SIGMEA WP2: conclusions relevant to GM coexistence from research on geneflow by pollen and seed

Preface

Workpackage 2 (WP2) in the SIGMEA project aimed to collate and synthesize experimental information on gene flow and to fill gaps in knowledge by designing and conducting further evaluations, particularly at the landscape-scale or over several years in the cropping sequence. Maize and oilseed rape were the major crops in this study - other crops under consideration were sugar beet, rice and wheat. Data were collated from WP2 partners on cross pollination, volunteers, ferals and wild relatives. Impurities in sown seed were recorded in some experiments, but their origin was not studied systematically in SIGMEA.

The provision of data by partners far exceeded expectations. New submissions were received, even up to mid-2007, based on research initiated in SIGMEA. By September 2007, 102 submissions had been received constituting more than 150 experiment-years. For oilseed rape, the datasets on cross pollination, volunteers and ferals comprise all but one of the main field experiments (and that one is included in the analysis). For maize, two additional major datasets are known, but the results have been published and again contribute to the conclusions. For each of oilseed rape, maize and beet, WP2 partners have access to all available information in Europe that could inform conclusions on coexistence.

The present document arranges, by species, the conclusions given in the full final reports for cross-pollination, volunteers, wild relatives and ferals[1]. The document is intended not to supplant the SIGMEA reports but to provide, in one place, a summary of the main experimental findings relevant to coexistence. The order of presentation is a) maize, b) oilseed rape, c) beet, d) wheat and rice, e) comparison of the species. Reference to the final reports on WP2 deliverables is given in parenthesis (e.g. D2.2.1) either for a whole section or for individual points, as appropriate.

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[1] www.inra.fr/sigmea.

Contributing partners, WP2 (partner number and abbreviation in parenthesis)

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Czech Republic	University of South Bohemia, Ceske Budejovice (21: USB)
Denmark	Riso National Laboratory (40: RISO)
France	University of Paris 11(37: UPS)
France	Centre Technique Interprofessionnel des Oléagineux Métropolitains (2: CETIOM; also contributing data from 3: INRA)
Germany	Technische Universitaet Muenchen (34: TUM)
Germany	University of Bremen (4: Uni Bremen)
Germany	Federal Biological Research Centre for Agriculture and Forestry (32: BBA)
Germany	University of Hohenheim (20: UHOH)
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Italy	Istituto Sperimentale per le Colture Industriali (15: ISCI)
Italy	Universita Politecnica delle Marche (14: UNIVPM)
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Poland	Plant Breeding and Acclimatisation Institute (41: IHAR)
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Spain	Consejo Superior de Investigaciones Cientificas (31: CSIC)
Switzerland	Swiss Federal Institute of Technology (12: ETH)
UK	Institute of Grassland and Environmental Research (11: IGER)
UK	NIAB (1: NIAB)
UK	Rothamsted Research (9: RRes)
UK	Scottish Crop Research Institute (10: SCRI)

Definitions of some terms used in this report:

Labeling threshold: the EU have set a threshold of 0.9% for GM content in non-GM product.

Coexistence in space: the capacity of different fields in the landscape to grow GM and non-GM crops.

Coexistence in time: the capacity of a field to change between GM and non-GM crops.

Volunteer: a plant derived from seed dropped by a crop, and growing as a weed in the cultivated part of a field.

Feral: a plant derived from seed dropped by a crop but growing outside cultivated fields in waysides, field margins and waste ground; it may be genetically the same as a volunteer but experiences different environments.

Wild relative: a wild plant that is sexually compatible with a crop and can produce crop-wild hybrids; the wild relative and crop may be different species, e.g. wild turnip (*Brassica rapa*) and oilseed rape (*Brassics napus*), or the same species, e.g. sea beet and cultivated beet (both *Beta vulgaris*).

