards of segregation and varietal purity. Mostly likely to be contaminated are seed tubers produced in regions where GM crops are extensively grown and seed tubers from merchants who also produce seed tubers of GM varieties. At present there is no commercial GM potato production in Europe, which makes it highly unlikely that seed and seed tubers produced in Europe will be contaminated.

3.3.3 Typical farm types

Potato production has been studied using two different farm types. The conventional Farm 1 is situated in the East Anglia region of England or in Niedersachsen, Germany. It grows GM and non-GM potatoes for direct marketing and processing in 5 to 6 year rotations. The farm is well equipped with machinery and has a central facility for washing, grading, boxing and packing potatoes, which is also used by neighbouring farms. The farmer saves seed tubers of certain varieties. The organic counterpart of this farm is represented by Farm 2.

Farm 3 represents a typical conventional farm that grows early potatoes, being situated in south-west England or north-west Germany. Certified seed tubers are used for about half of the crop, the rest is grown from farm-saved seed tubers. Different varieties are often grown in the same field in segments to meet market requirements. The potatoes are bagged or boxed on the farm and transported to a cooperative where the crop may be bulked with other crops. The farm is well equipped with machinery but occasionally shares it with its neighbours. Farm 4 represents the organic counterpart of Farm 3.

The farm characteristics are summarised in Table 33.

Table 33: Potato farm type characteristics

Farm	1	2	3	4
	Conventional	Organic	Conventional	Organic
	Potatoes grown for direct marketing and processing		Potatoes grown for early production and direct marketing	
Region	East Anglia (UK) & Braunschweig (D)		South West England, North West Germany	
Farm size	300 ha (UK) / 150 ha (DE)		75 ha	
Potatoes/AUA	20 %	17 %	20 %	
GM varieties	20 – 30 %	No	50 %	No
Seeds	Certified & saved	Certified & saved (majority)	Certified & saved (half / half) May exchange seeds with neighbours	Certified & saved (isolated field on the farm)
Rotation	5 to 6 years	Minimum 6 years	5 years	Minimum 6 years
Equipment for de-stoning planting, ridging & bed forming	Yes, may be shared with other farmers	Yes	Yes, may be shared with other farmers (when breakdowns)	Yes, may be shared with other farmers
Harvester	2	Yes	Yes, may be shared with other farmers (when breakdowns)	Yes, may be shared with other farmers
Equipment for washing, grading, boxing, packing	Yes, may be shared with other farmers	Yes	Yes, may be shared with other farmers (when breakdowns)	No
Storage	Yes	Yes	Yes	No
Segregation	Between potato varieties	Already implemented (organic farming)	No	Already implemented (organic farming)

3.3.4   Estimation of contamination levels

In the case of potato, no computer model was available to calculate potential in-farm contamination levels. Instead, the estimations were done by a panel of experts in seed certification and agronomy from the National Institute for Agricultural Botany (NIAB, UK) and the Institut National de la Recherche Agronomique (INRA, France). The estimations are based on the assumption that 25% to 50% of GM potatoes are grown in the region and on the conventional farms.

3.3.5   Evaluated measures to reduce contamination

3.3.5.1 Cross-pollination

Almost all potato varieties flower during the course of the crop cycle, but European crops are very often sterile. The probability of cross-pollination leading to contamination is therefore minimal. Still there are a few fruiting varieties (Saturna, Kaptah Vandel), which should not be planted close to GM potatoes (isolation distance more than 20 m). The cultivation of GM potatoes after this type of variety should also be avoided if groundkeepers are not completely controlled. Hybridisation may occur between groundkeepers and subsequent GM crops. If it is not possible to follow these recommendations, then strict management of groundkeepers must be observed (see below).

3.3.5.2 Groundkeepers

Groundkeepers in cultivated fields may be controlled using herbicides and/or by modifying rotations.

In conventional production, groundkeepers are difficult to reduce in dicotyledonous crops due to the lack of selective herbicides. They are easier to control in monocotyledonous crops (with methyl metsulfuron, for example). The introduction of a cereal in the rotation after potato, as in the rotations practised in northern France (potato/winter wheat/sugarbeet/potato) facilitates this type of technical solution.

Increasing the duration of the rotation is another possible means of control. A return to potatoes after seven years (or more) strongly decreases the number of groundkeepers. This measure could be combined with a destruction of all waste material (damaged and undersized tubers) remaining in the field after harvest rather than storage on the edge of the field as is usually the case.

The application of herbicides is prohibited in organic agriculture. One technical solution to the problem involves modifying the rotation to introduce crops in which mechanical weed elimination (by smothering or hoeing) is both possible and effective: fallow or weeded plants. Ploughing is also of use to manage weeds and among them, groundkeepers. The destruction of waste remaining in the field is also recommended.

3.3.5.3 Saved seed tubers

To ensure purity of farm-saved seed tubers isolated and dedicated fields for each kind of saved seed tuber (GM or non-GM) should be used. The farmer should record the type of crop and cultivation practices in each field of the farm and should control groundkeepers in the rotation (preventing the co-existence of several types of GM groundkeeper in the field). If this should not be possible a very strict control of groundkeepers must be practiced (see above).

3.3.5.4 Post-harvest contamination

Post-harvest contamination is a major commercial risk for farms on which both non-GM and GM varieties are grown. One of the key elements to minimise mixing is the precise recording of what is grown in each plot, effective co-ordination of harvesting and labelling of the various batches. A system of batch traceability should be developed. Bulk storage should be avoided, instead storage in boxes should be employed. Such a system is already in place for potatoes grown under contract with industry. This type of segregation could also be developed for farmers producing potatoes for starch production or potatoes for direct consumption.

3.3.6 Farm 1: Conventional potato production for direct consumption and processing

For Farm 1, which cultivates both GM and non-GM varieties, there is a probability of contamination at all stages of production: cultivation, harvesting, collection and storage. To reduce the main source of contamination, groundkeepers, the introduction of a longer rotation with an additional cereal after potato is recommended. All the waste remaining in the field should be composted or, preferably, destroyed (see above).

Since the farm has its own warehouses it should be possible to segregate GM varieties after the harvest. This would require adequate labelling and packing of GM and non-GM batches.

The estimated contamination levels for Farm 1 are summarised in Table 34. With current farming practices a production below a contamination level of 1% seems to be possible. The estimated contamination level, however, lies above 0.1%. Even by following the recommendations, a very low contamination level (< 0.1%) might not be achieved.

3.3.7 Farm 2: Organic potato production for direct consumption and processing

For Farm 2, the post-harvest manipulation of the crop, sorting (washing and packing) presents a source of contamination, because equipment is shared with producers of conventional potatoes. Contamination levels are already very low because segregation is in place (with respect to conventional production).

A major source of contamination is groundkeepers. The rotation on Farm 2 is already long and no other measures than those already used are available to decrease the number of groundkeepers present in the various crops during the rotation. The introduction of a fallow period during the rotation (combining the maintenance of soil fertility and management of weeds) or of a crop that can be weeded by hoeing, as well as the systematic destruction of all waste material remaining in the field is recommended.

The estimated contamination levels for Farm 2 are summarised in Table 34. As expected the contamination level for the organic counterpart of Farm 1 is estimated to be considerably lower, about 0.1%. Since there is a small probability of contamination connected to every cultivation step, this contamination level can hardly be reduced.

3.3.8 Farm 3: Conventional early potato production for direct consumption

Farm 3 has problems with groundkeepers and post-harvest management, but also with the purity of farm-derived saved seed tubers. Although produced, in principle, in isolation, these seed tubers may be exchanged with neighbours. Farm 3 also has potential problems associated with the sharing of harvesting and de-stoning equipment.

The recommendations for the management of groundkeepers are the same as for Farm 1. For post-harvest potato management, a physical or temporal separation of different varieties is recommended with cleaning of sorting and packing machinery between the different types of variety. Planting and harvesting dates could be manipulated so that all GM varieties are harvested together. Exchanges of seed tubers between farmers should be avoided. Sharing of equipment makes rigorous cleaning necessary.

The estimated contamination levels for Farm 3 are summarised in Table 34. Farm 3, because of saving seed tubers and growing different varieties on a segmented field, including GM potatoes, is assumed to have the highest probability of contamination of all studied farms. Still, the contamination level is estimated to be well below 1%. When following the recommendations given, a further reduction of contamination levels can be achieved, but it seems to be impossible to achieve a level below 0.1%.

3.3.9 Farm 4: Organic early potato production for direct consumption

The contamination level of Farm 4 depends mainly on the purity of the seed tubers and on the number of groundkeepers in the field. As the seed tubers are certified for use in organic agriculture or produced in isolated fields on the farm, there seems to be no possibility to decrease the levels. The groundkeeper problem is also complicated, as for Farm 2, because the rotation is already long. Certain types of cultivation (grassland for example) favour the control

of groundkeepers by smothering. One possible solution is the introduction of a fallow period or of a plant that can be weeded mechanically.

The estimated contamination levels for Farm 4 are summarised in Table 34. Farm 4 is assumed to have a lower contamination level as Farm 3, but estimated at 0.16% it is still above 0.1%. Since segregation is already in place, only groundkeepers could be further reduced, which would lead to only minor changes of the contamination level.

Table 34: Estimated contamination levels for Farms 1 to 4*

Farm type	Farm 1		Farm 2		Farm 3		Farm 4	
	current	adapted**	current	adapted**	current	adapted**	current	adapted**
Seed and seed production	0.05 (+/- 0.02)	0.05	0.02	0.02	0.1 (+/- 0.05)	0.05	0.04 (+/- 0.02)	0.04
Planting	0.02	0.02	0	0	0.03	0.03	0.01	0.01
Cultivation equipment	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Cross-pollination	0	0	0	0	0	0	0	0
Groundkeeper	0.1 (+/- 0.08)	*0.01*	0.02 (+/-0.02)	*0.01*	0.1 (+/- 0.08)	*0.01*	0.04 (+/- 0.03)	*0.01*
Harvesting	0.02	0.02	0.01	0.01	0.1	*0.05*	0.02	0.02
Transport from field to farm	0.02	0.02	0.01	0.01	0.04	0.04	0.01	0.01
Storage Cleaning	0.08 (+/- 0.05)	*0.01*	0.01	0.01	0.1 (+/- 0.08)	*0.05*	0.01	0.01
Packing	0.04	*0.01*	0.01	0.01	0.04	*0.02*	0.01	0.01
Transport from farm	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01
Total contamination expected	0.36% (+/-0.15%)	**0.17%**	0.1% (+/-0.02%)	**0.09 %**	0.54% (+/-0.21%)	**0.28%**	0.16% (+/-0.05%)	**0.13%**

*   Contamination levels are expressed as % of GM potatoes in the harvest;
** Adapted as explained in text

3.3.10 Costs of changed farming practices

Costs have been estimated for the introduction of a batch traceability system. The costs to equip one storage building containing 500 to 2500 tonnes of potatoes are calculated using the following data (Table 35).

Table 35: Costs estimation for a traceability system in potato production*

Type of material	Costs (€)	Life length (years)	Costs / year (€)
Boxing equipment	30500	10	3050
Palletising (including float)	22000	5	4400
Computerisation of production	7600	5	1520
Traceability total cost	**60100**		**8970**

*   For one storage building containing 500 to 2500 tonnes of potatoes;
     Source: personal communication, ITCF ITPT

The annual cost for a traceability system is estimated at 8970 €. For Farm 1, these costs correspond to 299 €/ha or about 13% (DE) or 7% (UK) of the gross margin plus subsidies. For Farm 3, the costs are higher, 598 €/ha, representing 21% (DE) or 8% (UK) of the gross margin plus subsidies.

3.3.11 General conclusion for potato

Compared to oilseed rape or maize, potato seems to be a rather simple crop concerning probability of contamination, based on the different biological characteristics of the crop. The main problems are connected to volunteers and post-harvest handling of the crop. Contamination levels are in general estimated to be low (< 1%), even though a threshold of 0.1% would be very difficult to achieve. The assumption of baseline contamination levels of 0.01% for nearly each production step makes this impossible. The recommended change of farming practices could be used to further reduce contamination levels to increase a security margin, but are assumed to be not effective enough to enable a production below a 0.1% contamination level.

Because no computer model was available for potato, contamination levels for a situation with 10% GMOs in the region was not carried out. In general, the probability of transgenic groundkeeper, seed impurities as well as mixing during the post-harvest handling of the crop would be reduced and accordingly, contamination levels would be expected to be lower.

4   MONITORING NON-GM AGRICULTURAL PRODUCTION

4.1 Detection and quantification of GMOs

There is a need to monitor and verify the presence and the amount of GMOs in agriculture crops and therefore a need for robust analytical methods capable of detecting, identifying and quantifying either DNA introduced or the protein(s) expressed in transgenic plants because these are the components that are considered as the comparative elements between GM and non-GM crops. The development of reliable analytical methods is essential for the good implementation of labeling rules.

This chapter presents in the first part, a detailed state-of-the-art in detection and quantification techniques, in a second part a review of the needs and procedures for harmonized methodologies in GMO analysis, and in the last part current techniques used for on-farm analyses and estimated costs.

4.1.1   State-of-the-art in detection and quantification techniques

The analysis of raw materials is generally carried out with the polymerase chain reaction (PCR method), a DNA analysis method. Protein detection methods are also used for raw materials, mainly immunological assays such as the enzyme-linked immunosorbent assay (ELISA). Processed foods are generally analysed with the PCR method. Although much progress has been achieved in the development of genetic analysis methods, such as those based on the use of PCR, several other analytical technologies that can provide solutions to current technical issues in GMO analysis are emerging. However, so far only PCR in its different formats has found broad application in GMO detection/analysis as a generally accepted method for regulatory compliance, mainly in Europe.

4.1.1.1 DNA analysis methods

DNA extraction methods
For the DNA analysis, the first step is the extraction of DNA from plant material. With a representative field sample and after adequate homogenization, aliquots between 100 mg[39] and 350 mg[40] are adequate for DNA extraction procedures in the laboratory. A vast range of methods is available for DNA extraction. Currently, three different approaches of DNA extraction from plant material and plant-derived products are favored for GMO detection: the CTAB method (cetyltrimethylammonium bromide used as cationic surfactant), the DNA-binding silica column method (various commercially available kits), or a combination of the two. They give low yields but satisfactory quality and purity of DNA.

The CTAB method procedure is part of the official protocols for GMO detection according to the German Food Act LMBG §35 (L24.01-1, 1997; L23.01.22-1, 1998; L25.03.01, 1999). It provides a good separation of DNA from polysaccharides. The use of DNA-binding silica columns (one of the commercially available kits) is described in the official Swiss method for GMO detection. However, it has been reported that polysaccharides tend to bind to silica columns affecting the efficiency of the separation.

Extraction of DNA from complex matrixes or food products is not always successful. Failures in extracting detectable DNA levels have so far been reported for soybean sauce, refined

---

[39] Pietsch K, Waiblinger HU, Brodmann P, Wurz A (1997) Dtsch Lebensm Rundsch 93(2):35–38
[40] Zimmermann A, Lüthy J, Pauli U (1998) Z Lebensm Unters Forsch 207:81–90

soybean oil[41], and distilled ethanol produced from GM potatoes[42]. However, method optimisation has allowed Hellebrand et al.[43] to extract fragments of GM DNA from cold-pressed oil as well as in samples of refined rapeseed oil, although in the last case the DNA could not be identified unequivocally. Pauli and co-workers were able to extract detectable DNA levels from a large variety of food products and processing stages, but did not succeed in extracting it from refined sugar and oil[44].

PCR detection

The detection of DNA from GMOs is possible using PCR. The principle of PCR is based on the million-fold amplification by an enzyme (a thermophilic polymerase) of a specific target DNA fragment framed by two primers[45]. It is a multiple-process with consecutive cycles of three different temperatures, where the number of target sequences grows exponentially according to the number of cycles. The cycle is repeated 20 to 50 times, depending on the amount of DNA present and the length of the amplicon (amplified DNA fragment).

New thermophilic polymerases have been placed on the market (e.g. Ffu, Pwo, Tma, Tli, Tfl) but both *Taq* and Ampli*Taq* DNA polymerases remain the enzymes of choice for GMO analysis (5' to 3' exonuclease activity).

Confirmation/verification of the identity of the amplicon is necessary and can be done by gel electrophoresis (completed with restriction endonuclease profile), by Southern blot assay, by a second round of PCR cycle (also called nested PCR) and by sequencing the PCR product (most reliable way but only few laboratories are equipped to carry out this approach routinely).

The efficiency of the PCR depends on DNA quality and purity. DNA purity can be severely affected by various contaminants in food matrices like substances present in the original material or chemicals used during DNA extraction procedure. DNA isolated from processed foods and certain agricultural matrixes is usually of low quality, and available target sequences may be rather short (e.g. 100-400 bp for soybean protein preparations and processed tomato products).

The practical limit of detection has been claimed by one group[46], for their PCR experiments, to be of 0.1% GMO/non-GMO (w/w) (20 times higher than the theoretical detection limit of 0.005% GMO/non-GMO (w/w)). No claims concerning limit of detection have been supported by appropriate validation studies, moreover the accuracy of the method is certainly dependent on the type of GMO, food matrix and processing involved and finally the analyses of samples containing a low concentration of GMOs may even show a greater error.

PCR methods for GMO identification

For the identification of a GMO by PCR, the analyst must know the nucleotide sequences at both ends of the target DNA in order to design oligonucleotide primers. The choice of the oligonucleotide primers will also depend on the objective of the PCR analysis.

For routine screening purposes, one should focus on target sequences that are characteristic for the group to be screened. Genetic control elements such as the cauliflower mosaic virus 35S promoter (P-35S), the *Agrobacterium tumefaciens* nos terminator (nos3'), neomycin-phosphotransferase II (nptII) are present in many GMOs currently on the market. The first GMO screening method was introduced by Swiss and German scientists and is based on the

---

[41] Meyer R, Jaccaud E (1997) In: Amado R, Battaglia R (eds) Proceedings 9th European Conference on Food Chemistry. Authenticity and adulteration of food – The analytical approach, vol 1. Interlaken, Switzerland 24–26 September 1997, pp 23–28; Pauli U, Liniger M, Zimmermann A (1998) Z Lebensm Unters Forsch 207:264–267

[42] Hübner P, Studer E, Lüthy J (1999) Food Control 10:353–358

[43] Hellebrand M, Nagy M, Mörsel JT (1998) Z Lebensm Unters Forsch A 206:237–242

[44] Pauli U, Liniger M, Zimmermann A, Schrott M (2000) Mitt Lebensm Hyg 91:491–501

[45] Primers are synthetic oligonucleotides, complementary to either one of the two strands of the target sequence

[46] Jankiewicz A, Broll H, Zagon J (1999) Eur Food Res Technol 209(2):77–82

detection of the P-35S and nos3' genetic elements. However, a few approved GMOs are not screenable/detectable with the P-35S or the nos3' primers and additional target sequences, are needed to guarantee a complete screening procedure. For unequivocal identification, primer selection has to be based on target sequences that are characteristic for the individual GMO, e.g. the cross-border regions between integration site and transformed genetic element of a specific GMO (the so-called edge fragments), or specific sequence alterations due to truncated gene versions (i.e. coda or altered codon usage).

Recently more emphasis is given to the development of event-specific methods, rather than screening methods.
Only a continuous survey of all data available on GMOs - especially the introduced genetic elements and their integration sites, not only for GM products approved for market release but also for any other GMO released for field trials worldwide – can guarantee a complete/comprehensive monitoring/detection of GMOs. Within the European Union preliminary efforts towards the establishment of a database providing at least part of the relevant information have already been made[47]. These efforts will be continued and extended within the European Commission Joint Research Centre (JRC) project "Development of a GMO register consisting of a database and accompanying bioinformatic tools designed for monitoring purposes as required under Directive 90/220/EEC" (contact person: Guy Van den Eede).

PCR methods for GMO quantification
The quantification of GMOs cannot be done by conventional PCR. Other PCR-based techniques, such as quantitative competitive PCR (QC-PCR) and real-time PCR have been developed to address the problem of establishing a relationship between the concentration of target DNA and the amount of PCR product generated by the amplification.

The analytical strategies to obtain quantitative information from PCR can be divided into two groups.
Quantitative competitive PCR (QC-PCR) and double quantitative competitive PCR (double QC-PCR) use the co-amplification of a target analyte with an internal standard to correct the decrease in reaction efficiency (E). By comparing the amount of amplified internal standard and target DNA, the starting copy number of the target DNA introduced into PCR can be determined. PCR-ELISA and real-time PCR use the measurement of the PCR amplicon at an early stage of the reaction, when the efficiency is still constant and the product concentration still correlates well with the concentration of the initial target molecules.