Seed production crop: a crop grown to produce seed that is sold to farmers who sow it to grow their cultivated crop (of maize, rapeseed or sugar beet). Seed production crops were not in the remit of SIGMEA Workpackage 2, and were not studied except in beet.

Cross-pollination: here refers to the movement of genes (by pollen-transfer and fertilization of an ovule) to a flowering crop from an external field or a volunteer, feral or wild relative.

Donor and receptor: terms used in experiments on cross-pollination to define the plant types that emit (donor) or receive (receptor) pollen. In most instances, donors and receptors both emit and receive pollen; but the process is usually measured in only one direction (e.g., GM to non-GM).

MAIZE

Maize: cross pollination between crops (D2.3)

- The decline of cross-pollination with distance has been well documented in maize, particularly in experiments or field trials where single donor blocks or fields are surrounded by larger areas of non-GM receptor crops. There is a large degree of consistency between regions and countries to show that:
  - cross-pollination declines steeply from the edge of the donor, typically reaching 1% at around 10 m and 0.1% at 50 m;
  - cross-pollination is usually (but not in all instances) greater in the direction of the prevailing wind.
- Two SIGMEA studies, in Switzerland and Spain, provide unique measurements of cross pollination in real agricultural situations: the studies differ in the density of fields in the landscape.
- Where there was a low density of non-contiguous donor and receptor fields (as in the Swiss study, D2.3.5), measured outcrossing is consistent with the low percentages found in plots and split fields. In such a landscape, cross-pollination averaged over a field is around or below 0.01%, and non-GM fields can be harvested without the need for discards or buffers.
- Where there was a high density of GM fields, interspersed with, and sometimes contiguous with non-GM fields (as in the Spanish study, D2.3.5) higher cross-pollination was usually found than in other experiments. Some small fields flowering in synchrony with GM fields had a mean cross pollination and %GM content greater than 0.9%.
- Reducing the overlap time in flowering between donors and receptors was highly efficient in reducing percentage cross-pollination.
- Coexistence in space between GM and non-GM maize would be feasible in most instances by –
  - staggered sowing, or using GM varieties whose reproductive period does not coincide with that of nearby non-GM crops;
  - for fields simultaneously in flower, the use of buffer or discard zones of around 20 to 30 m width.
- More experiments or field measurements are needed to clarify outcrossing rates in the 'worse-case' situation where donor and receptor fields are interspersed and include receptors completely surrounded by donors.
- Further tests are needed of the consistency and accuracy of GM determinations on field grown material.
- The results of WP2 suggest that a flexible approach, taking account of the density and pattern of fields, would be the best way to manage coexistence (see WP4). An inflexible approach, for instance the setting of a standard separation distance or buffer width, would be unnecessary in many

circumstances that do not require such measures to comply with the labelling threshold.

Maize - volunteers

- Volunteers (or crop-derived weeds) sometimes occur at high density in some countries, particularly in the south of Europe. The limited data available in Europe (D2.4.1) suggest their contribution is small and should be manageable.
- In the one published field study (in Spain), volunteers did not themselves create adventitious presence above the 0.9% threshold but would add to other sources of GM presence (D2.4.1).
- Further research is needed to understand the geographical distribution of volunteer maize in Europe, its life-cycle biology and its potential contribution to impurity.

Maize - landraces

- Maize landraces are still cultivated in most southern and eastern countries of Europe and some adjacent countries to the east (D2.2.1, D2.2.2).
- They are commonly adapted to particular farming systems and environments, and some are associated with the production of particular traditional products such as polenta.
- Maize landraces are a genetic resource that deserves study and active conservation.
- In the one comprehensive study (in Italy), genetic diversity in landraces had not decreased over 50 years. *In situ* conservation of landraces appears to offer an efficient strategy for maintaining their distinctiveness (D2.4.2).
- *In situ* conservation could be achieved in coexistence with modern non-GM or GM varieties, where spatial separation would be the main factor favouring the maintenance of the genetic identity of landraces.
- Knowledge from the direct estimation of geneflow between crops in the SIGMEA project could guide strategies for the conservation of landraces.

OILSEED RAPE

Oilseed rape - cross pollination between crops (D2.3)

- The decline of cross-pollination with distance has been well documented, particularly up to 100 m in experiments where single donor blocks or fields are enclosed by larger areas of receptor or where donors and receptors are located side by side. Typically, the % cross-pollination declines steeply from the edge of the donor, reaching 0.1% at around 50 m, as for maize.
- There is, however, great variation in the decline curve measured between different fields and regions. Cross-pollination is not generally found to depend

strongly on wind direction (as in maize) and the cause of the variation between fields has rarely been attributable to local meteorological conditions or insect activity. Further systematic and detailed analysis of existing data is recommended to assess the role of local conditions in determining levels of cross-pollination.

- Nevertheless, where there was a low density of non-contiguous donor fields in the landscape (as in work in France and the UK using GMHT donors), measured cross-pollination to receptor fields located 200 to 1000 m or more distant was well below 0.1%. Beyond 1000 m, the values were below 0.01%.
- Coexistence in space between GM and non-GM oilseed rape would be feasible in many circumstances during the early years of GM commercialization by the use of buffers, discards or separation of moderate width or distance (several tens of metres, as for maize).
- To date, there are very few examples – and none where the donor was a GM crop - of cross-pollination in situations where donor fields lie close to or surround receptors and are greater in combined area than the receptors. The only example of this configuration was for HEAR (high erucic acid rapeseed) donors and low erucic receptors in the UK, where (as for the example of Bt maize in Spain) a few receptors showed levels of cross-pollination around or just above 0.9%. At present, general conclusions are not possible on outcrossing in such circumstances of high pollen ‘load’.
- Certain varieties of oilseed rape, of which the commonest are termed ‘varietal association’ (VA), produce less pollen than the normal varieties. Pollination from donor fields to VA crops is much greater than the values cited above, and a much greater separation distance would be necessary to achieve coexistence between GM and VA crops. In general, the areas sown with VA crops are small and have decreased, but further work in a range of environments would be needed to measure rates of cross pollination to VA crops should they become more widely grown.
- Cross-pollination between fields is not the only factor, and probably not the major factor, to consider when drawing up spatial coexistence measures for oilseed rape. Following commercialisation, GM volunteer populations will begin to be transported to, and accumulate in, non-GM fields in the landscape (D2.4.1). Further measurement and modeling are needed to understand the mechanisms and rate at which impurities from the various sources will spread and accumulate and how such impurities can be reduced.
- A flexible approach to managing coexistence with oilseed rape is recommended, but will be much more difficult to achieve than with maize because of the higher level of seed-borne impurities (see the following sections).

Oilseed rape volunteers (D2.4.1, D2.4.5)

Characteristics of persistence and longevity

- There is evidence from several experiments that seed dropped from GM herbicide-tolerant oilseed rape crops at harvest was greater than from the non-GM comparators; the physiological cause of this difference (a GM/non-GM ratio of around 3/2) is unknown and should be investigated further.
- The timing and type of post-harvest cultivation strongly determined the subsequent GM seedbank. Immediate soil cultivation, whether shallow or deep, buried seeds, causing them to become dormant. Delaying soil cultivation by three weeks allowed germination of volunteer seed and subsequent control of the seedlings. Combining many experiments in several countries showed immediate deep ploughing led to a ten-fold increase in the abundance of the volunteer seedbank compared to delayed (3 weeks), shallow cultivation.
- After a rapid decline in the first year, oilseed rape seedbanks persisted at an abundance near or above 100 m^{-2} seeds, which is similar to the plant abundance in oilseed rape crops; seedbanks were detectable even 10 years after the previous crop in some field experiments.
- Recent evidence (not fully assimilated into the WP2 database) indicates volunteer plants comprised from zero to >50% of plants in oilseed rape crops; and though competitive exclusion reduced the reproductive capacity of the volunteers, they still contributed up to around 10% of harvested seed.
- Stages in the volunteer life cycle display high variability, much of which is unexplained, presumably because seed and plants respond to very local conditions (e.g. temperature, water, pathogens, soil physical structure) which are difficult to measure in typical field experiments. The high variability means it is very difficult to predict adventitious presence caused by volunteers.
- Coexistence in time can therefore be jeopardised by the long persistence of oilseed rape and the uncertainties over its emergence in crops.