To estimate GMO concentrations in mixtures, the quantification of GMO DNA is normalized to a plant-specific reference DNA. Therefore GMO concentration can be expressed in terms of genome/genome ratio (g/g) or weight/weight (w/w) ratio of the non-GMO component.

There is currently an intense debate on how the GMO concentration should be expressed. At present, the argument is somewhat academic. Control laboratories first measure the DNA concentration in the sample, and then use equal amounts of DNA to measure the number of copies for a GMO-specific sequence and for a crop-specific sequence. The ratio of both, taking into consideration the respective number of copies per genome, gives the percentage of the GMO present (g/g). Opponents of this approach argue that it is very difficult to quantify DNA and that in addition, such a methodology can only give relative data. Currently however, there is no real valid proposal for substituting the genome/genome ratio with other, more manageable units of measurement. Often, the genome/genome ratio is mentioned to be equal to the DNA weight/weight ratio. This assumption is probably an oversimplification since the genome size of crops is not a constant value and since there might be a variation of up to 25% within individual plant varieties.

---

[47] DMIF-GEN (1999) Development of methods to identify foods produced by means of genetic engineering. EU-Project SMT4-CT96-2072. DMIF-GEN Final Report, 15 December 1999

Real-time PCR is a quantitative PCR that improves accuracy and specificity and is rapidly gaining popularity due to the introduction of several complete real-time PCR instruments and easy-to-use PCR assays. One of the most popular assays for real-time PCR is the Taqman® or 5'-exonuclease assay, which employs a fluorogenic probe (TaqMan® probe). Because the development of the fluorogenic reporter signal takes place only if both the PCR primers and the TaqMan® probe anneal to the target DNA, the specificity of real-time PCR detection is considerably higher than that of conventional PCR. The relative quantification of the target gene is made possible by preparing a standard curve from known quantities of an additional endogenous gene and extrapolating from the linear regression.

The growing number of commercially available real-time PCR machines is an indicator of the success of this technology. Presently, real-time PCR can be considered as the most powerful tool for the detection and quantification of GMOs in a wide variety of agricultural and food products.

In the real-time PCR, the amplification of the target DNA sequence can be followed during the whole reaction by indirect monitoring of the product formation. Therefore, the conventional PCR has to be adapted in order to generate a constant measurable signal, whose intensity is directly related to the amount of amplified product. Real-time detection strategies rely on continuous measurements of the increments in fluorescence generated during the PCR.

Real-time PCR methods have been published for quantification of GM material in different food ingredients. Also, the quantification of the GMO and non-GMO internal control can be done in a single tube (multiplex PCR). The multiplex PCR approach reduces the possibility of introducing variability and the occurrence of false positives. Since both amplification and detection are combined in one step carried out in a closed tube, the risk of cross-contamination with PCR amplification products is minimised. Nevertheless, the risk of contamination during the DNA extraction is not eliminated.

Besides the possibility of accurate quantification, the advantage of real-time PCR is the ability to increase the sample throughput in comparison to other quantification techniques as post-PCR analysis is reduced to data treatment. While multiplex PCR formats with an endogenous reference gene will be able to increase the accuracy, precision and throughput of the real-time PCR technique, a more comprehensive evaluation of real-time protocols and formats (including data treatment) needs to be performed in the near future, possibly through inter-laboratory ring trials (see Chapter 4.1.2.3).

Limit of quantification of PCR

The limit of quantification of PCR methods can be estimated. Assuming that the GMO has a binomial distribution, 299 maize kernels are needed to detect ≤ 1% GMO (± 20%) with a confidence of 95%[48].

However, it happens sometimes during DNA extraction process that in the final reaction mixture for DNA amplification, the total genome copy number is below the critical particle size (e.g. 299 maize kernels for PCR screening purposes at threshold of 1%). In that case, the relationship between sample size at the beginning and at the end of the experiment has been lost.

Kay and Van den Eede[49] discussed limits of detection in a recent article. When considering the plant genome, the DNA amount in the unreplicated, haploid nuclear genome of an organism is referred to as its C-value. The 1C value for wheat (*Triticum aestivum*), and soybean (*Glycine max*) is 17.352 pg (16,978 Mb) and 1.25 pg (931 Mb) respectively. Based on these 1C values,

---

[48] Ryman N (1999) Statistical assessment of the proportion of GM grains in bulk consignment. EU-Project No. B4-3040/98/000272/MAR/E2. Final report, 16 June 1999
[49] Kay S and Van den Eede G (2001) Nature Biotechnology 19, 5: 405

100 ng of DNA (which is the typical amount used in PCR) may contain approximately 8×10^4 copies of soybean genome, 3.8×10^4 copies of maize genome or 5.8×10^3 copies of wheat genome. This corresponds to a total of 80 genome copies for soybean, 38 genome copies for maize and 5 genome copies for wheat if only 0.1% of 100 ng of DNA is of GMO origin. Consequently, the theoretical detection limit (which is equivalent to one copy of unreplicated haploid genome) in a 100 ng DNA reaction is about 0.001%, 0.003% and 0.02% in the case of soybean, maize and wheat respectively. Levels of DNA below this threshold cannot be detected reliably in samples of this size. When possible, increasing reaction volumes and /or quantities for analysis is recommended.

<u>PCR methods for variety identification</u>
Analysis of plant and animal genomes using DNA markers is providing a multitude of practical applications such as plant or animal variety identification through DNA fingerprinting. The four principal approaches for fingerprinting varieties have been so far: Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), micro satellites or short sequence repeats (SSR) and Amplified Fragment Length Polymorphism (AFLP). All four approaches have some merits but also a few inherent disadvantages.

The RFLP is a laborious technique that relies on Southern blotting and results in the detection of fewer alleles than other methods. The RAPD approach is instead sensitive to reaction conditions and presents problems of reproducibility. The micro satellites strategy on its turn, provides high throughput data on polymorphism but requires lengthy studies involving cloning and sequencing to obtain information on flanking nucleotide sequences. The AFLP approach overcomes some of the disadvantages of many of these earlier techniques and thus is quickly becoming very popular among plant genome scientists. The AFLP involves the detection of 'presence' or 'absence' of restriction fragments rather than differences in their lengths. AFLP has been shown to discriminate between plants even in processed vegetal materials.

Interestingly, AFLP has been investigated for its potential in the combined identification of variety genotypes and the monitoring of very low levels of GM material. Recent experimental findings[50] indicated that the AFLP technology could be used for the detection of genetic modifications by using GMO-specific primer in conjunction with AFLP primers specific for the flanking genomic region.

The AFLP approach, which combines RFLP and RAPD techniques, has been developed by a private company. In respect to the previously developed techniques the AFLP approach presents many advantages. Even though it is highly informative, however, it requires multiple procedures, is costly, and demands the use of radioactivity.

4.1.1.2 Protein analysis methods

The specific detection of a novel protein synthesized by the transgene is an alternative for the identification of GMOs. However, genetic modification is not always specifically directed at the production of a new protein. In addition, certain proteins may be expressed at very low levels and only in specific parts of the plant, or expressed at different levels in distinct parts or during different phases of the physiological development, complicating the analysis. The expression levels of transgenic proteins in plants were reported to be in the range of 0% to 2% of the total soluble proteins. In most cases, however, the expression levels reported (e.g. for approved GM crops) are much lower than the upper limit of 2%.

Protein detection methods are based mainly on immunoassays. Since they require proteins with an intact tertiary or quaternary structure, these methods are mostly limited to fresh and unprocessed products.

---

[50] DMIF-GEN (1999) Development of methods to identify foods produced by means of genetic engineering. EU-Project SMT4-CT96-2072. DMIF-GEN Final Report, 15 December 1999

Immunoassays are analytical measurement systems that use antibodies as test reagents. Antibodies are proteins produced in the serum of animals in response to foreign substances (antigens) and specifically bind the substance that elicited their production. In the case of detection of GMOs, the antigen can be the newly synthesised protein. Prerequisite for the development of immunological detection methods is that highly specific antibodies directed against the protein to be detected are available. In addition, the sample or the protein of interest should not be significantly degraded or denatured.

The most common type of immunoassay is the Enzyme-Linked ImmunoSorbent Assay (ELISA), which utilizes an enzyme-labeled immunoreactant (antigen or antibody) and an immunosorbent (antigen or antibody bound to a solid support). A variety of methods (e.g. competitive binding) may be used to measure the unknown concentration of the antigen.

Several immunoassay-based methods, mainly ELISA, have so far been developed that are specific for gene products widely expressed in transgenic plants such as the enzyme neomycin phosphotransferase II (nptII), the enzyme 5-pyruvylshikimate-3-phosphate synthase (EPSPS), the *Bacillus thuringiensis* (Bt) insecticide Cry1Ab, and herbicide-tolerance phosphinotricin acetyltransferase (PAT) protein. A direct sandwich Enzyme-Linked ImmunoSorbent Assay (ELISA) for the specific detection of the protein CP4-EPSPS in Roundup Ready® soybean has also been tested and validated by Lipp and Anklam[51]. Preliminary results indicate that the method (performed by using a commercialized ELISA kit) is able to detect the presence of GMOs in raw soybean material at concentrations ranging between 0.3% and 5%. Newly developed kits are able to detect specific proteins in food crops, such as Bt Cry1Ab, Cry1Ac, Cry1C, Cry9C, EPSPS and PAT. However, differences may be observed in the expression level of the protein between crop varieties. Furthermore, the quantification of Cry proteins is made more challenging by the fact that EPSPS is naturally expressed in all plant species and that many different Cry proteins are used for genetic modification. The ELISA method used for detection of GMO is simple to perform, offers a high degree of automation and sample throughput.

Lateral Flow Strip tests are field variants of the ELISA method and use an antibody specific for the protein of interest, which is immobilized on a nitrocellulose strip. Newly developed commercial kits are widely used and can detect specific proteins as Cry1Ab, Cry1Ac, Cry9C. The Lateral Flow Strip tests offer qualitative tests of considerable practical value for field testing with simple laboratory set-up.

One of the major drawbacks of immunochemical assays is that the accuracy and precision can be adversely affected in complex matrixes, such as processed vegetal and food products. Indeed, many substances present in the extraction solution such as surfactants (saponins), phenolic compounds, fatty acids, endogenous phosphatases, or enzymes may inhibit the specific antigen-antibody interaction. Moreover, detection capability may be hampered when the transgenic protein is expressed at a very low level, is degraded or denatured by thermal treatment. The newly expressed protein may not be evenly present in the tissue of the plant. For instance, in maize the highest expression values for some proteins were mostly observed in leaves and not in grain. Finally the commercially available antibody may display poor binding affinity for the protein of interest.

4.1.1.3 Alternative techniques for GMO analysis

Microfabricated devices and microchips for DNA analysis are promising techniques that will allow in the future GMO analysts to deal with rapid development of GM plants with new and multiple genes/genetic control elements. New technologies resulting from the merger of chip-

---

[51] Lipp M, Anklam E (2000) J AOAC Int 83(4):919–927

based microsystems (as microarrays) and microfluidic systems[52] appear to be a promising area for GMO analysis applications. However, PCR protocols for GMO analysis are still affected by polymerase error, undesirable PCR artefacts and false negatives.

Microarrays of DNA (commonly known as "DNA chips") can be used for expression analysis, polymorphism detection, DNA sequencing and genotyping and allow simultaneous analysis of several thousand nucleic acids within the very small area of a glass slide. The microarray system saves time and costs while maintaining high precision and reproducibility. Microfluidic systems have applications ranging from reactions to separations and analysis and may finally lead to the development of micro Total Analysis Systems (mTAS) that perform the complete analysis including sampling and sample pre-treatment.

PCR-microsystems ("portable systems") are also developed with currently only few examples of microchip applications to GMO analysis but with many perspectives in the field of GMO analysis. Some examples of miniaturized PCR have been performed[53] (MATCI real-time quantitative PCR) and the use of microPCR portable systems can be envisioned in field detection of crop disease and point-of-use GMO screening, e.g. in the early steps of the supply chain, without the need for an expensive laboratory setting.

Other microtechnology methods for GMO analysis are under development (Surface Plasmon Resonance (SPR), use for biosensor technologies and "scanometric DNA array detection"). The advantages are fast-time responses, easy use and lower costs.

Nanoscale GMO analysis
Single cells isolated by flow cytometry or micromanipulation can provide sufficient amounts of DNA to allow PCR detection, although amplification of single-copy genes may be particularly challenging. Single Molecule Detection (SMD), for monitoring the chemical and physical properties of biochemical reactions of individual molecules in real-time, represents the most advanced frontier in analytical technologies. SMD was recently applied to ultra fast DNA sequencing, capable of identifying the four nucleotides in a DNA-sequence according to their fluorescence lifetime. This method of DNA sequencing presents several potential advantages over conventional sequencing technologies, for example the possibility of sequencing much longer DNA strands at higher speed, since the exonuclease can cleave many nucleotides per second.

A promising future perspective for SMD appears to be the detection and direct quantification of trace amounts of DNA by counting single molecules in sub-microlitre volumes of liquid, possibly leading to the development of "nanoscale GMO analysis" techniques.

4.1.2   A need for harmonised methodology

This section of the report discusses aspects that need to be considered while establishing criteria for sampling, sample preparation, and result interpretation and covers the procedures for validation of PCR methods and immunoassay analyses.

4.1.2.1 Sampling

Sample and sample preparations are crucial steps in the process of GMO analysis and the sample size is extremely important. A sample has to be representative of the batch/lot of the

---

[52] Sanders GWH, Manz A (2000) Trends in Analytical Chemistry 19:364–378
[53] Belgrader P, Benett W, Hadley D, Richards J, Statton P, Mariella R Jr, Milanovich F (1999) Science 284:449–450; Belgrader P, Smith JK, Weedn VW, Northrup MA (1998) J Forensic Sci 43:315–319

product from which it was taken, and the sample plan and sample size have to meet statistical requirements with respect to homogeneity and threshold limit up to which the result should be reliable. Sampling, sample size and homogenisation must follow a protocol that may vary between the type of material to be analysed.

The number of samples to be taken and the appropriate sample size depends on the level of homogeneity of a given sample and the actual targeted threshold limit for presence of GM material. For example for maize, a single sample of 299 kernels giving a negative result, might be sufficient to assure a threshold lower than 1% with 95% confidence. For a 0.1% threshold, the sample should be ten times higher (3000 kernels). The size of the sample is subject to discussion and several different sample sizes are proposed[54]. The different sample sizes reflect different assumptions and degrees of sophistication in the sampling strategy that can be feasibly applied.

Attention should be given also to the laboratory samples (i.e. the DNA extracted from the field sample). There is a lower limit to the limit of detection for any analytical system created by the unutilised behavior of DNA copies and the statistical nature of random sampling. The problems of limit of detection, sampling error and error induced by dilution series with laboratory samples should be taken into consideration when taking samples for analytical methods[55]. When concentrations are low, the sampling error becomes (proportionally) larger. When calculating the range of the expected number of copies in the analytical sample for estimates of GMO concentrations (expressed as w/w) of 0.1%, analytical samples of 100ng would produce no better than ~30% of the mean value, 95% of the time. Furthermore, given that this is purely sampling error, degradation in this result can be expected due to the imperfect behavior of a real analytical system.

When undertaking a dilution series, it is important to note that the assumption of sampling with replacement may no longer be valid, since the number of copies available becomes strictly finite. In conclusion, there is insufficient acknowledgement in the domain that repeated analytical samples drawn from a "homogenized" laboratory sample would not have identical proportions of GMO/non GMO copies.

4.1.2.2 Principle of method validation

Method validation is necessary to show that the method produces reliable and repeatable results. The process of validation allows the independent use of methods and produces results that are comparable between different laboratories.

Depending on the intended purpose of the analysis, i.e. qualitative screening or quantification, different validation parameters have to be evaluated. Moreover, these studies must be carried out according to harmonised international protocols (e.g. IUPAC, AOAC, ISO) and cover as wide a range of laboratories as is feasible, usually considered to be no fewer than eight.

However, since large-scale collaborative studies require a considerable level of effort and resources, they should be conducted only on those methods that have undergone appropriate pre-testing. The objective of this preliminary work is to define the performance characteristics of the method, and to set target values for the parameters to be evaluated in the validation trials. Alternatively, a method performance study could be used to establish if the performance of a method (or, more commonly, test kit) is as claimed by a manufacturer. Typically, these data are collected either in-house, or through small scale multi-laboratory studies, which provide information on the expected precision (within laboratory standard deviation), possible

---

[54] Heissenberger A (2000) Proceedings The European Commission's Joint Research Centre (JRC) and International Life Science Institute (ILSI) Joint Workshop on Method Development in Relation to Regulatory Requirements for the Detection of GMOs in the Food Chain. Brussels, Belgium 11–13 December 2000. In: J AOAC Int, *submitted*
[55] Kay S and Van den Eede G (2001) Nature Biotechnology 19, 5: 405

systematic error (bias), recovery values (on the basis of spiked material), applicability, interference with other compounds during analysis and best calibration approaches. The output from this stage is the detailed method description (standard operation procedure) to be distributed to the participants in the actual validation trial study, along with a series of expected parameter values with which the full validation study results can be compared.

The validation parameters depend on the intended use and nature of the method (qualitative screening or quantification). For identification/screening purpose, parameters to consider are the specificity, sensitivity, detection limit, matrix effects/inhibition, precision (repeatability, intermediate precision, reproducibility) and robustness. For quantitative detection systems, accuracy, quantification limit, linearity, working range, coefficient of variation and measurement of uncertainty have to be evaluated.

4.1.2.3   Ring trials and collaborative studies on DNA methods

An increasing number of food control laboratories are adopting PCR as the technology of choice for GMO (qualitative) detection and (quantitative) determination. The adoption of official or validated methods as an analytical tool for GMO detection in raw plant materials or plant-derived foods is in its initial stage. An overview of the trials performed so far has recently been described[56]. Differences in the experimental design (for example, number of laboratories, sample concentrations, etc.) and lack of direct access to the data necessitate caution in evaluating performances between different ring trials.

PCR for detection methods for qualitative screening were assessed by the use of the Swiss method on soybean raw material and Soya lecithin[57], and were the subject of two European ring trials coordinated by the Joint Research Centre (JRC)[58]. The method was based on the detection of 35S promoter and *nos* terminator. In both cases, the results are favorable with overall accuracy of 90% for the Swiss study, and an overall specificity of 96% (i.e. correctly classified as GMO negative) and overall sensitivity of 93 % (i.e. correctly classified as GMO positive) for the European trials coordinated by JRC.

Qualitative PCR methods for specific identification of GMOs were assessed by several ring trials with overall successful results. Ring trials for the official German methods are based on the specific PCR-based GMO identification on raw materials as potato, soybean and tomato and demonstrated overall accuracy (i.e. percentage of laboratories correctly identifying the sample) above 97% (main performance parameters not presented). Studies of the Federal Institute for Health Protection of Consumers and Veterinary Medicine (BgVV), Germany, gave good overall accuracy for processed foods containing soy and maize (in concentrations of 0%, 2% and 100% - accuracy of 89% with high false positive rate) and for soy meal and maize flour samples (in concentration of 0.1% to 2%). A Swiss study, covering the specific detection of RoundupReady® Soybean, gave an overall accuracy of 96% (0.1 to 1% in concentration).

Quantitative PCR methods for determination of GMO content were assessed by several ring trials. A collaborative study evaluating four quantitative competitive PCR methods on soybean flour and several commercial food samples containing Roundup Ready® soybean showed good correlation and consistent classification for the method used[59]. A German study done on a semi-quantitative competitive PCR method for soy and maize meals and one PCR-ELISA method for soybean meals gave good results for maize and poor results for soybean. A double competitive PCR method for raw material from soybean and maize was also evaluated

---

[56] Anklam, E., Gadani, F., Heinze, P., Pijnenburg, H., & Van den Eede, G. (2001). *Eur. Food Res. Technol.*, (submitted)

[57] Brodmann P, Eugster A, Hübner P, Meyer R, Pauli U, Vögeli U, Lüthy J (1997) Mitt Geb Lebensm Hyg 88:722–731

[58] Lipp M, Anklam E (2000) J AOAC Int 83(4):919–927; Lipp M, Bluth A, Eyquem F, Kruse L, Schimmel H, van den Eede G, Anklam E (2001) Eur Food Res Technol, *in press*

[59] Hübner P, Studer E, Lüthy J (1999) Food Control 10:353–358

under the coordination of JRC[60]. An overall accuracy of more than 70% was reported for 0%, 0.1%, 0.5%, 1%, 2% and 5% GM soybean samples. The overall accuracy for 0%, 0.1%, 0.5%, and 1% GM maize samples was also above 70%, however for levels above 1% GM maize, the performance decreased significantly.