Management to reduce adventitious presence

- Careful harvesting, delaying post-harvest tillage, and the avoidance of ploughing after harvest, together constitute the most effective means of reducing subsequent volunteer populations, but do not guarantee low populations in all instances.
- Agronomic options are limited after seed has been incorporated into the soil, but include avoiding crops where volunteers might set seed, and (the next time oilseed rape is grown in the rotation) using a vigorous oilseed rape variety, sown in rows at high density, and controlling volunteers between rows.
- Extending the interval between crops will reduce the probability of high adventitious presence in the next crop; but emergence from the seedbank is too variable for any general recommendations to be given of a 'safe' and practical time-interval after a GM crop that would ensure adventitious presence of less than 0.9% in the next non-GM crop.

Long-term strategies to promote temporal coexistence

- Volunteer management needs to be flexible through adaptation and remediation: uniform measures, such as fixed intervals between crops, should not be imposed; rather, a system is needed in which farmers can assess the efficiency of their actions and implement corrective action if necessary within and between cropping seasons.
- Further research is needed on emergence and competitive interactions of oilseed rape volunteers in a range of European climatic zones.
- Some commercial varieties are known to have low secondary dormancy and persistence. Developing transgenic varieties having low-persistence traits would greatly reduce the problems facing temporal coexistence.
- Large reductions in seed loss can be achieved by deploying advanced harvesting machinery and harvesting when the water content of grain is within specified limits.

Oilseed rape ferals

The following is a summary of research on oilseed rape in Task 2.2**.**

Coexistence in space - ferals

- Feral oilseed rape was examined over several years in each of five study areas in Denmark, France, Germany (two) and the UK.
- Feral oilseed rape occurred widely on waysides, field margins and urban areas such as waste ground and industrial sites in all five study areas. The frequency of populations ranged from around 1 to 15 populations per square kilometre - the latter, high value in Selommes in France. A typical population consisted of 1 to 10 plants, but some populations were >1000 plants.
- If GM varieties were grown widely, they would become constituents of feral populations.
- A ‘worse-case’ (a very highly improbable one) can be estimated based on the following: if it is assumed that all the feral plants in a region were GM and pollinated conventional oilseed rape crops (equally plant per plant), then the level of impurity introduced from this source would be between 0.001% and 0.0001% among the five study areas.
- At their present density and spatial arrangement, therefore, oilseed rape feral plants need not be considered in management prescriptions to achieve GM levels below 0.9% in non-GM crops (but see *Caveat!* below).
- The occasional, very large populations (e.g. >10,000 plants) sometimes found in derelict fields or briefly around major construction works, do not affect the overall conclusions above, but - for the purposes of managing coexistence - should be treated in the same way as fields containing oilseed rape crops or large volunteer populations.

Coexistence in time - ferals

- Most populations do not persist from year to year in the same place but some have been recorded at a single locus for at least ten years. Seeds persist in the seedbank, so even if populations do not emerge in a given year, they may reappear later or be redistributed by machinery or vehicles.
- Molecular genetic analysis has shown that feral populations contain crop genotypes that are no longer grown; following GM cultivation, both GM and non-GM types would co-occur in feral populations.
- If GM cultivation were introduced then (for whatever reason) withdrawn, the arguments of relative number used above mean that their contribution to impurity would remain negligible and they need not be considered in any management prescriptions (but see *Caveat!* below).

Caveat!

- Transgenes are likely to persist in and be redistributed among feral populations for decades, in some instances co-occurring with wild relatives such as weedy *Brassica rapa*. They will be subject to selection and local evolution.
- GM traits such as tolerance to broad-spectrum herbicides would confer a selective advantage on ferals that were subject to weed control by the herbicide (but note that chemical control of wayside plants is not practiced in some countries, e.g. Denmark, where cutting after flowering is the usual means of control). A selective advantage might also be brought by new GM traits conferring resistance to pests and herbivores.
- Special attention should be given to situations where a relatively high density of ferals exists (the study area of Selommes is an example) and where a moderate or low selective advantage may be all that is required for ferals to become a problem for coexistence through geneflow.

Oilseed rape wild relatives - *Brassica rapa* (D2.4.2, D2.4.5)

- Hybrids between oilseed rape and weedy *B. rapa* occur in fields, and contrary to popular belief, hybrids in some environments have a similar or higher reproductive fitness than *B. rapa*. Occasionally, reproductive fitness of hybrids can be higher than that of the oilseed rape parent.
- In the normal conditions of agriculture, transgenic hybrids will occur if GM oilseed rape is grown in fields that contain weedy *B. rapa*: the transgenes will be expressed in the hybrids, but the likely frequency and persistence of transgenic hybrids are at present uncertain (depending on the genotype, the environment and the characteristics of the transgene).
- Because of its localised distribution, weedy *B. rapa* will be much less of a general problem for coexistence in Europe than volunteer oilseed rape, but where it occurs in abundance, its contribution to impurity in yield may be similar to that of volunteer oilseed rape, and it will need a similar degree of agronomic control.

- Further research is necessary on the persistence, dynamics and control of *B. rapa* and its hybrids with *B. napus* under a range of agronomic and environmental conditions.

BEET

- Crop varieties, in-field volunteers, ferals and wild types of beet are all sexually compatible variants of the species, *Beta vulgaris,* and together comprise the Beta complex. Crop beet plants are biennial, producing root bulk in the first season (after which they are usually harvested) and flowers in the second. By contrast most wild and weed beet forms are annual, producing flowers in the year they germinate. The main source of genetic impurity in commercial crops arises from seed produced in localised areas of Italy and France in fields consisting of male-fertile pollinators and male-sterile seed mother plants. The male sterile mother plants can also receive pollen from volunteers, ferals and wild sea beet in the surrounding countryside and from other seed production fields in the area. The wild and weedy forms introduce annual genes into the seed crop, which give rise to annual plants that flower in the first year of the sugar beet crop, but produce little or no root and sugar yield. If allowed to set seed, these annual weedy beets give rise to seedbanks lasting many years, from which annual volunteers (bolters) will flower.

Beet cross pollination between fields, particularly for seed production (D2.3**)**

- The decline in cross pollination with distance in beet is less well characterised than in maize and oilseed rape, Cross-pollination from external sources (e.g. wild beet, red beet, other seed production fields) nevertheless occurs over hundreds of metres, if not several kilometres, and introduces impurities to seed production fields.
- Extrapolations from the existing limited data are uncertain and further information to explain and predict cross-pollination rates is needed to formulate strategies for siting and managing GM seed production fields in relation to non-GM seed production and to populations of volunteers and wild beet.
- The limit of GM impurity which is to be set for beet seed needs very careful evaluation. The SIGMEA beet group recommends that the current limit of 0.2% (for impurities in beet seed generally) is too high, since this tolerated level still allows for the introduction of 200 weed beet seeds per hectare (see D2.4.1).
- Ensuring non-GM seed of very high purity in multiplication areas should be the main aim of a European strategy for coexistence in beet.

Beet volunteers (D2.4.1)

- Volunteer (weed) beet arises from impurities in seed that usually display an annual phenology and great phenotypic plasticity.
- Current production practice has encouraged them to become a serious infestation in some parts of central Europe.