4.1.2.4 Ring trials and collaborative studies on protein methods

As for PCR, there is a strong need of validated methods based on protein detection to make appropriate comparison of efficiencies. Two ELISA kits have been validated so far by collaborative trial studies.

The performance of a diagnostic ELISA kit for detection and quantification of CP4 EPSPS from genetically modified Roundup-Ready® soybean has been assessed in a European ring study performed under the coordination of the JRC (38 laboratories, from 13 Member States and Switzerland)[61]. In this validation study the ELISA assay gave an incorrect assignment of GM status in only 1% of the samples in which the GMO was present at a level of 2% or greater. The immunoassay demonstrated a good repeatability and a promising reproducibility and a detection limit of approximately 0.35% GMO.
Another recent collaborative study was successfully performed (including 40 laboratories in 20 countries) to detect Mon 810 maize with a specific ELISA test based on the CRY1(AB) protein. The quantitative range reported was between 0.15% – 2.0 %, with a reproducibility (RSD_R) figure of better than 23 %[62].

4.1.2.5 International dimension

Current legislation demands the labeling of food products when they contain more than 1% GMO at the ingredient level. In order to create confidence in the testing procedures and complement enforcement requirements, there is an urgent need for using methods that are validated and officially recognized at an international level. There is a need for international standardization and validation of GMO analysis by harmonized and accepted protocols. At European level, the Directorate General of the JRC is actively working on the validation of methods for GMO analysis with the European Network of GMO Laboratories. Moreover, some standardization bodies as the European Committee for Standardization (CEN) and the French Standardization Association (AFNOR) are working on the production of guidelines for sampling strategies and GMO detection methods[63] and the International Organization for Standardization (ISO) is working on the harmonization of standards including analytical methods and accreditation services.

---

[60] van den Eede G, Lipp M, Eyquem F, Anklam E (2000) Validation of a double competitive polymerase chain reaction method for the quantification of GMOs in raw materials. EUR 19676 EN, European Commission Joint Research Centre, Institute for Health and Consumer Protection, Food Products and Consumer Goods Unit, Ispra, Italy
[61] Lipp M, Anklam E (2000) J AOAC Int 83(4):919–927
[62] Stave JW, Magin KM, Schimmel H, Lawruk T, Wehling P, Bridges AR (2000) Cereal Foods World 45:497–501
[63] Heissenberger A (2000) Proceedings The European Commission's Joint Research Centre (JRC) and International Life Science Institute (ILSI) Joint Workshop on Method Development in Relation to Regulatory Requirements for the Detection of GMOs in the Food Chain. Brussels, Belgium 11–13 December 2000. In: J AOAC Int, *submitted;* AFNOR (2000) Foodstuffs – Detection and quantification of genetically modified vegetal organisms and derived products – Part 1 – Guidelines and requirements. Association Française de Normalisation, Paris, France

4.1.2.6 Proficiency testing

To demonstrate that the results of a validated method are correct, control laboratories should participate in proficiency testing programs, this experience being also a valuable step in the preparation for accreditation. In contrast to a validation study, a proficiency-testing program does not specify which method will be used to determine the result. The various proficiency schemes are designed to assess qualitative results as well as quantitative analysis capabilities. The participation is becoming systematic for laboratories (especially official control laboratories). So far, only five proficiency tests on GMO detection have been publicly reported within Europe, from the programs coordinated by the Department for Environment, Food and Rural Affairs (DEFRA, former Ministry of Agriculture, Food and Fisheries) or the Food Standards Agency (FSA) of the United Kingdom[64].

4.1.2.7 Reference samples and controls

Reference samples are an indispensable part of any analytical protocol. These may be certified reference samples or may be internal standards, such as DNA preparations[65]. The Institute for Reference Materials and Measurements (IRMM) from the Directorate General Joint Research Centre, provides certified reference samples for the validation of PCR screening methods intended to detect GMOs Roundup Ready Soya, Bt-176 maize and Bt-11 maize in food. The Certified Reference Materials (CRMs) are available with a certificate of validation for the PCR screening method. The validation procedure was coordinated by the Environment Institute (EI) of the Joint Research Centre (Ispra, Italy) and included 22 laboratories, where 352 unknown and randomly distributed samples of the four CRMs were analyzed. Additionally, supplementary gravimetrically prepared samples are available. It should be noted that degradation of DNA and/or protein might occur during the production of the test materials, affecting DNA and/or protein based GMO quantification.

Difficulties exist for determining what should be the most appropriate positive reference material or control. If one considers the approved GMO-line, it is likely that it does not match with the genetic make-up of the commercial variety. On the other hand, if the commercial variety is taken into account, then the exact genetic composition is simply not known.

Another aspect to consider when setting up a validation method is the choice of the most appropriate negative control. The only "true" negative control for analytical methods should be the parental organism used in the laboratory at the time of cell transformation. In other words, some of the protoplasts used in the transformation process should be used to regenerate crops for obtaining a source of negative reference material.

Finally, great biological difference may exist between the "approved variety" and the "cultivated variety". Since such biological difference may reflect great differences at the molecular level, problems may arise for calculation of quantities based on measurements of gene copy numbers. Likewise, the appropriate choice of reference materials for method development and analysis requires specific attention.

---

[64] Howell, M (2000) Proceedings of the Joint AOAC conference on Genetically Modified Organisms in the food chain, Munich, 17-18 May 2000; FAPAS (2000) Report No. 2301 (Series 23, Round 01). Central Science Laboratory, MAFF, London
[65] Pauwels J, Kramer GN, Schimmel H, Anklam E, Lipp M, Brodmann P (1999a, b) http://www.irmm.jrc.be/rm/irmm-crm-410.pdf, http://www.irmm.jrc.be/rm/irmm-crm-411.pdf

4.1.3   Current techniques for on-farm analyses and estimated costs

Currently available methods used for GMO analysis and their costs are presented below.

Protein detection methods are widely used for in field control, mainly ELISA and Lateral Flow Strips. The detection of transgenic proteins by immunoassay tests facilitates on-site yes/no screening of grain, leaves and other unprocessed foods (need for intact tertiary and quaternary structure of the protein). The tests should be therefore done at an early stage in the production chain.

Newly developed commercial kits are widely used and can detect specific proteins in maize, cotton, soybean, oilseed rape as Cry1Ab, Cry1Ac, Cry9C, neomice phosphotransferase II (nptII), 5-pyruvylshikimate-3-phosphate synthase (EPSPS), CP4-EPSPS in Roundup Ready® soybean[66]. Several Bt endotoxin proteins cannot be detected by ELISA methods because they are expressed at very low levels or are not expressed in the grain (Cry1Ab in Maize Bt176).
The ELISA method is less expensive than the PCR testing and simpler to perform. Some specialised equipment and training is required and generally, raw materials are sent to a commercial testing laboratory. The results achievable with the ELISA method are qualitative, or semi-quantitative. The results are available within 2-4 days post-submission.

The Lateral Flow Strip tests are promoted as being cheap, requiring little training and no sophisticated laboratory equipment. The test gives a qualitative yes/no result for the presence of GMO in 10-20 minutes and is very useful for quick on-farm testing.

PCR provides qualitative, semi-quantitative and quantitative results. PCR allows quantification of GMOs even in the presence of very small quantities of DNA. Analytical testing using PCR can be performed at any stage of the agricultural production, including raw material and seed. PCR is estimated to be 100-fold more sensitive than Lateral Flow Strip tests and 10-fold more sensitive than ELISA tests.

At present the method of choice in Europe for analysing GM contamination is the PCR. The method is extremely sensitive, nevertheless care should be given to false positives due to inadvertent contamination. Laboratories providing PCR-based GMO testing services are participating in various proficiency testing schemes (see 4.1.2.6) to develop more accurate and reliable methods for detection and quantification of GMOs using PCR.

PCR is more expensive than the methods based on the detection of proteins, it must be performed in a controlled laboratory situation and requires specialised equipment and training. Samples for testing are sent to a testing laboratory and results are obtained after 5-10 days.

Appropriate sampling procedures are critical to ensure reliable GMO analysis. The two critical sampling points are the field sample and the analytical sample. Several organizations offer guidelines for representative sampling of grain and seed. Some recommendations for sampling oilseed rape, maize and potato are listed below. Nevertheless there is a need for agreement and harmonization on the sampling procedure (see discussion in Chapter 4.1.2.1).

For a representative sample for a field, several organizations specified general conditions for the sampling of grain in bulk or in bags (GAFTA, ISO). These sampling procedures are well established and based on a sound mathematical basis for the calculation of appropriate sampling frequency. They are not specifically developed for GMO testing but can be used as a basis. For bulk samples, 3kg samples are required for the purpose of GMO testing. For bags, increments should be taken from different parts of the bag such as the top, the middle and the bottom to be representative.

---

[66] Lipp and Anklam (2000) J AOAC Int 83(4):919–927

For grain maize for feed production, as for oilseed rape, it is currently recommended to sample post-harvest. If good agricultural practices are followed, it might be sufficient to sample and analyse bulked deliveries at the elevator. In order to avoid any risk of contamination, it can be envisaged to sample and test individual deliveries prior to delivery at the elevator.

In contrast to maize and oilseed rape, potato can be sampled pre-harvest. Due to the very large volume that would be required to have statistically representative field samples of potato, and due to the fact that GM potato can be detected by analyzing the leaves, it is recommended to take a single leaf from 10,000 individual plants selected randomly from the field. Alternatively, samples can be taken from each lot of seed that is planted.

For a representative sample for the analysis, it is recommended, to quantify at the 0.1% level (1 maize grain in 1000), to take at least 10,000 maize grains to be ground finely, thoroughly mixed and 1g samples removed for DNA extraction. This number of maize grains equates to approximately 2.5kg. For statistically sound quantification at the 0.01% level, the sample size would need to rise to 100,000 maize grains (25kg) which is obviously impractical with large numbers of samples.

For oilseed rape, it is recommended that 10,000 seeds are ground into a fine powder, thoroughly mixed and 1g removed for DNA extraction.

Potatoes offer significant problems for the detection of GMOs at a quantification level of 0.1%. In the same manner as for grain, statistically, plugs or peelings of 10,000 individual potatoes would be required for homogenization and removal of a 1g sub-sample for DNA extraction. The total number of potatoes from a harvest and the time involved in taking plugs or peelings would suggest such sampling is not viable in the absence of specialized sampling machinery.

Costs for GMO analyses are given in Table 36 based on available data provided by different laboratories and companies on the basis of commercialised tests. The validation of the methods used in these tests is not discussed. The costs are only indicative and should not be taken as references. The table presents the type of analysis, the event/protein analyzed, the limit of detection, the sensibility of the test (when available), and the application.

The variety of prices that can be observed in Table 36 for a similar GMO analysis might be explained by several factors: the diversity of individual laboratories (USA, Europe) doing the analyses, the number of tests and controls done might vary between laboratories, the representative sample (raw material or mixture food) might differ, the level of confidence for each analysis is different.

The current average price for a quantitative PCR analysis of a single sample is 320 €/test. For a semi-quantitative analysis by ELISA, the price would be around 150 €/test. If the monitoring of GMO content were done more frequently, one can imagine that the price for PCR analysis would probably decrease significantly.

Table 36: Costs for currently available methods for GMO analysis

DNA analysis	Price Euro/test	Event/DNA analyte	Limit of detection	Sensibility/ variability	Applications
Qualitative (detection) PCR	178 €	CaMV 35S, nos terminator			GMO detection in complex mixture
	187 – 158 € (1 to 40 tests)		0.1%	+/- 20%	All GM crops approved in Europe and world-wide
Quantitative PCR	396 €	Cry1Ab, EPSPS, Bar for maize Bar for oilseed rape			
	305-260 € (1 to 40 tests)		0.1%	+/- 20%	All GM crops approved in Europe and world-wide
Real-time quantitative PCR	436 €		0.1%	+/- 20%	All GM crops approved in Europe and world-wide

Protein analysis	Price Euro/test	Event/ protein analyte	Limit of detection	Sensibility/ variability	Applications	Recommended for
ELISA Plate kit	143 €	Cry1Ab Cry1Ac	-	2.5% - 0.55%	Bulk grain maize, cotton leaf tissue	Bt11 maize; not recommended for Cry1Ab in Bt176 maize
	222 €	Cry9C	-	0.05% - 0.25% 0.01% - 0.125%	Bulk grain	Starlink™
	570 €	Cry1Ab	-	-	-	Mon810 maize, Bt 11 maize
	570 €	Cry9C	≤0.01%, 0.01% - 0.1%, 0.1% - 1%, >1%	-	-	Aventis Starlink
Lateral Flow Tests	200 €/ 50 strips	Cry1Ab Cry1A	1%		Bulk grain	Bt11 maize grain
	200 €/ 50 strips	Cry9C	0.1%		Bulk grain maize	
	912 €/ 50 strips	Cry1Ab	0.1%, 1%		In field or laboratory, leaf, seed, bulk grain	Maize Mon810, Bt11 Novartis, Novartis KnockOut®, Mycogen NatureGard®
	912 €/ 50 strips	Cry9C	0.1%, 1%		In field or in laboratory, maize grain, leaf, seed, bulk grain	Aventis Starlink® (CBH-351)

4.1.4   Conclusion

The introduction of agricultural commodities derived from biotechnology could have a profound impact on society and the economy in the coming decade, if the projected technological advances in plant genetic modification and genomics can be realised. As more and more GM traits enter the worldwide market, the monitoring of very low levels of GM materials and the identification of variety genotypes will be a pre-requisite for the determination of seed purity and for the verification of non-GMO status of agricultural crops throughout the supply and marketing chain.

Prospects for effective monitoring of genetically modified traits in the development, quality assurance and post-release phases of the GMO agriculture will be favoured by the availability of gene registers and dedicated information systems. The JRC endeavours the development of a molecular register that contains information on the specific genetic modifications and the appropriate identification methods. The use of gene registers must be accompanied, however by ready access to certified reference materials, which should be achieved through increased cooperation among all the stakeholders in GM crop development, from seed developers to processors and manufacturers.

Because of its unparalleled sensitivity and specificity, PCR with its various formats is currently the leading analytical technology employed in the qualitative and quantitative analysis of GMOs. On the other hand, immunoassays are becoming attractive tools for rapid field monitoring of the integrity of agricultural commodities in identity preservation systems, whereby non-specialized personnel can employ them in a cost-effective manner.

The integration of conventional and new molecular tools for plant variety development will give rise to an increasingly wide range of GMOs with multiple gene constructs, i.e. with multiple analytical targets in the same product. Although, at present these new analytical issues and challenges cannot be addressed with the available technologies, far-reaching possibilities may be realized in the near future, for example by research on the miniaturization of analytical devices, and the consequent introduction of microchips and microfluidic systems for genetic analysis.

While GMO testing techniques are continuously improving with respect to accuracy, reliability and speed, it should be stressed that their performance is strongly affected by sampling strategies and processes. Sampling plans are to be thoroughly evaluated and defined for each new crop material and/or ingredient. It is therefore necessary to work towards the establishment of internationally accepted and harmonised sampling protocols such as those being developed by the Working Group "Genetically Modified Foodstuffs" (WG 11) in the Technical Committee CEN/TC 275 of the European Committee for Standardization (CEN, Brussels, Belgium).

Finally, considering the potential economic impact of GMO co-mingling in the supply and marketing chain, it appears to be of paramount importance that analytical determinations on GMO presence/absence in food and agricultural products are being made by the use of internationally validated and approved methodologies and standards. The adoption of official or validated GMO testing methods is however in its initial stage. Validation and harmonisation of quantitative methods will be needed to address compliance with GMO thresholds, which take into account the possibility of inadvertent co-mingling of GMOs with conventional materials during agricultural production, shipping or processing.

4.2 Proposal for a monitoring system

To ensure the segregation of GM and non-GM crops on the farm level the control of the product at the end of the production process would not be enough. Several measures have to be taken during the cultivation and post-harvest handling of the crops to minimise contamination and to deliver a crop with a contamination level below a certain threshold. The implementation of these measures should be monitored on-line, thereby ensuring the efficiency of these measures and avoiding expensive end-product controls as much as possible.

Based on the analysis of existing segregation and monitoring systems (e.g. organic farming, certified seed production, SCIMAC guidelines, Soja de Pays, etc.) a monitoring system for controlling GMO contamination of non-GM crops has been developed. It is based on the well-known Hazard Analysis and Critical Control Point methodology (HACCP), which has been adapted to the needs of on-farm monitoring.

4.2.1   Hazard Analysis and Critical Control Point methodology

HACCP methodology has been used in the food industry since the 1960's when it was originally developed for NASA to ensure the safety of astronauts' food. It is a preventative system of food safety based on the identification and control of potential hazards with internationally agreed protocols developed by Codex Alimentarius. However, the same methodology can be applied to any process and used to control a variety of different characteristics, such as GMO content in agricultural production systems.

The methodology follows seven HACCP principles:

Principle 1. Conduct a hazard analysis and identify control measures

Principle 2. Identify Critical Control Points (CCPs)

Principle 3. Establish the critical limits for control measures associated with each identified CCP

Principle 4. Establish CCP monitoring requirements

Principle 5. Establish corrective actions to be taken when monitoring indicates that a particular CCP is not under control

Principle 6. Establish procedures for verification that the HACCP system is working correctly

Principle 7. Establish documentation concerning all procedures and records appropriate to these principles and their application

HACCP methodology is a preventative system that approaches the problem of quality assurance very systematically and could be used for quality assessments by international standards as well as for auditing purposes by regulatory authorities.

The HACCP methodology, adapted to farming, is based on Good Agricultural Practice. The developed scheme requires appropriate employee training, documentation on the origin and status of non-GM products, commitment to segregation of non-GM products and evidence of testing to support non-GM status. At each stage of the cultivation process, steps to assure segregation have to be documented. The scheme is supported by qualitative and quantitative PCR analysis of GMOs.

4.2.2   Structure of the system

Setting up and maintaining the system can be viewed as a number of different steps. The initial phase includes *planning* and *implementation*, while maintaining the system consists of *on-line monitoring activities*, *sampling and testing for GMOs*, *internal reviews* and *external audits*. Below each of these steps, as well as associated costs are presented in detail. Three different versions of the HACCP based monitoring system have been developed to adapt to three different levels of additional monitoring needs. These three different version have an identical structure, with the major difference being the number of identified CCPs. Therefore costs do only differ slightly between the different versions.

The cost calculations are based on the following assumptions:
- The costs are related specifically to the activities that are associated with establishing and running a *monitoring system*, which is subject to third party audit/verification. The costs associated with change of agricultural practices to prevent the contamination of crops by GMOs, e.g. cleaning machinery, are not included here. These costs are presented in Chapter 3.

- The scheme and its operation is largely a confirmation of the rationale underlying Good Agricultural Practice (GAP) and the regulatory controls relating to production of GM crops. It is assumed that the farm types are fully subscribed to these but that none has a HACCP-type system.

- None of the monitoring requirements or records indicated by the scheme are totally new but some will need additional items and current recording will need to be cross-referenced to the scheme.

- The model farms are already using a Management Information System (MIS) to maintain the records.

- In case conventional farms grow both non-GM and GM varieties, the monitoring activities are assumed to cover both non-GM and GM production.

- The hourly rates used for staff are:
  Manager   € 25.00
  Foreman   € 11.20
  Craftsman   € 9.76

Planning the system
To undertake the planning, implementation and running of the system would require training of the person to be responsible for the system, a small team (manager + 2 staff) to assist in planning, and implementation and awareness training of all employees who will have responsibility to operate the system. It is assumed that an experienced consultant would be used as a facilitator to train and lead the group at each farm to put together a draft plan for confirmation by the group. The costs associated with planning the system are described in Table 37. This investment, which mainly consists of education, is assumed to have a life length of 5 years.

Table 37: Cost estimation for planning the monitoring system

	Time (working hours)	Cost (€)
Training of 1 manager, 2 supervisors and development of draft plan	24	1339.20 *(960 fees + 379.20 pay)*
Group development and validation of the plan (1 manager + 2 supervisors for 1 day)	24	379.20
Awareness training of all operators (3 hours for 5 staff + manager)	18	221.40
Total	66	1939.80
Annual cost per farm assuming a life length 5 years		388

Implementation of the system

This phase involves putting the plan into practice. This will include cross-referencing existing practices and record keeping and devising the necessary recording systems, and setting up internal audit procedures. It is estimated that approximately 90% of the required procedures and records will already be in place to meet the requirements of GAP and control of GMOs.

It is estimated that the implementation phase will take 1 person day for the manager (200 €) and 1 person day for the foreman (89.6 €). These investments in education are assumed to have a life length of 5 years (58 €/ year & farm).