- The roots of volunteers can, in principle, be admixed with harvested tubers in some circumstances (though no recombinant DNA will occur in the produced sugar); good agricultural practice should ensure that admixture from this source is minimal.
- The main importance of volunteer beet is as weed. If herbicide tolerant (HT) beets are grown, HT weed beets will arise and introduce HT genes into non-GM fields. For example, if the HT trait conferred tolerance to glyphosate, this same herbicide would become less effective for weed beet control in non-GM beet crops.
- Traits can be dispersed among fields between volunteers simultaneously in flower, but though cross pollination can occur over several hundred metres, its precise distance-dependence has not been adequately assessed.
- A combination of rigorous control of seed purity (D2.3.1) and an agronomy aimed at controlling volunteers (D2.4.1) is needed to curtail the problem of volunteer beet.

Wild (sea) beet and its role in the Beta complex

- The range of information on wild, weedy and cultivated beets from the Baltic to the Adriatic (as described under D2.2, D2.4.1, D2.4.2) constitutes a unique case history, structured along well defined geographical and climatic gradients. This case history deserves further research and consolidation.
- Sea beet populations were assessed along the Baltic coasts in Denmark and Germany, and the Adriatic coasts in Italy and the Balkans, and found to differ genetically and to be much more genetically diverse than crop beets.
- The demographic records show that cross pollination has the potential to occur between sea beet and (flowering) crop or weed beets at all coastal locations where they exist in proximity (D2.2). There is still insufficient spatial demographic information, however, with which to assess the total population size of sea beet along either coast and its likely survival, dynamics and spread.
- Evidence of gene flow from crops (mainly seed production not sugar production) to sea beet was found, but at low rates that are insufficient to erase inherent genetic differences between the wild populations (D2.4.2).
- Sea beet populations display high dynamics, mainly it is believed through the annual variation in abiotic factors such as salinity, temperature and drought, but are not strongly controlled by pests and diseases.
- Accordingly, the introgression of transgenes for disease resistance (for instance, virus infection) is unlikely to alter the fitness of individuals at this time.
- The value of wild germplasm for sugar beet breeding is a major reason to preserve and study the structure of the sea beet populations.
- Adriatic wild beets should be regarded as a particularly important plant genetic resource that merits (proactive) conservation (D2.4.2).

- There is a requirement for isolation measures for beet in some countries. In Denmark, for instance, the distance is 2000 m between crop and seed production fields. As recommended in Deliverable 2.3.1, it is desirable to isolate seed propagation from sea beet populations, both to avoid impurities in the seed production and to conserve sea beet's genetic characteristics.
- Wild beet, by exchanging genes both ways with crops, provides a major Europe-wide case study of crop-wild interactions and requires further comprehensive physiological and genetic characterisation. Crops are not considered to have been a major threat to the persistence and diversity of sea beet, but close monitoring for genetic erosion is needed using existing markers that are specifically present or absent in sea beet populations.

WHEAT

- Research on wheat in SIGMEA mainly examined hybridisation between wheat and wild relatives in Spain.
- Hybridisation at low frequency between wheat and some wild relatives was shown to be possible under field conditions of the "meseta norte" in central Spain.
- In addition, cross pollination among cultivars in field plots occurred at low rates and decreased with distance.
- More generally, there is little data on crossing from wheat to wild relatives - research is needed particularly at the field scale and above and over a range of climates.

RICE

- Research on rice in SIGMEA examined cross pollination from small plots of transgenic rice to non-transgenic varieties and the red rice weed in Spain.
- Cross pollination occurred at very low rates and strongly decreased with distance.
- The local wind conditions during the flowering period appear of primary importance for implementing strategies to minimise gene flow in rice.
- The appearance of transgenic red rice weeds is a risk that should not be neglected.