On-line monitoring activities

The on-line monitoring activities mainly consist of documentation of applied measures. The vast majority of costs associated with the system are incurred during the set up and implementation phases, while the yearly on-line monitoring costs are less significant. This is partly due to the assumption that the model farms will have an existing Management Information System (MIS) in operation. The costs of setting up, implementing and running the new monitoring system are therefore restricted to those additional procedures which are required over and above those which are likely to be incurred in association with the existing MIS. It is assumed that supplier assessment would be carried out on all potential suppliers at the start of the season and that recording onto the system would take place only once. Some of the extra recording required would only need an extra tick-box on an existing form.

In order to put the operation of the system into perspective a comparison has been made with operation of an existing MIS. It is estimated that inputting of records onto a simple computerised MIS for a single crop (e.g. oilseed rape) on 5 fields, with each field treated the same, would require 20 person hours per year, which is estimated at 500 € per year at 25.00 €/hr. More complex farming practices might require greater time inputs but these costs are largely constant and do not vary with production volume or between crops.

For a very rigorous monitoring system the costs for on-line monitoring activities are estimated at 80 €/year per farm (additional 3.2 hours/year). For an intermediate system and for a low level system the on-line monitoring costs are estimated to 10 €/year per farm. Thus, where the annual running costs of an existing typical MIS are 500 €, the additional on-line monitoring costs represent a further 16% per annum for the most rigorous system and 2% for the two less rigorous system (see 4.2.3 below).

Sampling and analysis of GMO content

The number of samples to be taken for analysis will vary, depending on the requirements of the first purchaser of the crop. For some crops, e.g. oilseed rape, each batch delivered may be

required to be tested. The definition of "batch" will be quite variable. It might be a field; a part of a field; a storage bin/silo/building; an individual load leaving the farm etc. Here it is assumed that the unit to be tested is the individual field. In a commercial on-line monitoring system the sampling procedures will, when possible, be integrated in the sampling for analysis of other quality characteristics and consequently the additional costs for sampling to control the GM content is likely to be rather low. The following costs have been assumed for the different crops:

- Oilseed rape 0.5 €/tonne
- Maize 0.5 €/tonne
- Potato 5 €/ha

Oilseed rape and maize are sampled after harvest and thus the total sampling costs are strongly correlated with the production size. Therefore the costs are estimated on a per tonne basis. For potato, on the other hand, the sampling takes place in the field prior to the harvest by sampling leaves from the growing potato plants. The total sampling costs are therefore strongly correlated to the area of production and the costs are estimated on a per hectare basis.

Verification costs of testing harvested seed to check GMO contamination levels are assumed to be 180 €/test (based on current prices quoted in Table 36 for quantitative PCR analysis and assuming price reductions in response to increased demand), with one GMO analysis per field being required. This assumption makes the size of the individual fields to be an important factor, affecting the costs for GMO analysis.

In an established system where the probability of contamination has been identified, it is expected that the frequency of GMO content testing (and sampling) will be adjusted according to this and the level of negative impact of GM contamination in the next steps of the production chain. For maize and potato it is assumed that each field will be tested every second year. For the oilseed rape production, which is either fully or partly devoted to seed production, each field is assumed to be tested on an annual basis.

Review of the system
The system should be subjected to an annual review (or earlier if changes are made to the operations). It has been calculated that this would require 1 day for the manager, corresponding to an annual cost per farm of 200 €.

External audit
Based on existing HACCP-type systems, external auditing costs are calculated on the basis of one telephone audit per site per year at a cost of 85.50 € and an on-farm audit, which is estimated to cost 480 €. As the on-farm audit is supposed to take place every three years, the annual costs for a visit would amount to 160 €, resulting in an annual cost per farm of 245.5 €.

4.2.3   Adaptation to different levels of monitoring needs

The general structure presented above was used for developing three different versions, a *rigorous system*, an *intermediate system* and a *low level system*. The three versions are adapted to different farm types based on a number of parameters affecting the need for additional monitoring activities
- targeted threshold level,
- probability of contamination, and
- monitoring activities already taking place in the context of other regulatory or market requirements.

The major difference between the three versions, and the only one addressed in the cost estimations, is the number of CCPs. Table 38 summarises the process steps that would have to be controlled and points out the differences between the three versions.

Rigorous monitoring system
An extremely rigorous system, which considers all processes in which contamination could occur, would be suitable for the lower tolerance level of 0.1% contamination. The system is appropriate for organic farms as well as non-organic farms producing conventional crops to the lowest possible level of GM contamination and also for farms producing seed crops to the lowest GMO threshold level. In this study it is applied to all organic farm types. Additional time spent on the system for documentation would be 3.2 hours a year.

Intermediate monitoring system
The intermediate monitoring system is developed to identify and control not all but significant sources of GM contamination. It would be suitable for a conventional production that would have to respect a threshold of 1% or a seed producer who would have to respect a threshold of 0.3%. Of the farm types studied, the conventional farms producing oilseed rape (seed), maize and early potatoes would be suitable for this monitoring system. This system is appropriate to farms producing seed for sale or for their own use. The intermediate monitoring system would identify 18 CCP in comparison to 28 CCP, identified for a rigorous monitoring system. The main differences are based on less control regarding site selection, site preparation and crop management. In contrast, harvest and post-harvest procedures as well as sowing and planting are controlled to the same extent. The on-line monitoring cost is lower than for the rigorous system, additional time spent on the system for documentation would be 0.4 hours a year.

Low level monitoring system
For a system in which the probability of contamination is already adequately controlled by Good Agricultural Practice, a low level monitoring system would be sufficient. This is an increasingly common situation where farms produce high value crops for human consumption or where they seek to achieve added value through participation in quality assurance or identity preservation schemes, which are subject to audit by third parties or through their own management systems. This system would be best suited for farms producing crops with a low susceptibility to GM contamination, e.g. potatoes. It would also be appropriate for farms operating to the highest levels of management control and probably producing crops to rigorous customer specifications. Here, the monitoring system is applied to a conventional potato producing farm (Farm 1). None of the other farm types described in the study would be suited for this system. Compared to the other proposals this low level system identified only 9 CCP. The usage of certified seed and sowing and planting activities are also for this system important to control. Additionally unintentional co-mingling during harvest and storage should be controlled as well as the sampling process. The basis for the cost estimation for the least stringent monitoring system are the same fixed costs as identified for the other proposals. The on-line monitoring costs are the same as for the intermediate system.

Table 38: Contamination probability analysis record for rigorous, intermediate and low level monitoring systems

Process Step	Probability of Contamination	Control Measure	CCPs		
			Rigorous	Intemediate	Low level
1. Site Selection	too near neighbouring GM crop	find alternative site	√	√	
	GM trash from previous crop	assess probability			
	GM volunteers	assess probability - use knowledge of rotation	√		
	near transport line	assess probability - find new site	√		
	GM contamination of weeds and wild plants - Organic grower concern	assess probability	√		
	neighbour changes cropping plan	reconsult near sowing time	√		
2. Seed receipt	GM contamination of seed - certified seed	certified seed standards - save sample	√	√	√
	Farm- saved seed	controlled by previous crop management - save sample	√	√	
3. Site preparation	GM volunteers	cultivate / spray with appropriate herbicide. Hand weed - organic grower / liase with neighbour	√	√	
	GM contaminated weeds and wild plants	identify probability, destroy by normal cultivations	√		
	Machinery – contractor/ - neighbours /	GAP* - cleaning between fields	√		
	GM contaminated manure - organic grower concern	ensure GM free	√		
4. Sowing / planting	contamination	GAP drill non-GM crops first	√	√	√
	wrong seed	GAP accurate management records + well trained staff	√	√	√
	wrong field	GAP accurate management records + well trained staff	√	√	√
	Dirty / shared machinery	GAP clean machinery	√	√	√
5. Crop management	contaminated equipment particularly at flowering	GAP clean machinery - spray non-GM crops first	√		
	Machinery – contractor / -shared	GAP as above	√		
	volunteers	spray / hand rogue	√		
6. Harvest & transport	Machinery – contaminated / - contractor / - shared	GAP clean machinery	√	√	√
	mixing part loads	GAP	√	√	√
	harvesting barrier rows	harvest separately	√	√	
	load contamination	cover as necessary - organic grower	√	√	
7. On-farm storage	co-mingling GM/non-GM	GAP management communication	√	√	√
	dirty equipment/plant	GAP	√	√	
	vermin / bird transfer	GAP	√	√	
	workforce - clothing/footwear	GAP	√	√	
	inaccurate records/identification	GAP records / labelling	√	√	
	inaccurate sampling	sample to approved protocols	√	√	√
* GAP: Good Agricultural Practice					

4.2.4 Total costs of monitoring systems – fixed costs

The way the proposed monitoring structure is outlined, the major part of the costs are fixed on a farm level. The annual costs for the initial activities of planning and implementing the monitoring system together with the annual costs for internal reviews and external reviews result in total fixed costs of 892 € per farm and year. For small farms, this would lead to extremely high costs per hectare and per tonne production. One can expect that small farms, in order to increase the cost efficiency, will be forced to co-operate with other small farms to keep a profitable production.

Therefore it is assumed that farms with less than 10 hectares model crop area will co-operate and share the annual costs that are fixed to the farm unit, markedly reducing the cost per hectare and per tonne production. Farms with model crop area smaller than 2 ha join together in groups of five farm units, while farms with model crop area smaller than 10 hectares but larger than 2 hectares join together in groups of three farm units.

4.2.5 Costs of monitoring for oilseed rape

In Table 39 the total costs of initiating and running monitoring systems for oilseed rape, Farms 1–3, are summarised. To guarantee a low GMO content in all deliveries over time, the production is tested each year. The range of costs for the presented farms is very large. The certified seed production (107-112 €/ha) has a much higher cost than the normal production including seed saving (31 €/ha). The most important factor determining the cost difference per hectare is the size of the crop area. Farms 1 and 2 only use 12 ha for oilseed rape production, while the crop area of Farm 3 (70 ha) is almost six times as large, resulting in very low costs per hectare.

Table 39: Total monitoring costs for oilseed rape seed production (Farms 1 - 3)

Oilseed rape	Farm 1 Conventional certified seed production		Farm 2 Organic certified seed production		Farm 3 Conventional production with farm-saved seeds	
Crop area (ha)	12		12		70	
Field size (ha)	6		6		11	
Yield (tonne/ha)	3.5		2.3		3.14	
Monitoring system	intermediate		rigorous		intermediate	
GMO analysis frequency (no./field & year)	1		1		1	
	€/ha	€/tonne	€/ha	€/tonne	€/ha	€/tonne
Planning	32.3	9.2	32.3	14.1	5.5	1.8
Implementation	4.8	1.4	4.8	2.1	0.8	0.2
On-line monitoring	0.8	0.2	6.7	2.9	0.1	0.1
Sampling	1.7	0.5	1.1	0.5	1.5	0.5
GMO Analysis	30.0	8.6	30.0	13.0	16.4	5.2
Review	16.7	4.8	16.7	7.2	2.9	0.9
External audit	20.5	5.8	20.5	8.9	3.5	1.1
Total costs	**107**	**30.5**	**112**	**48.7**	**31**	**9.8**

In the certified seed production, the organic Farm 2 that has implemented the most rigorous monitoring system has a slightly higher cost as compared to the conventional Farm 1, which has adapted the intermediate alternative. The difference originates from the higher annual on-line monitoring cost, 6.7 €/ha as compared to 0.8 €/ha for the conventional farm. On the other hand, the organic farm has lower sampling costs as measured per hectare. This is the result of the

lower yield, while the sampling cost per tonne is the same. The lower yield also leads to a 50% higher cost per tonne as compared to Farm 1.

For the two farm types not included in the table, the costs can be viewed in Figure 8. Farm 4, which is the organic version of Farm 3, has almost identical costs as Farm 3. The costs for the small organic Farm 2' differ very much. With only 1 hectare of oilseed rape production, costs fixed on farm level affect the total costs drastically. Even though it is assumed that the farm co-operates with similar farms, the total costs (439 €/ha and 191 €/tonne) are prohibitive for the introduction of a monitoring system as described here.

4.2.6   Costs of monitoring for maize

The cost estimations for maize are based on the same assumptions as for oilseed rape. The annual costs per farm for planning and implementation of the system as well as for a review and an external audit are assumed to be the same, regardless of the farm for which the system is going to be developed. The total costs of initiating and running monitoring systems for maize production are summarised in Table 40. With presented costs ranging from 46.2 €/ha for the conventional intensive production to 91 €/ha for the organic production, the general level of costs is somewhat lower than for oilseed rape production. Annual sampling costs and GMO analysis costs per tonne are lower, because tests are expected to be carried out only every second year and yields are higher.

Table 40: Total monitoring costs for conventional grain maize production (Farms 1 - 3)

Maize	Farm 1 Conventional, intensive production		Farm 2 Organic production		Farm 3 Conventional, non-intensive production	
Crop area (ha)	50		6 (18)*		20	
Field size (ha)	3.5		3.5		20	
Yield (tonne/ha)	10.15		9.0		10.06	
Monitoring system	intermediate		rigorous		intermediate	
GMO analysis frequency (no./field & year)	0.5		0.5		0.5	
	€/ha	€/tonne	€/ha	€/tonne	€/ha	€/tonne
Planning	7.8	0.8	21.5	2.4	19.4	1.9
Implementation	1.2	0.1	3.2	0.4	2.9	0.3
On-line monitoring	0.2	0 (0.02)	13.3	1.5	0.5	0.1
Sampling	2.5	0.2	2.2	0.2	2.4	0.2
GMO Analysis	25.7	2.5	25.7	2.9	4.5	0.5
Review	4.0	0.4	11.1	1.2	10.0	1.0
External audit	4.9	0.5	13.6	1.5	12.3	1.2
Total costs	**46.2**	**4.5**	**90.8**	**10.1**	**52.0**	**5.2**
* It is assumed that three farms co-coperate and share the costs, which are fixed on farm level.						

As for oilseed rape, the crop area is decisive for the total monitoring costs. Farm 1, a conventional intensive producer with 50 ha of maize production, has a total monitoring cost of 46.2 €/ha, while Farm 2, an organic grower with only 6 ha of maize production, has almost double costs. Farm 3, the non-intensive conventional grower with 20 ha, has costs only slightly higher than Farm 1. Here the high fixed costs resulting from the relatively smaller production area is balanced by very low costs for GMO testing. Farm 3 has only one large field, while Farm 1 has several smaller fields. This leads to less GMO tests per ha and lower GMO testing costs per hectare for Farm 3 as compared to Farm 1. Since yields do not differ substantially between the farm types, differences in costs per tonne follow the same trends as costs per hectare.

For the farm types not included in the table, the costs can be viewed in Figure 8. Farm 4 is the organic equivalent to Farm 3 (conventional non-intensive production). For these two farms costs are very similar. Slightly higher costs per hectare for Farm 4 are mainly due to the adaptation of the rigorous monitoring system. This difference is amplified when measuring the cost per tonne as a result of a lower yield. Farm 4' is a smaller alternative of Farm 4. Monitoring costs per hectare are high due to the small crop area (3 ha as compared to 20 ha for Farms 3 and 4) and, despite assumed co-operation between three farms of the same size, total costs per hectare equal 158 €/ha. Farm 2' is a very small version of Farm 2. The farm only has 1 ha of maize production, thus the large fixed part of the monitoring costs lead to very high monitoring costs, 296 €/ha or 33 €/tonne. Farm 5 is similar to Farm 1 but total maize production is lower (25 ha) while the fields are larger (8 ha). Costs are 50 €/ha, or 5.3 €/tonne.

4.2.7   Costs of monitoring for potato

The same cost structure is applied as for oilseed rape and maize. As for maize, each field is analysed for GMO content every second year. Sampling is assumed to be done pre-harvest using in-field sampling, taking leaves of the potato plants. Sampling potatoes post-harvest is not feasible due to the large weight such a potato sample would represent. This causes slightly higher sampling costs per hectare as compared to the sampling of other model crops. Total costs per hectare are in line with the total costs for maize, but with the relatively high yield of potato the costs per tonne are lower, ranging from 1.0 €/ha to 3.4 €/ha. The total costs for the monitoring system for potato are summarised in Table 41.

Table 41: Total monitoring costs for conventional potato production (Farms 1-3)

Potato	Farm 1 Conventional production		Farm 2 Organic production		Farm 3 Conventional, early production	
Crop area (ha)	30		25		15	
Field size (ha)	10		5		3	
Yield (tonne/ha)	41.9		25.1		27.2	
Monitoring system	low level		rigorous		intermediate	
GMO analysis frequency (no./field & year)	0.5		0.5		0.5	
	€/ha	€/tonne	€/ha	€/tonne	€/ha	€/tonne
Planning	12.9	0.3	15.5	0.6	25.9	1.0
Implementation	1.9	0.05	2.3	0.1	3.9	0.1
On-line monitoring	0.3	0 (0.01)	3.2	0.1	0.7	0 (0.02)
Sampling	2.4	0.05	2.4	0.1	2.4	0.1
GMO Analysis	9.0	0.2	18.0	0.7	30.0	1.1
Review	6.7	0.2	8.0	0.3	13.3	0.5
External audit	8.2	0.2	9.8	0.4	16.4	0.6
Total costs	**41.5**	**1.0**	**59.3**	**2.4**	**92.5**	**3.4**

As seen from the other model crops, the crop area is again decisive for the total costs, with lowest costs for Farm 1, which is a conventional producer with 30 ha of potato production. Total costs per hectare are 41.5 €/ha while total costs for the organic equivalent, Farm 2 with 25 ha, are 59.3 €/ha and almost 50 % higher than for Farm 1. The main part of this difference is caused by the higher costs for GMO analysis, which is a result of the smaller field area. Farm 3, which is a conventional producer of early potatoes, has total costs of 92.5 €/ha. The higher costs, as compared to the other farms, are caused by the smaller crop area (15 ha). Costs measured as €/tonne are even higher due to the lower yield for early potatoes.

For the farm type not included in the table, Farm 4, the costs can be viewed in Figure 8. Farm 4 is the organic equivalent to Farm 3 (conventional early potato production). Costs for the two farms are very similar. The only difference, higher on-line monitoring costs per hectare for Farm 4, is due to the adaptation of the most rigorous monitoring system. This difference is amplified when measuring the cost per tonne as a result of a lower yield (6.0 €/tonne for Farm 4 compared to 3.4 €/tonne for Farm 3).

4.2.8   Conclusion

The costs estimated for the proposed monitoring systems, which are all based on the HACCP methodology, are not directly proportional to the level of stringency. This is due to fixed costs for planning and implementation as well as internal review and external auditing. A main cost factor is the implementation cost in form of investment in education. This investment is assumed to have a life length of 5 years. With a longer assumed life length, calculated costs would be lower. This investment concerns each farm unit, which makes the cost per hectare higher for small farms. Figure 8 summarises estimated monitoring costs for all model farms studied.
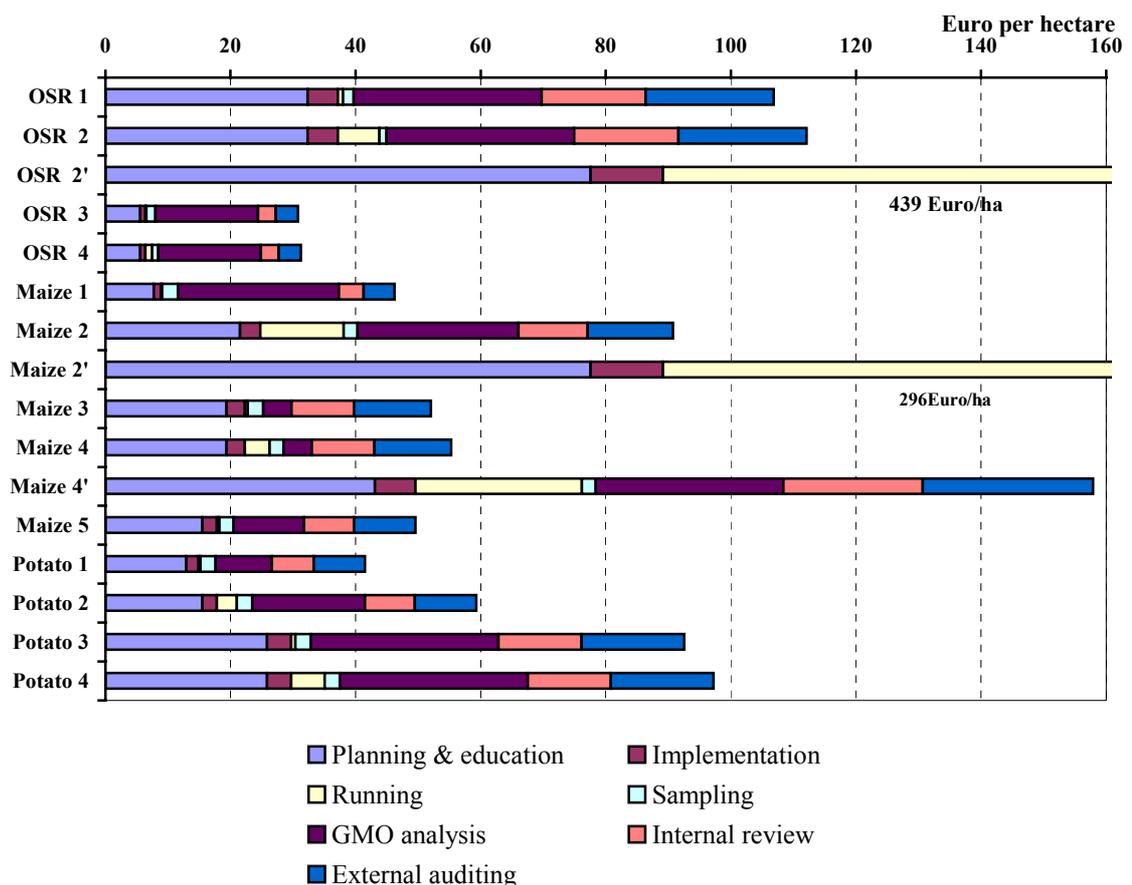
Figure 8: Estimated annual monitoring costs per hectare for each farm type

It is assumed that smaller farms (farms with a total area of the studied crop below 10 ha) co-operate with other small farms, thus reducing the investment cost per farm and per hectare. Still, it is obvious that the costs affect the small farms much more with considerably higher costs per hectare. As Figure 8 shows, another important cost factor are the costs for GMO analysis. Here,

the unit to be tested is assumed to be the individual field rather than single batches. Thus the testing rate per field and the field size are important variables for determining the monitoring costs. During an introduction phase and for high value crops, the rate of testing needs to be high. However, in an already running segregation system, the probability of contamination is normally well established, which leads to a reduced testing frequency. In this analysis, the oilseed rape seed fields are assumed to be tested annually, while the maize and potato fields would be tested every second year. The assumed field sizes are normal sizes for the studied regions but one could expect field sizes to vary widely on individual farms. On the other hand, sampling costs are not very high compared to other costs. It is expected that controlling for GMO content will be done in parallel with other quality controls, leading to a low additional cost caused by the sampling requirements for GMO content analysis.

As the price levels for the three different model crops differ widely, the monitoring costs measured as percentage of product price gives a more representative picture of the importance of the monitoring costs. For potatoes the additional average costs are minor, with costs representing 0.9% - 1.9% of the product price. Regarding maize, the monitoring costs equal 2.7% - 7.7%, disregarding the very small farms with only 1 ha of maize production. Oilseed rape production for certified seed is the model crop that has the highest impact from monitoring costs, with costs representing 6.6% - 8.3% of the price, also here disregarding the very small farm type. The associated costs for oilseed rape production for consumption represent 4.2% - 5.5% of farm gate price.

5   FINANCIAL LOSSES IN CASE OF CONTAMINATION

Any segregation system in agriculture to segregate GM and non-GM crops could fail due to, for example, accidents, abnormal weather conditions or human failure. This raises the question, what possible consequences such a failure could have for conventional and organic farms (or GMO farms in case of premia for special products). The following analysis will focus on direct impacts of possible contamination on the economic performance of agricultural production of the selected crops and on the farm as a whole. In this context it can be distinguished between short-term impacts (which arise within the current planting season), medium-term impacts (which might have consequences for the activities in the following 3 to 5 years) and long-term impacts (which might arise after a 5 years period).

One major factor influencing the short-term loss of conventional and organic farms in case of contamination with GM material represents the price of GM crops. So far almost no empirical data exist concerning this aspect with respect to the EU. Transferring the experiences gathered in the USA, it seems most likely that the prices of GM varieties of crops grown in the EU will be lower than the prices of non-GM varieties with comparable quality characteristics. Price premia paid in the USA for non-GM varieties range between 3% and 9% of the farm gate price of maize and rapeseed for oil production. Therefore a 10% price decrease in case of contamination with GM material has been assumed as a starting point for calculating the short-term losses of organic and conventional farms. This assumes that the contamination level is beyond a specified threshold, when crops have to be labelled as containing GM material, and that the contaminating GM variety has been approved for commercialisation in the EU. If the GM variety were unapproved and the contamination level were above 1%, the contaminated crop would not be saleable. It is assumed in this study that there are no additional variable costs caused by contamination. Area payments for maize and oilseed rape production based on CAP are assumed not to be influenced by contamination.

5.1   Impacts of contamination with GM crops on conventional farms

5.1.1   Short-term impacts

The short-term impacts of contamination of conventional crops with GM material depend on the price differences between conventional crops and GM crops. As Table 42 shows, the influence of the assumed price difference of 10% on the gross margin plus subsidies varies according to the share of fixed payments like area payments and on the loss of price premia. For example, an oilseed rape seed producer would lose more than 50% of the gross margin due to loss of the price premia for seed. The moderate losses in case of conventional oilseed rape and maize are due to high area payments. For potatoes the area payment plays a minor role, here the price difference determines the losses.

Table 42: Short-term losses for conventional farms in case of contamination with GM crops*

Model farm	Loss expressed in €/ha	Loss expressed in % of gross margin**	Loss expressed in €/tonne
Rapeseed for oil production			
Farm 3 (DE)***	72.4	10.4	23.1
Farm 3 (FR)	53.5	6.5	15.25
Rapeseed for seed production			
Farm 1 (data from UK)	671.6	54.5	191.9
Maize (irrigated)			
Farm 1 (FR)	100	10.5	9.85
Farm 3 (FR)	108.7	9.9	10.8
Potato			
Farm 1 (DE)	386	17	9.2
Farm 3 (DE)	481	17	17.7
Farm 1 (UK)	556	26	13.1
Farm 3 (UK)	500	19.8	22.2

*   Values are based on data on economic performance of the different crop production systems (see Annex).
**   Gross margin refers to gross margin plus subsidies.
***   DE, FR, UK refers to origin of data

Since 1998 in Germany and Austria it is possible on a voluntary basis to label products as produced "without genetic engineering". Under these regulations, producers are responsible for showing evidence that their products have been produced in accordance with specified criteria. However, the regulation includes an essential exemption clause: Products, which have been contaminated unintentionally and unavoidably with GM material, may nevertheless be labelled as being produced "without genetic engineering". Additional rules, which intend to implement these requirements in e. g. agricultural practice, have not been worked out in detail so far in Germany and Austria. If farmers with a "without genetic engineering" production line lost their right to sell their products under this label in case of contamination, they would have to sell their products at lower prices and would face financial losses, which might be higher than those of conventional farmers because of price premia.

5.1.2   Medium- and long-term impacts

On conventional farms the management of the volunteer problem (especially in rapeseed and potatoes) represents the most challenging task for farmers in the medium-term, but is facilitated by the use of herbicides. In addition, it seems most unlikely that conventional farmers are not allowed to grow conventional crops in the rotation in the year following the contamination, so that the medium-term loss of conventional farms is mainly influenced by the costs of additional activities necessary to control the GM volunteers. The variable production costs in the years following the contamination will increase due to these additional activities (e. g. additional costs for herbicides, machinery use and labour input) as well as additional costs for inspection and testing activities. The medium-term loss of conventional farms which participate in "without genetic engineering" labelling programmes most probably will be placed between those of organic farms and conventional farms without such programmes. These losses will mainly depend on the price difference of non-GM crops covered in specific "without genetic engineering" programmes and crops contaminated with GM material.

The long-term impacts of GM contamination on conventional farms cannot be assessed at the moment since these highly depend on the nature of farming systems to minimise the unintended contamination with GM material. When adventitious contamination with GM material occurs every year (e. g. due to wide-ranging cultivation of GM crops in a certain region) conventional farms will face severe problems in order to grow conventional varieties without any GM content. In such a scenario the impacts highly depend on the specific regulations either within a "without genetic engineering" labelling programme or the allowed threshold for GM contamination.

5.2 Impacts of contamination with GM crops on organic farms

5.2.1 Short-term impacts

The calculation of financial losses for organic farms is based on the same assumptions as for conventional farms. It is assumed that the contamination level is above a legal threshold and the crop has to be sold as a GM crop. Also in this case the contaminating GM variety must have been authorised for commercialisation in the EU to be able to sell the contaminated crop. It is assumed that organic farms will lose subsidies connected to organic farming as well as organic price premia (this does not apply for all organic crops, some do not carry price premia) in the case of contamination with GM crops. Financial short-term losses are summarised in Table 43.

In the case of rapeseed crop production, based on German farm data, the loss is moderate due to relatively small price premia and the fact that only part of the harvest is sold as organic (60%). It is mainly influenced by the loss of the subsidies for continuous organic farming in Germany. In contrast, the loss in case of organic rapeseed seed production is much higher. This effect is based on the assumption that the price premium for organic certified seed is the result of increased variable costs, so that the gross margin is the same as for the conventional seed producer. When the gross income due to price decreases falls considerably, the farmer can expect huge financial losses. Also in the case of organic maize production the loss is comparatively high. Since no direct subsidies are paid for continuous organic farming in France this loss is due to price differences between contaminated and organic maize (135% - 160%). In the case of potatoes, the short-term economic losses are also very high. These drastic losses are based on high price premia for organic potatoes.

In general the financial losses for organic farms are considerably higher compared to conventional farms. The most important factor influencing the short-term loss of organic farms represents the price premia paid for organic products since it has been assumed that organic, but GMO contaminated crops can be sold to prices 10% lower than those of conventional crops. In addition to the loss of price premia, specific activities to minimise the impacts of contamination with GM material (like cleaning of machinery, segregation of crops) as well as additional costs for inspection activities or clarifying the GM contamination can influence the short-term loss of organic farms.

Table 43: Short-term losses for organic farms in case of contamination with GM crops*

Model farm	Loss expressed in €/ha	Loss expressed in % of gross margin**	Loss expressed in €/ton
Rapeseed for oil production Farm 4 (DE)***	217	25.8	106.4
Certified organic oilseed rape seed production Farm 2 (data from UK****)	1290.5	131.5	561.1
Maize (irrigated) Farm 2/4 (FR)	1221.6	70.7	135.7
Potato Farm 2 (DE)	4733	91.6	188.6
Farm 4 (DE)	5890	99.3	361.3
Farm 2 (UK)	7305	101	292.2

*	Values are based on data on economic performance presented in the Annex.
**	Gross margin refers to gross margin plus subsidies.
***	DE, UK, FR refer to the origin of data
****	For the organic certified seed producer 65% of the yield of conventional seed production and a 100% price premium, based on higher costs, have been assumed. The gross margin remains identical to the conventional seed producer, because of higher variable costs.

5.2.2   Medium- and long-term impacts

In the medium-term the volunteer problem (especially in oilseed rape and potatoes) represents the most important challenge for organic farmers because it is possible that they will not be allowed to grow and sell crops under organic labels as long as their fields are contaminated with GM volunteers. Besides the difficulties arising from the up to 10 years lasting survival rate of seeds in the soil and the "manual separation" of small potatoes, organic farms face additional difficulties to control the volunteers in oilseed rape and potato production because they are not allowed to use herbicides for this purpose which are frequently used on conventional farms. This results in a longer "decontamination phase" on organic farms compared to conventional ones. In this context a period up to five years has been suggested from interviewed experts.

The costs resulting from the reduction of a GM volunteer problem depend on the time period necessary for "decontamination activities", the exact shaping of the activities (e. g. whether it is allowed to grow some crops or not) and the costs of additional measures which have to be carried out in order to reduce survival of volunteers in the seed bank. In addition, it is most likely that additional labour input will be required on organic farms (e. g. for manual destruction of volunteer plants). If organic farmers will be allowed to grow conventional crops in the rotation on the contaminated fields during the "decontamination phase" and the grown crops can be sold to prices of conventional products, the medium-term losses of organic farms will be the difference in the gross margin of the entire rotation of organic farms compared to conventional ones. In case organic farms are not allowed to grow any crop on "contaminated" fields during the "decontamination phase", the organic farm will lose the gross margin achieved in average for the rotation of the farm on the affected fields. In addition, the organic farm has to cover the fixed costs related to the contaminated fields during the "decontamination phase".

The long-term impacts of GM contamination on organic farms cannot be assessed totally at the moment since they are highly dependant on the exact shaping of a farming system which intends to minimise the unintended contamination with GM material. In cases where unintended contamination with GM material occurs every year (e. g. due to wide ranging cultivation of GM

crops in a certain area), organic farms will lose their organic status and face severe problems to grow their crops according to the regulations given by the EU and the national authorities. In such a scenario it might be conceivable that it is almost impossible to grow organic crops so that the affected farms will face significant financial losses and economic problems. However, in such cases the question of compensation payments will most probably be on the political agenda because organic farms in regions with high cultivation rates with GM crops will suffer damage of their incomes without being able to prevent contamination with GM material.

5.3 Insurance against contamination

5.3.1   Indicative insurance costs

Since currently no experience exists with "common" failure rates of a farming system which intends to minimise the probability of unintended contamination with GM material, the "failure of the system" of certified seed production and organic farming has been analysed with data from Germany and Denmark. Around 5% to 6% of the marketed seeds of maize as well as oil and fibre plants cause complaints in post-marketing control activities in Germany. The complaint rates in potatoes range up to 10%. In general, around half of the complaints are caused by poor seed quality namely problems with the germination rate, presence of seeds of other plants or weeds and the purity of seeds.

Statistical data on infringements in organic agriculture in Denmark as well as estimations of interviewees indicate that about 0.2% to 0.3% of the farmers lose their organic status per year and that up to about 3% of the organic farmers have to pay monetary penalties. Based on these data two different "failure rates" have been chosen (0.2 %, 3.0%) and combined with the short-term losses for conventional and organic farms (see Chapter 5.1.1 and 5.2.1) to estimate the average "failure costs" of a farming system which intends to minimise adventitious contamination with GM material (Table 44). Due to significantly higher short-term losses of organic farms, the "failure costs" are up to the factor 13 higher than those of conventional farms. This relates in particular to potato production ("failure costs" up to about 220 € per hectare) but also in maize production significantly higher costs (up to 37 € per hectare) can be observed. Compared to the gross margins achieved without contamination with GM material the estimated "failure costs" are on a relatively low level both for organic and conventional farms.

The calculations are based on the assumption that the contaminated crop has to be sold as a GM crop. At present this would mean that the contamination level is above 1%. In the case of oilseed rape for seed production, where a threshold of 0.3% was assumed, a contamination level above 0.3% but below 1% would mean that the crop cannot be sold as non-GM seed but instead as non-GM conventional crop. If this possibility would be taken into account, the costs would slightly decrease but the difference would be negligible.

Table 44: Cost of "failure of the system" for organic and conventional farms considering failure rates of 0.2% and 3%*

Crop	Country	Loss of organic[1] farms	Loss of conventional[1] farms	Cost of "failure of system" (€/ha) considering a failure rate of			
				0.2 %	3.0 %	0.2 %	3.0 %
		€ per hectare		Organic farms		Conventional farms	
Rapeseed (certified seed production)	United Kingdom	1290	672	2.58	38.7	1.34	20.16
Rapeseed (oil production)	Germany	217	72	0.43	6.51	0.14	2.16
Rapeseed (oil production)	France	n. a.	54	n. a.	n. a.	0.11	1.62
Maize (irrigated grain production)	France	1222	109	2.44	36.7	0.22	3.27
Processing potatoes	Germany	4733	386	9.47	141.99	0.77	11.58
Early potatoes	Germany	5890	481	11.78	176.7	0.96	14.43
Processing potatoes	United Kingdom	7305	556	14.61	219.1	1.11	16.68
Early potatoes	United Kingdom	n. a.	500	n. a.	n. a.	1.0	15.0

*   The calculations are based on data on economic performance of the different crop production systems (see Annex).
1)   A price reduction of 10% compared to conventional crops is assumed in case of contamination with GM material.

The unintended contamination of crops with GM material might be managed by insuring this commercial risk within a general product liability insurance or a specific insurance which covers the specific commercial risks associated to the release of GMOs. The results of the above cost calculation could be taken as an indication of future insurance costs. The calculated costs are rather low, compared to the achievable gross margins and the possible damage. However, the failure rate, on which this calculation is based, might be different corresponding to the threshold that needs to be respected. If the failure rate were higher, for example in case a stricter threshold had to be respected, then potential insurance costs would rise. This scenario of course raises the question, if such a system would be viable.

5.3.2   Insurance and individual contracts – actual situation

The possibilities to insure the commercial risks of adventitious contamination with GM material highly depend on liability in this field. There is a rather heterogeneous legal framework related to deliberate release of GMOs into the environment in the Member States of the EU, and in particular how liability issues in relation to such releases are established. Some Member States use existing legislation mainly in the field of environmental laws or general product liability regulation for this purpose while other countries prefer the creation of specific laws to deal with individual industries like it is the case e. g. in Germany. In several EU Member States the legal regimes are based around "strict liability" principles which impose liability for contamination by GM material on the producer of the GMO regardless of fault. Under such a system, the plaintiff does not need to demonstrate any wrongdoing in order to affix liability to the defendant. Strict liability systems are introduced e. g. in Germany, Austria, France, Spain and Finland. Under a "fault based" liability system, compensation is dependant on the ability of the plaintiff to show negligence or some wrongdoing on the part of the producer of the GMO. Such

a system is applied e. g. in the United Kingdom and in Denmark. In some EU Member States, farmers are excluded from liability of damage caused by deliberate release of GMOs either by legislation or by the judiciary. In seed production the farmer multiplying seed is usually excluded from liability suggesting that either the seed company or a distributor who is bound to the seed company by contract will be liable in practice since both have to ensure quality of the produced seeds. The European Commission presented a legislative proposal on environmental liability in January 2002, which includes damage to biodiversity, water and soil caused by GMOs. In case the release of the GMO has been specifically authorised or the damage was not foreseeable on the basis of current scientific knowledge, there would be no strict liability. The proposal does not cover economic damage due to contamination of non-GM crops by GM crops[67].

All in all, there might be insufficient insurance coverage on farms in case of growing of GM crops. There are specific hurdles for insurance companies to offer (general of specific) policies, which cover the damage caused by adventitious contamination with GM material. Little if any experience is available to insurers in the EU on commercial risks associated with the deliberate release of GMOs or products containing GMOs. This applies for means for calculating likely loss patterns in this area as well. This absence of data promotes a fundamental doubt among insurance companies over the insurability of such commercial risks. The commercial risk profile of the use of genetic engineering in agriculture and the deliberate release of GMOs or products containing GMOs is extremely diversified and very difficult to quantify. In the view of the insurance industry, there is no clear perception of commercial risks involved in this area making this fields hard to measure and thus to insure.

There are also rather high restrictions for individual partners to handle the complex problem of the impacts of contamination with GM material in individual contracts. These relate to the lack of clear regulations in this area which can form the framework for individual contracts, the very limited experience with this problem between the individual partners and advisers active in this field as well as the missing of empirical data which allow the calculation of the probability and the extent of damage in case of contamination with GM material. This results in a rather uncertain position for both contract partners which they might try to avoid not least due to the fact that currently there are only very limited possibilities to insure such a commercial risk. This situation is rather unsatisfactory for persons or institutions as well which might be damaged in case of contamination with GM material since they cannot trust to get full compensation of damage.

---

[67] EC (2002) Frequently asked questions on the Commission's proposal on Environmental Liability. Memo 02/10

6   TOTAL COST ANALYSIS FOR THE SELECTED CROPS

In the previous chapters, individual costs are described and estimated. Chapter 3 proposes changes in agricultural practices including estimations of associated costs. Chapter 4 introduces a set of proposals on how to monitor the GMO content on farm level, and gives estimations of the costs connected with each farm type. Finally Chapter 5 addresses the financial risk of failing to comply with the studied threshold levels and associated costs (here called indicative insurance costs). In this chapter, the costs of changed agricultural practices, monitoring and indicative insurance costs are brought together for each model crop and each farm type and the total costs are presented and analysed. It should be noted that no empirical data is available for the costs since there are no systems running under the assumed conditions. Some of the cost estimations are based on data from other regions or from other systems. All cost estimations given in this chapter should therefore be interpreted with care.