COMPARISON OF SPECIES

- Oilseed rape is the one species studied in SIGMEA for which there are major problems in the management of coexistence. The problems arise principally because of gene movement through volunteers or wild relatives, which are difficult to manage agronomically because of local stochastic effects in the biology of seeds. Issues arising from volunteers or wild relatives in other crops, namely maize and beet, are manageable under best, and for beet this means very rigorous, agronomic practice.

- Wild relatives and ferals are, in general, less of a problem than volunteers when drawing up management plans for coexistence.
- Impurities through cross pollination alone can in general be managed through separation and related measures.

Maize

- The processes can be graded as follows. The potential to introduce GM impurities is:
  - moderate for cross pollination between fields, which can be managed through separation, buffers or discards (D2.3.1),
  - low through volunteers, and then mainly in southern Europe (D2.4.1),
  - low for introgression to landraces from modern crop varieties (2.4.1).
  - zero through wild relatives since there are none in Europe.
- Coexistence should be achievable by management of cross pollination through staggered flowering, deploying buffers or discards and using high purity seed.

Oilseed rape

- The processes can be graded as follows. The potential to introduce GM impurities is:
  - moderate for cross pollination between fields, which can be managed through separation, buffers or discards (D2.31),
  - high through volunteer populations that admix with and pollinate non-GM crops - volunteers are ubiquitous, mobile and commonly in high abundance and are of maximum importance to coexistence (D2.4.1),
  - moderate through wild relatives in localised areas of Europe where they occur in high abundance in the fields (2.4.2, 2.5.2),
  - low through ferals (with some local exceptions) because of their low overall density compared to crops in the landscape (D.2.2).
- In addition, the potential for low levels of cross pollination among crops, volunteers, ferals and wild relatives by insects and wind up to long distance in the landscape may lead to potentially significant background levels to augment impurities from other sources (2.3.1).
- Problems of coexistence during the first few years of commercialisation can be reduced by management of cross pollination (through separation, etc.) and seed purity, but large uncertainties remain in the cumulative, long term movement and amplification of volunteers and wild relatives.

Beet

- The processes can be graded as follows. The potential to introduce GM impurities is:

- low through cross pollination between sugar beet crops since the harvest is vegetative,
- low through volunteer (weed beet) populations which arise in crops from impurities in sown seed, since best management should minimise any contamination of the harvest with roots of these weed beets,
- low through ferals and wild relatives exchanging genes with sugar beet crops since the harvest is vegetative,

The main source of adventitious presence is therefore through impurities in the seed sown to grow crops of sugar beet. Coexistence should still be achievable by strategic siting and separation of seed production fields.

Wheat

- The knowledge-base for wheat in Europe is much less than for the other crops. Given present understanding, the potential for introducing impurities is likely to be
  - low through cross pollination between crops,
  - low through hybridisation with wild relatives in those local areas where they occur.
- The contribution of volunteers needs to be clarified, but their importance for temporal coexistence is likely to be low or moderate.
- Further investigations on all aspects of cross pollination and life cycle dynamics are needed before firm prescriptions can be made on the management of coexistence in wheat.

Rice

- Given present understanding, both from research in SIGMEA and more widely, the potential for introducing impurities is likely to be
  - low through cross pollination between crops,
  - low through volunteers,
  - low to moderate through the weed, red rice, in local areas where it occurs, provided agricultural practices to control this weed are applied.
- Coexistence should be achievable through separation of crops, controlling weedy relatives and using high purity seed.

General

- There remains uncertainty in the relevance to coexistence of transgenes that might confer differential fitness, for example by being associated with reduced pollen production or resistance to common herbicides. Measurements at previous GM release sites are needed to assess the persistence and genetic structure of relevant populations (e.g. volunteers, wild relatives).
- State of the art modelling tools (individual based, spatially explicit, incorporating introgression of multiple events) have been developed to simulate the

population dynamics around complex transgenic events, and could be adapted as aids to monitoring following commercialisation.