This study only addresses the cost side of the economic effects from a future situation with up to half of the production being GM crops. Cost estimations are presented relative to the gross margin, including possible subsidies. The costs of labour[68] and capital are not included in the gross margin. Thus, the gross margin symbolizes the farmer's income before taxes, not taking into consideration the capital costs of having access to the agricultural land[69]. The comparison between costs and the gross margin is only carried out to better picture the range of the costs. Presented results can only indicate whether it is possible for non-GMO based agriculture to adjust to changed conditions, caused by the introduction of GM varieties in agricultural regions, considering the assumed labelling threshold levels. In reality, the segregation of non-GM and GM crops will also affect the demand side and market prices. Therefore the results presented here should not be used to forecast future market prices, nor the demand for non-GM and GM crops.

There are a number of earlier studies addressing the costs of segregation of GM and non-GM crops, although not using a scenario approach as applied here. A majority of the research has been carried out on the American market where examples of separation of non-GM and GM crops already exist. Buckwell et al.[70], analysed a number of case studies for crop separation, some of them being separation of non-GM and GM crops. However, the farm level costs were only presented in two cases: identity preservation of Brazilian non-GM soybean production resulted in increased costs of 10% of the price, and Canadian producers of identity preserved GM oilseed rape had cost increases equal to 6% - 8% of the price. The first case had a targeted threshold of 1%, although the working threshold was 0.1% with analyses carried out pre-harvest. For the second case, no threshold was applied since the GM crop was segregated. Moreover, it was not indicated whether cost of monitoring of neighbouring non-GM production was included.

In a more recent study, Bullock et al.[71], studied the economic effects from identity preservation of non-GM maize and soybean production in the US. They concluded that non-GM maize

---

[68] In some cases when labour input is assumed to be purchased from sources outside the farmer's family, labour costs are included in the calculation of the gross margin.

[69] The lack of empirical data made it impossible to take into consideration land costs. There are two methods that could be used:
  1. Use of empirical data of lease prices of the land used for production of the studied crops in the chosen regions. When detailed data is available, it gives a very straightforward result and it may incorporate quality aspects included in the study, such as fields prepared for irrigation or fields already converted to organic agriculture.
  2. Use of empirical data of land prices. From the hectare price, the annual capital cost can be estimated by choosing an appropriate interest rate. Results are highly dependent on the applied interest rate.

[70] Buckwell A, Brookes G and Bradley D (1998) "Economics of Identity Preservation for Genetically Modified Crops" CEAS Consultants (Wye) Ltd. CEAS 1745/GJB. Wye, England.

[71] Bullock D, S, Desquilbet M and Nitsi E, I (2000) "The Economics of Non-GMO Segregation and Identity Preservation" Working document, October 21, Dep. of Agricultural and Consumer Economics, University of Illinois. USA.

production below the threshold of 1% would be very hard to achieve without large isolation distances or GMO-free areas. For non-GM soybean to comply with the same threshold, additional farm level costs would be approximately 5-6 €/tonne. The only process identified by which contamination might occur was through the mixing of beans at planting and harvesting, thus costs only covered cleaning of machinery. No farm level monitoring was assumed and testing for GMO content was assumed to be done at point of delivery to a cost of less than 1 €/tonne. Together these costs represent approximately 3% of the price. According to their findings, the main costs along the food chain for separating non-GM and GM crops will most likely originate from logistic problems at the grain handling system, and not from adapted agricultural practices and monitoring of the GMO content. However, the size of associated costs largely depends on the targeted threshold level.

Assuming a very high demand elasticity, premia for non-GM crops can give a good indication of the costs of crop separation. According to USDA, farm level price premia for non-GM soybeans in the US 1999/2000 where around 4-6 €/tonne[72], which are very similar to the costs quoted from Bullock et al. above. They also indicate very low price premia for non-GM maize in the US 1999/2000 (2-4 €/tonne). This is a clear discrepancy compared to the conclusions drawn by Bullock et al., who suggests that separation of maize would require substantial changes of the agriculture practices, resulting in very high costs. A possible explanation could be that the non-GM maize, regarded by USDA, does not fulfill the 1% threshold requirement that was assumed by Bullock et al.

Similar to the study by Bullock et al. the Co-existence study has a forward looking approach, assuming a future with non-GM varieties being grown in presence of GM varieties in European agriculture. By studying a number of farm types, implications for non-GM agricultural are identified and quantified. In the study two alternative GM variety pressures are studied: 10% and 50%. The two different alternatives are used only to study the probability of GM contamination and are not intended as forecasts of future market shares for GM varieties. Compared to the studies cited above, the cost analysis is going wider by also including the potential costs of failing to comply with targeted thresholds. To estimate these costs, a price relation between non-GM crops and GM crops has to be established, despite the fact that this price relation will be determined by production costs and (consumer) demand. Here it is assumed that for all model crops, the market price for the GM crop is 10% lower than the price for the corresponding conventional non-GM crop. This is based on present North American price premia, but adjusted upwards to picture an expected lower European consumer confidence in products including GMOs, compared to the present situation in the US. It should be noted that reasonable changes in this assumption would only cause minor changes to the final results.

Neither monitoring nor indicative insurance costs are assumed to be affected by changes of the threshold level, instead adaptations are only done with the agricultural practices, leaving the assumed probability of exceeding the threshold unchanged. In reality, a changed threshold level would affect the overall risk management, including agricultural practices, monitoring activities and indicative insurance costs, and any of the three could be adjusted according to the change. For example, if a downward change of targeted threshold does not induce any change of practices due to an already low estimated GMO content, the probability of exceeding the (now lower) threshold will increase. This could be seen as an increase in insurance costs (in our model the failure rate would increase) or the on-line monitoring activities could be strengthened (e.g. by intensifying sampling schemes), increasing the monitoring costs while again reducing the probability of contamination and thus the failure rate. The most cost efficient approach of the two would be chosen or a combination of the two.

---

[72] Lin W, Chambers W, Harwood J (2000) "Biotechnology: U.S. Grain Handlers Look Ahead", Agricultural Outlook, April 2000, ERS/USDA. USA

6.1 Breakdown of costs

6.1.1 Costs of changing farming practices

The costs presented in Chapter 3 correspond to specific agricultural practices proposed for different farm types to comply with the studied thresholds. For a set of adapted farming practices, the costs of implementing the changes have been estimated in Chapter 3 and these are used directly in the calculation of total costs. In some cases, changes affect the logistics of the farm and post-harvest management, for example avoiding the practice of saving seed and seed exchange with neighbouring farms, dedicated storage facilities. The costs associated with these practices have not been estimated.

6.1.2 Costs of monitoring

The proposed monitoring systems are based on the HACCP system, which is largely based on a documentation approach. Presently PCR is the only detection method with enough functionality and accuracy to detect and quantify GMO content in this context. Unfortunately PCR analyses require several days between the sampling and the availability of results. Therefore it is likely that harvested crops will be delivered before the results of the tests are known, making it likely that crops of high GMO content will be mixed with non-GM crops. The HACCP approach substantially decreases this probability by the pro-active on-line monitoring structure.

A large part of costs origins from initial investment costs in the form of education and setting up the monitoring system. Here, these costs are distributed over 5 years. The initial costs together with costs for internal reviews and external audits do not vary according to farm size. This would lead to extremely high costs for very small farms. Instead it is assumed that farms smaller than 10 hectares co-operate with other small farms in setting up, reviewing and auditing the monitoring system (for details, see 4.2.4). The unit analysed for GMO content is the production from one field rather than single batches. Oilseed rape is tested each year while maize and potatoes are tested every second year.

6.1.3 Indicative insurance costs

Indicative insurance costs are calculated based on short-term costs for "failure of the system" (Chapter 5). The failure cost is estimated as the economic damage potentially to be covered by an insurance company in the case of unintended non-compliance with an agreed threshold. The analysis is based on the assumption of a 3% failure rate (based on failure rates of systems like certified seed production and organic production). The resulting costs could reflect possible insurance fees for the commercial risk of contamination of the harvest and are therefore called indicative insurance costs. The calculations assume a contamination above 1%, forcing the crop to be sold as a GM variety. A price reduction of 10% is assumed for GM varieties, compared to conventional varieties for each crop. In the case of oilseed rape seed production, if the contamination would be above 0.3% but below 1%, the crop could be sold as a conventional crop. If this possibility were taken into consideration, costs would slightly decrease, but the difference would be negligible. Failure costs are estimated for each crop in Chapter 5 and are summarised in Table 45.

Table 45: Costs of "failure of the system" for organic and conventional farms considering a failure rate of 3%

Crop	Country	Conventional farms (€/ha)	Organic farms (€/ha)
Oilseed rape/certified seed	United Kingdom	20.2	38.7
Oilseed rape/farm-saved seed	Germany	2.2	6.5
Maize (irrigated)	France	3.3	36.7
Potatoes	Germany	11.6	142
Early variety		14.4	176.7

6.2 Total costs for selected farm types

In the following chapters, costs of changing agricultural practices, monitoring GMO content and indicative insurance costs are presented for each farm type. Total costs are shown per hectare and per tonne. In addition, costs per hectare are shown as percentage of gross margin[73] and costs per tonne as percentage of price. For oilseed rape and potato, two different tables are presented, giving the estimated total costs for different thresholds. In this section, only the situation of 50% GMO share in the region is considered. For all three crops, Farm types 1-3 are presented in the crop-wise description. Two sections point out the impacts of conventional/organic production and of farm size, using additional farm types as examples. This is followed by a brief comparison of the different model crops to highlight differences[74]. The chapter ends with a comparison of costs related to gross margin, including and excluding agricultural subsidies.

6.2.1   Total costs for oilseed rape for seed production

Here, Farms 1, 2 and 3 are discussed as three base alternatives, each presenting a specific management system. Background information on each farm and associated total costs are presented in table 46.

Costs per hectare (targeted threshold 0.3%)
Total costs range from 126 €/t for Farm 3 and 127 €/t for Farm 1, to 345 €/t for Farm 2. For Farm 1 the main part of the costs comes from monitoring of the GMO content, while the costs for changes of agricultural practices are estimated to be zero (adding an extra spring crop to the rotation). The organic Farm 2 needs to introduce sowing of set-aside to assure a low rate of contamination. Therefore, costs for changing agricultural practices are very high, causing total costs to be almost three times as high as the corresponding conventional farm. The estimated additional costs for this practice (194 €/ha) are based on the assumption that current agricultural practices do not include any treatment of the set-aside land (see Chapter 3.1 for details). However, when far-reaching weeding problems exist, ploughing the set-aside and destroying the weeds may already be included in current practices. In this case the additional (new) costs would be less, leading to lower total costs. Monitoring costs are very high for both Farm 1 and Farm 2 because yields (2.3 – 3.5 t/ha) and the area of the oilseed rape producing fields (12 ha) are small. Both farms are selling a high added value product and thus also the indicative insurance cost is high, especially for the production of organic certified seeds.

The distribution of the costs for the conventional food and feed producer Farm 3 is different from the conventional producer of certified seed Farm 1. Farm 3 is a conventional grower that

---

[73] Gross margin is here defined as the gross revenue plus the area payments incl. payments for organic agriculture minus the variable costs.
[74] Farm type 5 for maize is not presented due to difficulties in estimating costs of changed practices.

saves seeds from one year to another. He will need to avoid sharing of machinery with neighbours and increase cleaning of the equipment in order to reduce the probability of contamination, which causes machinery costs to increase[75]. Compared to Farms 1 and 2, Farm 3 has six times more area cultivated with oilseed rape (70 ha). This reduces the monitoring costs per hectare considerably. The financial losses in case of contamination will be minor, thus the indicative insurance cost per hectare is low (2.2 €/ha).

Table 46: Associated costs for oilseed rape farms[(1)] (targeted threshold 0.3%)

Oilseed rape	Farm 1 Conventional certified seed production	Farm 2 Organic certified seed production	Farm 3 Conventional production with farm-saved seeds
Farm data: Model crop area (ha) Yield (t/ha) Price (€/t) Gross Margin (€/ha)	12 3.5 369.2 [(3)] 981.2	12 2.3 738.4 [(4)] 981.2 [(4)]	70 3.14 231 696.8
Cost of adapted agricultural practices (€/ha)	0 [(2)] *(Introducing an extra spring crop)*	194.3 *(Spring sown set-aside)*	93.2[(5)] *(Dedicated farming equipment)*
Monitoring cost (€/ha)	106.8	112.1	30.8
Indicative insurance cost (€/ha)	20.2	38.7	2.2
Total cost in €/ha (percentage of the gross margin)	127 (12.9 %)	345 (35.2%)	126 (18.1 %)
Total cost in €/t (percentage of price)	36.3 (9.8 %)	150 (20.3 %)	40.1 (17.4 %)
(1) Conditions: 50% GM varieties in the landscape, no GM varieties on the farm;			
(2) Cheapest solution chosen to reach the targeted threshold. Another measure would be a spring sown set-aside, efficient but more costly;			
(3) UK data;			
(4) For Farm 2 no empirical data exist: price per tonne has been assumed to be 100 % higher than the corresponding UK conventional price, while the gross margin is assumed to be identical with the gross margin for Farm 1[76];			
(5) Additional cost of dedicated farming machinery and cleaning of machinery for conventional oilseed rape farmers is estimated to 93.2 €/ha, corresponding to a 50 % increase of present machinery costs			

Costs per tonne (targeted threshold 0.3%)

For Farms 1 and 3, the cost per tonne is around 40 €/t, while the organic producer of certified seed will face extra costs of 150 €/t. This difference is explained by the costs for changed practices and the difference in yield between Farms 1, 3 and 2. The assumed price premium given to the organic product reduces the difference when relating the costs to product prices. Thus extra costs correspond to 20.3% of the price for the organic certified seed, 9.8% for the conventional certified seed and 17% for the conventional seed saving production of food and feed crop.

---

[75] To indicate the increased restrictions in use of machinery, machinery costs are assumed to increase by 50 % (93.2 €/ha).

[76] For conventional certified oilseed rape seeds, the price corresponds to 369.2 €/ton. Thus, the price for organic certified OSR seeds is assumed to be 369.2 x 200%=738.4 €/ton. This price premium was validated by discussions with a representative of a European producer of organic certified seed. It originates from cost increases from not using pesticides etc. It is therefore mainly a cost driven premium, as opposite to the price premia on organic products sold to consumers, which at present time are strongly affected by a short term structural lack of supply and which do not always reflect long term differences in production costs.

Impact on profitability and markets

These costs indicate a rather severe impact on the profitability of the studied farms and a loss in competitiveness. For certified oilseed rape seed, the possibility of passing on the extra costs to the buyer is realistic, given the fact that costs for seed purchase represent only a minor share of the input costs for farmers. In case of competing certified seed production in GMO-free areas (within or outside the European Union), these might acquire a competitive advantage and make the situation for seed producers in regions with GM crops more difficult.

For Farm 3 producing conventional oilseed rape, but using a share of the crop as seed in the following rotation, the implications could be different. If this farm failed to meet the 0.3% threshold for certified seed production, the contamination level could still be below the labeling threshold for food and feed production of 1%. So in fact the only loss in this case would be the costs of replacing the farm-saved seeds with certified seed purchased to the market price. This would give the farm a larger safety margin against economic losses than the other farms presented here.

Threshold of 0.1%

Recommended changes for agricultural practices differ depending on the targeted threshold. For both Farms 1 & 2, the recommended practice to respect a 0.1% threshold is to change the management of the set-aside part of the rotation by sowing in spring Italian rye-grass or hybrid clover. In Table 47, total costs to respect a low threshold of 0.1% are presented (for background information on each farm, see Table 46).

Table 47: Associated costs for oilseed rape farms[1] (targeted threshold 0.1%)

Oilseed rape	Farm 1 Conventional certified seed production	Farm 2 Organic certified seed production	Farm 3 Conventional production with farm-saved seeds
Cost of adapted agricultural practices (€/ha)	194.3 *(Spring sown set-aside)*	194.3 *(Spring sown set-aside)*	- *(not achievable)*
Monitoring cost per hectare (€/ha)	106.8	112.1	-
Indicative insurance cost per hectare (€/ha)	20.2	38.7	-
Total cost in €/ha (percentage of the gross margin)	321 (32.7 %)	345 (35.2%)	-
Total cost in €/t (percentage of price)	91.8 (24.9 %)	150 (20.3 %)	-
(1) Conditions: 50% GM varieties in the landscape, no GM variety on the farm.			

The cost of implementing recommended practices represents about 35% of the gross margin for Farms 1 and 2. The total cost per ton represents around 20% to 25% of the price for the farms. These costs are very high, for Farm 1 it is more than twice as high as for the threshold of 0.3%, while for the organic Farm 2, costs are the same.

Conclusions

The results point out that the monitoring costs would be crucial for the conventional certified seed producer. It might be possible to reduce these costs if the monitoring system were also be

applied to other crops on the farm, thus reducing the costs per hectare. The average life length of the investments in planning and implementing the system is assumed to be 5 years. With a longer life length, monitoring costs will decrease. Other factors influencing the costs of monitoring are the sampling and GMO analysis costs. One can consider that in the future, development in testing techniques would allow a reduction of the costs for detection and quantification of GMOs.

For the organic certified seed producer, in contrast to Farm 1, the additional costs for changing agricultural practices result in very high total costs for production in areas with GM varieties. In the case of competing production of organic certified seed from GMO-free areas, market prices might be too low to sustain the production of organic certified seed in areas with GM varieties. The same conclusion applies conventional and organic producers of certified seed when aiming at a threshold of 0.1%.

No change of farming practices can be proposed for conventional farmers of oilseed rape using farm-saved seed (Farm 3) to respect the 0.1% threshold in the production.

6.2.2   Total costs for maize for grain production

Farm types 1, 2 and 3 are presented as three base alternatives, each one presenting a specific agricultural system. Background information for each farm and estimated costs are presented in Table 48.

Costs per hectare and per tonne
The total costs per hectare vary between 55 €/ha for Farm 3 to 127 €/ha for Farm 2. For Farm 2 (organic farm), the extra cost is mainly influenced by monitoring and indicative insurance costs, while there is no need to change the current farming practices to respect the threshold of 1%. These costs are high, compared to larger conventional farms, despite the assumed co-operation for monitoring between three farmers (all in all 18 ha of maize). The high price premium for organic maize leads to high indicative insurance costs. Related to the price, the high price premium leads to lower total costs compared to Farm 1 (6% compared to 9%).

The distribution of the costs for Farm 1 is different. The distance between fields is very small (0.8m – 100m) and the probability of contamination by cross-pollination is higher than for Farm 3. Farm 1 needs to change farming practices at cultivation level (50 °days difference in flowering time) in addition to changes at post-harvesting level, which also applies to Farm 3. Therefore, Farm 1 has nearly twice as high additional costs compared to Farm 3.

Farm 3 has the lowest total costs per hectare. Farm 3 is a farm growing grain maize in a region with low percentage of maize in the landscape (20% of the cultivated area) and with large distances between maize fields (500m). The farmer will only need to change post-harvest management, a cost that has not been estimated.

Impact on profitability and markets
The conventional farmer growing maize in a region with intensive production of maize (Farm 1) will have to support a higher cost (9 €/t) than the farmer who is growing maize in a region with less maize in the landscape (5 €/t). This result can be interesting for new farmers who could choose where to grow maize and who would compare this extra-cost with the cost of production in these two regions.

Table 48: Associated costs for maize production[1] (targeted threshold: 1%)

Maize	Farm 1 Conventional intensive production (maize 80% AUA[2])	Farm 2 Organic production (maize 10% AUA[2])	Farm 3 Conventional non-intensive production (maize 20% AUA[2])
Farm data: Model crop area (ha) Yield (t/ha) Price (€/t) Gross Margin (€/ha)	50 10.15 98.5 956	6 9.0 228.7 1726	20 10.06 108.1 1098
Cost of adapted agricultural practices (€/ha)	45.4[3] *(50 °days difference in flowering time + post-harvest management[4])*	0 *(current practices satisfactory)*	*n.d.[4] (post-harvest management)*
Monitoring cost (€/ha)	46.2	90.8[5]	52.0
Indicative insurance cost (€/ha)	3.0	36.7	3.3
Total cost in €/ha (percentage of the gross margin)	95.6 (9.9 %)	127 (7.4 %)	55.3 (5.0 %)
Total cost in €/t (percentage of price)	9.3 (9.5 %)	14.2 (6.2 %)	5.5 (5.1 %)

(1) Conditions: 50 % GM varieties in the landscape, 50% GM varieties on the farm for conventional farms, no GM variety on the organic farm
(2) AUA: Agricultural used area
(3) Costs for neighbours to Farm 1 growing GM maize to change from late to mid-early variety
(4) Due to small area of maize production, it is assumed that three identical farms co-operate to lower the investment costs (3 x 6 ha maize)
n.d. not determined. Costs of changes in post-harvest management are not estimated and are not included in the total costs. The changes might be to dedicate an entire silo to one variety of maize, or to declassify first batches when drying different varieties in the central dryer.

Threshold of 0.1%

The production of maize with a level of adventitious presence of GMOs lower than 0.1% might only be possible employing an isolation strategy with a good control of seed purity, effective practices in the field as well as in the management of batches after harvest. The cost for such an isolation strategy has not been estimated because of the very complex nature and the involvement of different farms. The cost of monitoring and insurance was assumed not to change with different targeted thresholds.

Conclusions

Farm 1 producing conventional maize in a region with high intensity of production will have the highest additional costs among the three farms (10% of the gross margin), while Farm 3 will have the lowest additional costs (5% of the gross margin). Monitoring costs are important for all farms and represent the main part of the total costs. The farmer can reduce the costs of monitoring by increasing the area of production of maize to reduce the costs per hectare. Also the production of varieties with higher added value could compensate the costs of monitoring the GMO content.

6.2.3   Total costs for potato for food production

Farm types 1, 2 and 3 are presented as three base alternatives, each one presenting a specific agricultural system. Background information for each farm and associated total costs are presented in Table 49.

Table 49: Associated costs for potato farms[1] (targeted threshold 1%)

Potatoes	Farm 1 Conventional potatoes	Farm 2 Organic potatoes	Farm 3 Conventional early potatoes
Farm data: Model crop area (ha) Yield (t/ha) Price (€/t) Gross Margin (€/ha)	30 41.9 92 2275	25 25.1 276 5166	15 27.2 177 2813
Cost of adapted agricultural practices (€/ha)	0 *(current practices satisfactory)*	0 *(current practices satisfactory)*	0 *(current practices satisfactory)*
Monitoring cost (€/ha)	41.5	59.3	92.5
Indicative insurance cost (€/ha)	11.6	142	14.4
Total cost in €/ha (percentage of the gross margin)	53.1 (2.3%)	201 (3.9%)	107 (3.8%)
Total cost in €/t (percentage of price)	1.3 (1.4%)	8.0 (2.9%)	3.9 (2.2%)
(1) Conditions: Conventional farms grow both GM and non-GM varieties, no GM variety on organic farms, 25% - 50% GMOs in the landscape, data for German farms			

Total costs per hectare
Total costs range between 53 €/ha for Farm 1 to 201 €/ha for Farm 2 (organic). The costs have the same origin for all three farms: monitoring and indicative insurance costs. The current farming practices are sufficient to comply with a 1% threshold and no costs due to changes in farming practices are envisaged. For Farms 1 and 3, the main part of the costs is caused by monitoring activities. For the organic Farm 2 the indicative insurance cost is extremely high (142 €/ha), due to the very high added value of organic potato production, while it is much lower for the conventional Farms 1 and 3. For all farms, additional costs are comparatively low in relation to gross margin (2% - 4%).

Total costs per tonne
The total costs per tonne vary between 1.3 €/t for Farm 1 to 8 €/t for Farm 2. This is rather low compared to both oilseed rape for seed production (36 - 66 €/t) and grain maize (6 - 9 €/tonne), and is due to a higher yield for potatoes (between 25 t/ha and 42 t/ha).

Lower threshold
Several recommendations can be made to reduce the contamination at farm level, but it probably would not be sufficient to reduce the contamination level below a 0.1% threshold (see Chapter 3.3 for details). The proposed actions include the use of seed tubers coming from areas free of GM potatoes, introduction of a cereal in the rotation after potatoes and storage in labeled boxes during post-harvesting. Among these actions, only the cost of implementing a batch traceability system has been estimated. The total cost analysis (including the costs of introducing a traceability system) is presented in Table 50. With the introduction of all

measures described above, threshold levels of 0.25% for Farms 1 and 2, and of 0.5% for Farm 3, are feasible (see Table 34 for details concerning contamination levels, and Table 49 for background information on each farm).

Table 50: Associated costs for potato farms including the introduction of a batch traceability system[1]

Potato	Farm 1 Conventional potato	Farm 2 Organic potato	Farm 3 Conventional early potato
Cost of adapted agricultural practices (€/ha)	299 *(system of batch traceability)*	359 *(system of batch traceability)*	598 *(system of batch traceability)*
Monitoring cost (€/ha)	41.5	59.3	92.5
Indicative insurance cost (€/ha)	11.6	142	14.4
Total cost in €/ha (percentage of the gross margin)	352 (15.5%)	560 (10.8%)	705 (25.1%)
Total cost in €/t (percentage of price)	8.4 (9.1%)	22.3 (8.1%)	25.9 (14.6%)
(1) Conditions: Conventional farms grow both GM and non-GM varieties, no GM variety on organic farms, 25% - 50% GMOs in the landscape, data for German farms			

The cost of introducing a traceability system is very high for the producer of potato and leads to an increase of associated costs to 16% of the gross margin for conventional growers and 25% for the producers of early potatoes. For Farm 3, the total cost of implementing a traceability system, monitoring and insurance cost will represent 15% of the price. This cost can be reduced if the farmers increased the area under production and thus could distribute the investment cost over a higher production.

The proposed cost for a batch traceability system was also calculated for organic potatoes. However, in the case of organic farmers, their crop management system might already include a traceability system. This would mean that the cost for organic farms would be over-estimated.

Conclusions
Potato production will be less affected in economic terms than maize and oilseed rape. Costs for complying with the 1% threshold represents 1.4% – 2.9% of price for the three farms presented here. No changes of agricultural practices are needed and monitoring costs are low due to high yields. The organic production has the highest costs due to higher indicative insurance costs. However, it is not feasible for any of the farms to safely comply with the lower 0.1% threshold, even with changes of agricultural practices.

6.3 Additional analyses

The overall implications for producers of different crops depend on the specific agricultural characteristics of each crop and the structure of the production. Individual farm types for the different model crops have been developed based on present farming structures. If identical farm types in terms of e.g. size and climatic conditions had been used, a comparison between model crops would have better pointed out the differences between crops. It had not, however, given a better picture of the cost implications for the actual farmers. Below, the impact of two

key features are analysed, causing differences within the model crops: type of agriculture system (conventional or organic production) and variations in farm size. This is followed by a summary of the differences between the model crops, using the defined farm types. Finally, a comparison is made of including or excluding the subsidies in the gross margin when relating the costs to current farm profitability levels.

6.3.1   Impact of agricultural system

Organic production is affected differently by the co-existence with GM production than conventional production. The probability of contamination is sometimes higher due to agricultural practices that for example allow more weeds to grow but often the probability is lower, for example due to higher seed purity. Monitoring of the crops does not differ markedly, even though the lower yield normally associated with organic farming can lead to higher costs per tonne. The only general and substantial difference is the financial risk of failure to meet the threshold. The risk of losing the often high price premia substantially increases the expected economic impact. However, not all organic crops carry high price premia. Table 51 compares total costs between the conventional Farm 3 and the organic Farm 4 for all three model crops.

The differences between the conventional oilseed rape Farm 3 and the organic Farm 4 are similar to the differences found between Farms 1 and 2 (see 6.2.1), with dramatically higher total costs for Farm 4, compared to the conventional Farm 3. Total costs are 323 €/ha compared to 126 €/ha for the conventional farm. Costs per tonne equal 41% of the price, compared to 17% for the conventional alternative. All costs increase, but most notably the costs for adapted practices due to the introduction of sowing the field during the set-aside phase of the rotation. As for Farm 2, additional costs may be reduced if current agricultural practices already include some management of the set-aside areas, e.g. ploughing and destroying of the weeds.

For the organic maize Farm 4, costs per hectare are 92 €/ha, almost 70% higher than for the conventional Farm 3. The low yield makes the difference per tonne even larger with a close to 100% cost increase. The key factor is the indicative insurance cost which is substantially higher due to the price premium for organic maize (229 €/t compared to 108 €/t). However, the high premium also reduces the costs as percentage of the gross margin (5.3%) and of the price (4.5%), in fact they are almost identical to the relative costs for the conventional farm.

For the organic early potato producer, Farm 4, the trends are the same but reinforced. The main difference between the organic and the conventional farm is again the indicative insurance cost (274 €/ha as compared to 107 €/ha). Since conventional early potato is a labour intensive crop with a high price, gross margin excluding labour and land costs is also high. Thus, the 200% price premium received for organic production corresponds to dramatic increases in gross margin, leading to very high indicative insurance costs. The effect of the high price is reduced when comparing the costs as percentage of gross margin and of price with only slightly higher relative costs for the organic Farm 4.

In the future, if organic production volumes increase, it is likely that the organic price premia will be reduced. The indicative insurance costs would then decrease, lowering total costs per hectare and per tonne. However, since price and gross margin also would be reduced, the costs as percentage of gross margin or price could actually increase.

Table 51: Associated costs for the conventional Farm type 3 and the organic Farm type 4 for all three model crops
(Targeted threshold: 0.3% for oilseed rape and 1% for maize and potato)

	Oilseed rape [1] seed saving production		Maize [1] non-intensive production		Early Potato [2] production	
	Farm 3 conv.	Farm 4 organic	Farm 3 conv.	Farm 4 organic	Farm 3 [3] conv.	Farm 4 [3] organic
Farm data: Mod. cr. area (ha)	70	70	20	20	15	15
Yield (t/ha)	3.14	2.04	10.06	9.0	27.2	16.3
Price (€/t)	231	277	108.1	228.7	177	531
Gross Margin (€/ha)	696.8	841	1098	1726	2813	5930
Cost of adapted agricultural practices (€/ha)	93.2[4] *(dedicated farming equipment)*	194.3 *(sowing of set-aside)*	*n.d.[5]* *(post-harvest management)*	0 *(current practices satisfactory)*	0 *(current practices satisfactory)*	0 *(current practices satisfactory)*
Monitoring cost (€/ha)	30.8	31.2	52.0	55.3	92.5	97.2
Ind. insurance cost (€/ha)	2.2	6.5	3.3	36.7	14.4	176.7
Total cost in €/ha (percentage of the gross margin)	126 (18.1 %)	232 (27.6 %)	55.3 (5.0 %)	92.0 (5.3 %)	107 (3.8%)	274 (4.6 %)
Total cost in €/t (percentage of price)	40.1 (17.4 %)	113.7 (41.1 %)	5.5 (5.1 %)	10.2 (4.5 %)	3.9 (2.2%)	16.8 (3.2 %)

(1) Conditions: 50% GM varieties in the landscape and on the conventional farms; (2) Conditions: conventional farms grow both GM and non-GM varieties, no GM variety on organic farms, 50% GMOs in the landscape; (3) German data; (4) Additional cost of dedicated farming machinery and cleaning of machinery for conventional oilseed rape farmers is estimated to 93.2 €/ha, corresponding to a 50 % increase of present machinery costs; (5) n.d. not determined. Cost of changes in post-harvest management is not estimated and not included in the total costs. The changes might be to dedicate an entire silo to one variety of maize, or to declassify first batches when using different varieties in the central dryer.

When viewing these results, one should remember that the targeted threshold is identical for conventional and organic production. The level of the targeted threshold is of utmost importance. It is not economically feasible to achieve a long-term production complying with the lower threshold of 0.1% for any of the 13 food and feed producing farms studied – conventional or organic – with GM varieties representing a substantial part of the production on a landscape level.

6.3.2   Impact of size

The total size of the farm, the area producing the studied crop and the size of the individual fields are affecting costs, smaller areas leading to higher costs per hectare and per tonne production. Naturally, the crop area and the field size are both strongly correlated with the total farm size. Everything else identical, smaller areas increase the probability for contamination and the costs for monitoring are distributed over a smaller area and production. In Table 52, the effects are pointed out by comparing Farms 2 and 2' for oilseed rape and Farms 4 and 4' for maize. Both pairs of farm types are identical except for the size of the farms, the crop area and the field size.

Both the larger Farm 2 and the smaller Farm 2' will have high costs for changing agricultural practices, mainly originating from the sowing of set-aside (see Chapter 3.1 for details). Farm 2' is more vulnerable to cross-pollination than Farm 2 due to the proximity of GM crops caused by the small acreage and needs to introduce some additional measures (border cutting, later sowing of non-GM rape and chiselling instead of ploughing for some parts of the rotation). In addition Farm 2' will have extremely high costs for monitoring of GMO content. The crop area is only 1 ha which makes the co-operation with other farms of the same size insufficient to reduce costs. The result is more than twice as high costs, as compared to the already very high costs for Farm 2. It seems obvious that a farm of this size will not be competitive with additional costs representing 40% of the price as compared to less than 20% for the larger units.

For the small organic maize Farm 4', the outlooks are different. Neither the large Farm 4 nor the small Farm 4' need to change agricultural practices, and the monitoring costs are markedly reduced through the co-operation with other farms of the same size. Still, the additional costs will be equal to almost 10% of present price, which is more than double compared to the larger Farm 4.

As for the second very small maize farm, Farm type 2' (not shown in Table 52), costs of changed practices and indicative insurance costs are identical with the larger maize Farm 2. Although the very small crop area, 1 ha, causes extremely high monitoring costs per hectare. The total costs are 333 €/ha, compared to 127 €/ha for the larger but otherwise identical maize Farm 2.

With a cost structure as assumed here, it seems that size is of higher general importance than whether the production is conventional or organic, as long as the same threshold is applied to both production systems. Small farms will have to bear higher cost per hectare and per tonne production, and this with no chance of getting a premium since the output from identical but differently sized farms are equally priced.

Table 52: Associated costs for oilseed rape Farms 2 and 2' (targeted threshold 0.3%) and for maize production Farms 4 and 4'
(targeted threshold: 1%)

	Oilseed Rape [1] organic certified seed production		Maize [2] organic non-intensive production	
	Farm 2 **Large farm**	**Farm 2'** **Small farm**	**Farm 4** **Large farm**	**Farm 4'** **Small farm**
Farm data: Model crop area (ha) Yield (t/ha) Price (€/t) Gross Margin (€/ha)	12 2.3 738.4 981.2	1 [3] 2.3 738.4 981.2	20 9.0 228.7 1726	3 [4] 9.0 228.7 1726
Cost of adapted agricultural practices (€/ha)	194.3 *(Spring sown set-aside)*	200.5 *(combination of changed practices)*	0 *(current practices satisfactory)*	0 *(current practices satisfactory)*
Monitoring cost (€/ha)	112.1	439.4	55.3	157.9
Indicative insurance cost (€/ha)	38.7	38.7	36.7	36.7
Total cost in €/ha (percentage of the gross margin)	345 (35.2%)	679 (69.2 %)	92.0 (5.3 %)	195 (11.3 %)
Total cost in €/t (percentage of price)	150 (20.3 %)	295 (40.0 %)	10.2 (4.5 %)	21.6 (9.5 %)
(1) Conditions: 50% GM varieties in the landscape, no GM varieties on the farm (2) Conditions: 50% GM varieties in the landscape (3) It is assumed that five farms co-operate and share the costs, which are fixed on farm level. (4) It is assumed that three farms co-operate and share the costs, which are fixed on farm level.				

6.3.3   Comparison between model crops

To compare the effects of the additional costs on the different model crops, costs as percentage of price is used. Using costs per hectare or costs per tonne could give a false picture when yields and product prices vary widely. Percentage of gross margin is slightly better but since the study uses gross margin excluding costs for own labour as well as land costs, differences in labour input and requirements on soil and climate would not be considered. In Figure 9, the percentage of price is presented for Farm types 1-4 for the three model crops for the 0.3% (oilseed rape) and the 1% threshold (maize and potato). All values given are extracted from Tables 46, 48, 49 and 51.

There are clear differences between the three crops. Oilseed rape has high additional costs (8.9% - 41%) with the organic certified seed producing Farm 2 and the seed saving Farms 3 and 4 having the highest costs. Oilseed rape production has a lower targeted threshold (0.3%) than the other two crops (1%), which affects Farms 2, 3 and 4. The seed saving Farms 3 and 4 would probably have to stop saving seeds and instead buy certified seeds. The 0.3% threshold for seed production may then be replaced by the 1% threshold for food and feed production. This would decrease additional costs significantly, much more than the costs of having to buy additional seeds for sowing. Maize production is less affected by the additional costs, ranging from 4.5% for the organic Farm 4 located in a non-intensive area, to 9.5% for Farm 1 with intensive production. The lower relative costs compared to oilseed rape are due to larger areas of production, higher yields and a higher targeted threshold. For maize, in contrast to oilseed rape, the conventional producers will have higher costs than the organic producers. The reason for this is that the organic farms do not have to introduce any agricultural changes. In addition, for conventional producers, the estimated costs are underestimated, as costs for necessary changes in the post-harvest management are not included. For potato production, the high yields give even lower additional costs ranging from 1.4% to 3.2%.
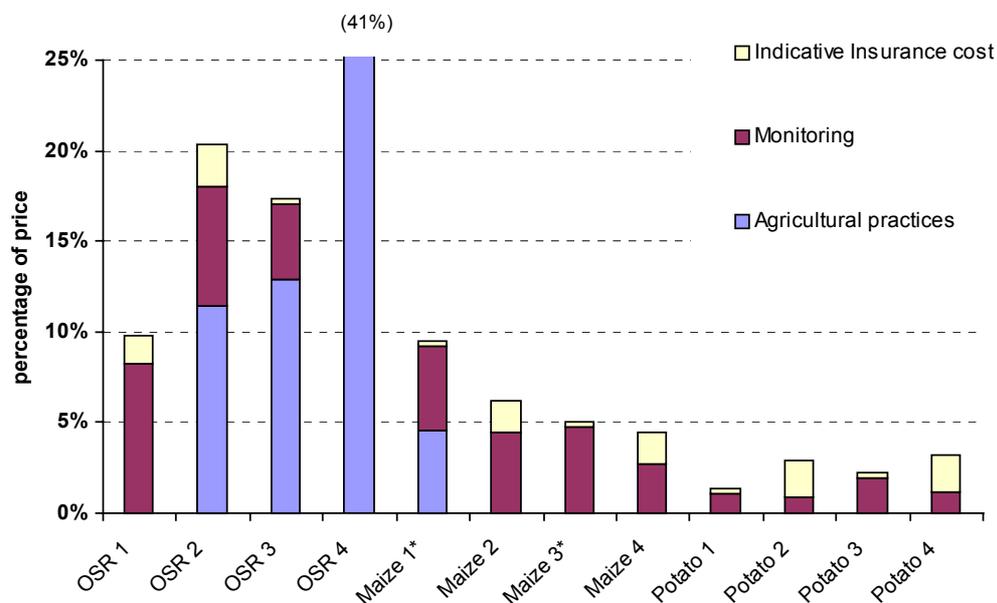
Figure 9: Comparison of costs as percentage of price between the three model crops.
Farm types 1-4 (Targeted threshold: 0.3% for oilseed rape and 1% for maize and potato) (*for conventional maize costs for changes in the post-harvest management are not included)

6.3.4   Impact of subsidies

In all calculations presented above available subsidies are included. The subsidies form an integrated and important part of the farmers' income and can be seen as income from internalised positive external effects for society. However, if costs per hectare are related to the gross margin excluding subsidies, the impact as a share of gross margin increases dramatically in many cases. In Figure 10 the costs as a share of gross margin, including as well as excluding subsidies, are presented for Farms 1-4 for each model crops. The subsidies consist of area payment and subsidies for organic production (when applicable) and are presented in the Annex.
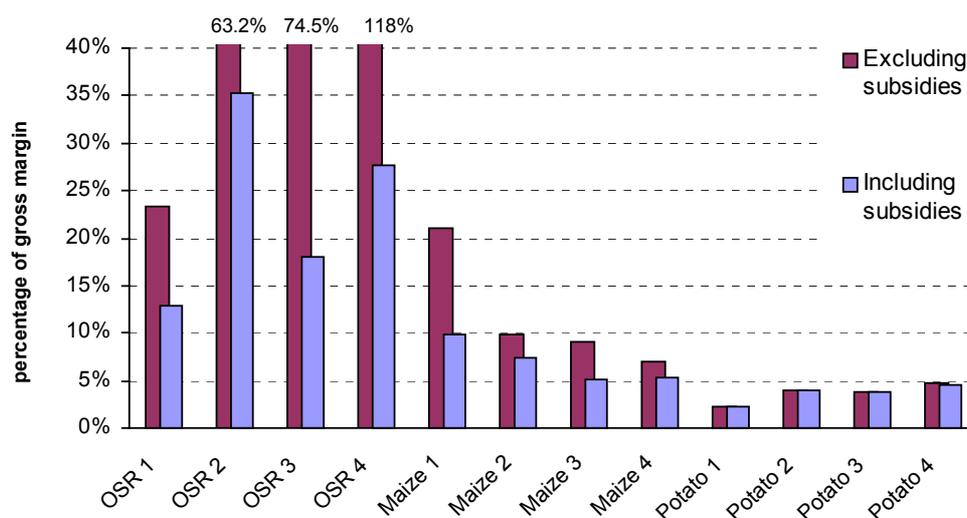
Figure 10: Costs related to gross margin, with gross margin including and excluding subsidies Farms 1-4 for each model crop (Targeted threshold: 0.3% for oilseed rape and 1% for maize and potato)

For oilseed rape the difference is very large, with costs for Farms 3 and 4 increasing from 18.1% to 74.5% for Farm 3, and from 27 % to 118% for Farm 4, of the gross margin. For the rest of the oilseed rape farms and for maize Farms 1 and 3 the share approximately doubles. For all these farms the subsidies play a major role in farm profitability, and when subsidies are deducted from the gross margin, the gross margin falls dramatically. For maize Farm 2 the importance is minor while the three potato farms have no subsidies at all (Farm 1 and Farm 3), or the importance is negligible (e.g. Farm 2 receives 114 €/ha with a total gross margin of over 5000 €/ha).

7   GENERAL CONCLUSION

From the results presented in Chapters 2 to 6, the conclusions presented below can be drawn. At this point it should be stressed again that the results presented in this study are based on certain assumptions and partly have been achieved by using computer simulations. The results are suitable for comparing different farming practices regarding their efficacy for contamination minimisation but are less precise for determining defined contamination levels. For this reason the results should be interpreted with care and can only be generalised to a certain extent. Regarding the costs, any changes in demand and market prices, that would probably accompany an increased level of GM crops in agriculture have not been taken into account in this study. The results should not be used to forecast neither future market prices nor the demand for GM and non-GM crops.

The study focused on non-GM and organic farming and on additional costs that might arise caused by intentions to produce non-GM crops. In most cases changing of farming practices and the additional costs presented are directly connected to conventional or organic farms. When proposed agricultural changes are partly aimed at the GM production, costs are still borne by the non-GM production. The possibility of containment of transgenes, by using for example infertile GM varieties or by inserting the transgene in the chloroplast genome, which would not be transferred by pollen, has not been considered.

The results obtained for the different crops and the different farming types point out that the question, if co-existence of GM and non-GM crops in the European agricultural landscape would be possible, can only be answered on a case by case basis. The specific crop characteristics as well as the farm structure, cultivation and post-harvest processes have to be taken into account. The applied threshold level, defining acceptable adventitious contamination rates, is of utmost importance. Costs associated with the co-existence of GM and non-GM crops increase dramatically with a lowered threshold level.

7.1   Crop specific results

7.1.1   Oilseed rape for seed production

- Regarding the studied farm types and defined farming practices, already a low GMO share of 10% could lead to contamination above 0.3%. For all farm types studied, a significant reduction of contamination levels seems to be possible in the presence of 10% as well as 50% GMOs, mainly by management of borders and sowing set-aside to minimise volunteer problems. The results suggest that even a contamination value below 0.1% could be achieved for most farms, but at higher costs.

- Organic farms seem to be more vulnerable to contamination, mainly because of less efficient volunteer control. But also for these farms there are effective farming measures at hand to reduce contamination levels.

- For certified seed production, the total costs (including costs for changing practices, monitoring and potential insurance costs) would represent between 10% (conventional) and 20% (organic) of the price for a targeted threshold of 0.3% and assuming 50% GMOs in the region. The costs originate from costs of changing farming practices, monitoring costs and indicative insurance costs. Aiming at the lower threshold (0.1%) costs would increase to 25% of the price for the conventional producer, due to increased costs for changed farming practices. For the organic producer, costs would be the same as for the higher threshold. The costs might be passed on to the seed buyer, since costs for seed are a minor part of agricultural input costs.

- The farms producing food and feed crops that are saving seed cannot as easily adapt to the 0.3% threshold. The costs represent 17% and 41% of the product price, with the organic farm worst affected. For both farms the costs for changed agricultural practices dominate the total costs. Due to the high costs, these farms would probably be forced to stop saving seed. The farms grow crops for food and feed use, and the threshold of 0.3% is applied to them only because of the seed saving practice. If the farms stopped this practice, the 1% threshold could be applicable. This would result in dramatically decreased costs of changed agricultural practices, which would reduce the total costs substantially. Concerning the lower threshold 0.1%, it is not possible for the conventional farm to achieve this low contamination rate, while the organic farm would have costs corresponding to almost half of the product price.

- The simulations are made for the production of hybrid seed, describing a worst case scenario. Under identical conditions, one can expect the contamination level for non-hybrid seed production to be lower than for hybrid seed. This could lead to differences when developing best practices for non-hybrid seed production, compared to the agricultural practices proposed here.

7.1.2   Grain maize for feed production

- Regarding maize, the conventional farms studied would probably have contamination problems at 10% as well as 50% GM maize in the region. In contrast, the organic farms studied might be able to produce maize with GM contamination below 1% without changing their farming practices. A very low contamination level seems very difficult to achieve for all types of farms even by changing farming practices.

- A main source of in-field contamination is cross-pollination from GM sources, the impact being dependent on relative plot size of the GM source and the non-GM recipient as well as on isolation distances. Small farms or farms with smaller fields would be more affected. Volunteers in maize are not a significant source of contamination.

- Apart from cross-pollination, post-harvest handling of the grains presents a major source for potential contamination, which is difficult to avoid. Investment in additional storage facilities or reorganising the central collection and storage organisations would improve the situation. Probably the introduction of "production islands", dedicated to specific maize varieties, would allow to respect very low levels of contamination.

- In the case of maize, seed purity plays a major role. If pure seed could be purchased, contamination levels could be reduced considerably.

- Additional costs (including costs for changed practices, monitoring and indicative insurance costs) would amount to between 4% and 9% of price. Although costs originating from post-harvest management changes have not been included in the calculation, this would represent a very high price increase for a commodity crop like maize, if passed on to the buyer. Main costs arise because of the monitoring system, thus a reduction of these costs, e.g. through increasing production units or through distributing the fixed costs on more than one crop, could reduce the total costs considerably.

7.1.3   Potato for food production

- The example of potato shows that crop characteristics influence probability of contamination considerably. A threshold of 1% seems to be achievable for all studied farm types without changing current farming practices. The necessary monitoring system and insurance costs would amount to between 2% and 5% of the gross margin or between 1% and 3% of the price, which is a comparatively small amount.

- Surprisingly, also with this crop, the results indicate that a 0.1% contamination level would not be feasible to achieve, considering a GMO share of 25% - 50% in the region.

7.2 General results

- General factors that influence contamination levels have been identified:
  - Seed purity
  - Crop variety (homo-/heterozygous, hybrid variety)
  - Isolation (isolation in space / isolation in time, e.g. difference in flowering time)
  - Volunteer management
  - Field sizes
  - Field pattern
  - Grain handling processes (harvest, storage, drying, transport)

- Generally a very low contamination threshold (here 0.1%) seems to be very hard to achieve. In all cases studied, reducing contamination levels below 0.1% is very difficult and connected to high costs, or impossible.

- Problems with the handling of the crop seem to be more difficult to solve than in-field contamination problems. Generally, investments in additional machinery and storage facilities would be necessary or complete changes of processes, affecting the logistics of the farm.

- To grow GM and conventional or organic crops on the same farm might be an unrealistic scenario, considering the thresholds applied in this study. Due to the importance of volunteers, oilseed rape seed producers will exclude growing GM crops on the same farm to avoid the risk of contamination of their seeds. Also for maize and potatoes, co-existence on the farm would make the handling of the crops more difficult.

- Co-existence of GM and non-GM crops in a region might be possible, depending on the threshold that is envisaged. As the results show, a very low threshold might not be achievable with neither 10% nor 50% GMOs in the region. The establishment of GMO-free regions might be an issue, especially considering seed production.

- For some farm types, changing farming practices at the level of the farm unit is sufficient to reduce contamination. Nevertheless, most farm types require at least a partial co-operation between neighbours and these are generally the most effective measures.

- The performance of organic farms regarding probability of contamination depends on the crop and on the farm and field size. The latter is also a factor that would influence conventional farms, all the more as the average size of organic farms in the EU with 25 ha is larger than the average size of conventional farms (19 ha). However, the situation in the individual Member States is very variable. Generally, since organic farms are segregating their crops from conventional crops, the handling of the crops seems to be no problem. Still, achieving a contamination level of "0%" appears to be very problematical. Regarding oilseed rape, organic farms have more difficulties with contamination than conventional farms, because of volunteer management. Regarding maize, since volunteers do not pose a problem, organic farms in this study have fewer problems with contamination. This is also true for potato production.

- Segregation systems in place (such as those for waxy maize or high erucic acid oilseed rape) are not suitable without changes for the purpose of minimising contamination of crops with GM crops. In general the thresholds assured by these systems are less stringent than those being established for GM crops. Also, some of these segregation systems are backed

by cheap, fast and easy detection methods (iodine staining for waxy maize) while current methods for detecting and differentiating GM varieties do not yet have these characteristics.

- The costs for monitoring are very high, partly because the high costs for GMO analysis. In future it can be expected that faster and cheaper methods will be developed to detect and quantify GMOs in crops.

- Monitoring of very low levels of GM materials and identification of a variety of genotypes is a pre-requisite for the determination of seed purity and for the verification of non-GMO status of agricultural crops. PCR analysis (DNA detection) is the method of choice for qualitative and quantitative analysis while immunoassays (protein detection) are used for quick yes/no answer for in-field evaluation. GMO analysis will benefit with the development of new analytical methods (miniaturization devices, microchips, microfluidic systems) and the establishment of gene registers and dedicated information systems.

- Sampling strategies and analytical methods need validation and harmonization at European and international level in order to have more accurate and reliable methods. The European Network of GMO Laboratories undertakes validation of analytical methods at European level.

- The GMOs considered in this study are assumed to express the so-called *input* traits. If the introduced GM varieties mainly include value-adding traits, the GM crops could receive a price premium. This might lead to a market driven identity preservation of GM varieties, thus facilitating the segregation of non-GM production, e.g. adding incentives for changing flowering time on GM varieties. However, due to a number of reasons the effects are likely to be minor. Firstly, the threshold levels will probably be higher, due to the increasing marginal costs of increased purity. One can compare these identity preservation systems with the system for waxy maize, where a 4% threshold is applied. Secondly, many possible agricultural changes only reduce the probability of cross-pollination and seed spreading, while leaving other sources of GM contamination in non-GM crops unchanged.

- Another conclusion to be drawn from the study is that important data are not available. Regarding probability of contamination, additional research is necessary to provide experimental data on gene flow for oilseed rape, maize, potato and other crops.

- More information on actual levels of seed impurities in the lots marketed in the EU (which is becoming available from some Member States laboratories) is essential for simulations like the ones presented here. Also, a study similar to the one described here for OSR seed could be useful for maize seed, to better understand how co-existence will impact on seed production and to provide information for an adaptation of seed production standards.

- Regarding economic data, the study lacks the cost estimation of some of the proposed agricultural changes. To estimate costs of for example introducing large isolation distances, the alternative use of the agricultural land has to be analysed. Changing post-harvest management could include changes of the logistics at the next step of the supply chain, again leading to very complex analyses. This points out the need for a further study, concentrating on the economic part and probably going into more detail with a reduced number of cases taking into account the complete economic structure of a farm.

ANNEX I: ECONOMIC PERFORMANCE OF OILSEED RAPE

Table 53: Economic performance of oilseed rape seed production in the United Kingdom
Source: Nix & Hill, 2000, White, 2000 [4]; own calculations

Region	UK	UK
Crop	**Conventional certified seed**	**Organic certified seed [3]**
Farm type	**OSR 1**	**OSR 2, 2'**
Yield (t/ha)	3.50	2.3
Price (€/t)	369.2	738.4
Gross income (t/ha)	1292.2	1698.32
Variable costs (€/ha) **Seeds** **Fertiliser** **Crop protection** **Machinery and other costs**	 129.7 160.1 205.2 251[2]	 n. a.
Total variable costs (€/ha)	746	1152.12
Gross margin (€/ha)	546.2	546.2
Area payment (€/ha)[1]	435.0	435.0
Gross margin + payments (€/ha)	981.2	981.2

1) The area payments include price compensation payments as well as payments for set-aside programmes which have been introduced in the reform of CAP in 1992/93.

2) Machinery and other costs have been added using data from the conventional German farm

3) For certified organic seed a price premium of 100% compared to conventional certified seed was assumed. This price premium was validated by discussions with a representative of a European producer of organic certified seed. It originates from cost increases from not using pesticides etc. It is therefore mainly a cost driven premium, as opposite to the price premia on organic products sold to consumers, which at present time are strongly affected by a short term structural lack of supply and which do not always reflect long term differences in production costs. Thus, the gross margin is assumed to be similar to conventional seed production, and the total variable costs have been calculated as the difference between the gross income and the gross margin. Therefore no breakdown costs for the organic production is available.

4) Nix, J. & Hill, P. (2000) Farm management pocket book. Edition 31. Wye: Imperial College; White, D. (2000) Personal communication. *NIAB Seed Certification Data*.

n.a. not available

Table 54: Economic performance of conventional and organic rapeseed production in central Germany and France
Source: KTBL, 1997, 1998, 1999, CETIOM, 1999, own calculations based on Michelsen et al., 1999, Offermann & Nieberg, 2000[7])

Region	Germany[1]	France[2]	Germany
Crop	Conventional oilseed rape production with seed saving practices	Conventional oilseed rape production with seed saving practices	Organic oilseed rape production with seed saving practices
Farm type	OSR 3	(OSR 3)	OSR 4, 4'
Yield (t/ha)	3.14	3.51	2.04
Price (€/t)	231	152.5	277
Gross income (t/ha)	725.3	535.1	527[3]
Variable costs (€/ha)			
Seeds	36.3	-	63
Fertiliser[4]	134.3	84.1	16
Crop protection[4]	136.5	120.1	186
Machinery	186.3	-	65
Other costs	64.8	78.6	
Total variable costs (€/ha)	558.1	282.9	330
Gross margin (€/ha)	167.1	252.3	197
Area payment (€/ha) [5]	529.6	562[6]	530
Payment for organic agriculture (€/ha)	-	-	114
Gross margin + payments (€/ha)	696.7	814.3	841

1) Average of data of KTBL (1997, 1998, 1999)
2) Information of the year 1999 published by CETIOM (1999)
3) 60 % sold as organic, 40 % sold as conventional rapeseed (Michelsen et al., 1999).
4) The costs of fertiliser and crop protection are aggregated in organic farms.
5) The area payments include price compensation payments as well as payments for set-aside programmes which have been introduced in the reform of CAP in 1992/93.
6) Information provided by Teyssier (1999)
7) Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (1997) Standarddeckungsbeiträge 1996/97. Darmstadt. http://www.dainet.de/ktbl/manag/stdb/stdb97.htm; Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (1998) Standard-deckungsbeiträge 1997/98. Darmstadt. http://www.dainet.de/ktbl/manag/stdb/stdb98.htm; Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (1999) Standarddeckungsbeiträge 1998/99. Darmstadt. http://www.dainet.de/ktbl/manag/stdb/stdb99.htm; Michelsen, J., Hamm, U., Wynen, E. & Roth, E. (1999) The European market for organic products: growth and development. In: *Organic Farming in Europe: Economics and Policy*. Volume 7. Stuttgart: Department of Farm Economics, University of Hohenheim.; Offermann, F. & Nieberg, H. (2000) Economic performance of organic farms in Europe. In: *Organic Farming in Europe: Economics and Policy*. Volume 5. Stuttgart: Department of Farm Economics, University of Hohenheim.

ANNEX II: ECONOMIC PERFORMANCE OF GRAIN MAIZE PRODUCTION

Table 55: Economic performance of conventional and organic maize production in France 1997 to 1999 (with irrigation)
Source: Les 4 saison Sud-Adour, 2000, Enquête Unigrain, ITAB

Region	France Pau [1]	France Vienne [2]	France Pau and Vienne[3]
Crop	Conventional intensive maize production	Conventional non-intensive maize production	Organic maize production
Farm type	Maize 1	Maize 3	Maize 2, 2', 4, 4'
Yield (t/ha)	10.15	10.06	9.0
Price (€/t)	98.5	108.1	228.7
Gross income (€/ha)	999.8	1087.5	2058.3
Variable costs (€/ha)			
Seeds	123.1	159.2	133.4
Fertiliser	186.1	165.1	160.1
Crop protection	96.5	87.4	21.3
Other costs[4]	143.8	67.0	444.4
Total variable costs (€/ha)	549.4	478.7	759.2
Gross margin (€/ha)	450.4	608.8	1299.1
Area payment (€/ha)[5]	506.0	488.9	426.9
Gross margin + area payment (€/ha)	956.4	1097.7	1726.0

1) Average of Pau region 1997 to 1999 (representing Farm type 1)
2) Average of Vienne region 1997 to 1998 (representing Farm type 3)
3) Average of France 1995 to 1999 (representing Farm types 2, 2', 4 and 4')
4) Due to different sources of information the "other costs" include different items in the included regions: harvesting, hail insurance and irrigation costs in Pau, work made by enterprises in Vienne and harvesting, drying and irrigation costs in case of organic maize production.
5) The area payments include price compensation payments as well as payments for set-aside programmes which have been introduced in the context of the reform of the CAP in 1993/94.

ANNEX III: ECONOMIC PERFORMANCE OF POTATO PRODUCTION

Table 56: Economic performance of conventional and organic potato production in Germany 1996/97 to 1998/99
Source: KTBL, 1997, 1998, 1999, own calculations based on Michelsen et al., 1999, Offermann & Nieberg, 2000[4]

Region	Germany Brunswick	Germany Brunswick	Germany North-west coastal area	Germany North-west coastal area
Crop	**Conventional potatoes for processing[1]**	**Organic potatoes for processing**	**Conventional early potatoes[1]**	**Organic early potatoes**
Farm type	**Potato 1**	**Potato 2**	**Potato 3**	**Potato 4**
Yield (t/ha)	41.9	25.1	27.2	16.3
Price (€/t)	92	276	177	531
Gross income (€/ha)	3855	6698[2]	4814	8372[2]
Variable costs (€/ha)				
Plants	566	979	1159	2005
Fertiliser[3]	182	22	146	19
Crop protection[3]	188	379	164	387
Machinery	379	265	387	145
Other costs	265		145	
Total variable costs (€/ha)	1580	1645	2001	2556
Gross margin (€/ha)	2275	5052	2813	5816
Payment for organic farming (€/ha)	-	114	-	114
Gross margin + payment organic farming (€/ha)	2275	5166	2813	5930

1) Average of data of KTBL (1997, 1998, 1999)
2) 95 % sold as organic, 5 % sold as conventional potatoes (Michelsen et al., 1999)
3) The costs of fertiliser and crop protection are aggregated in organic farms.
4) Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (1997) Standarddeckungsbeiträge 1996/97. Darmstadt. http://www.dainet.de/ktbl/manag/stdb/stdb97.htm; Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (1998) Standard-deckungsbeiträge 1997/98. Darmstadt. http://www.dainet.de/ktbl/manag/stdb/stdb98.htm; Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (1999) Standarddeckungsbeiträge 1998/99. Darmstadt. http://www.dainet.de/ktbl/manag/stdb/stdb99.htm; Michelsen, J., Hamm, U., Wynen, E. & Roth, E. (1999) The European market for organic products: growth and development. In: *Organic Farming in Europe: Economics and Policy.* Volume 7. Stuttgart: Department of Farm Economics, University of Hohenheim.; Offermann, F. & Nieberg, H. (2000) Economic performance of organic farms in Europe. In: *Organic Farming in Europe: Economics and Policy.* Volume 5. Stuttgart: Department of Farm Economics, University of Hohenheim

Table 57: Economic performance of conventional and organic potato production in the United Kingdom
Source: Nix, J. & Hill, P. (2000)

Region	UK East Anglia	UK	UK South West England
Crop	Conventional potatoes for food processing	Organic potatoes	Conventional early potatoes
Farm type	(Potato 1)	(Potato 2)	(Potato 3)
Yield (t/ha)	42.5	25.0	22.5
Price (€/t)	131.4	410.5	221.6
Gross income (€/ha)	5584	10262	4986
Variable costs (€/ha)			
Plants	1034	1231	1149
Fertiliser	361	164	287
Crop protection	739	-	328
Machinery	656	821	328
Other costs	656	821	369
Total variable costs (€/ha)	3446	3037	2461
Gross margin (€/ha)	2138	7225	2525
Source: Nix, J. & Hill, P. (2000) Farm management pocket book. Edition 31. Wye: Imperial College			