Forecasting impacts of co-existence within agricultural systems

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Although gene flow is a common phenomenon for crop species, its implications for Genetically Modified Plants have raised new concerns. Undesirable effects related to gene flow may result in ecological or agronomic considerations (persistence of resistant volunteers; creation of new weeds; multiple resistance) as well as in commercial considerations (unintended presence of GMOs in conventional crop production affecting its competitiveness in the marketplace). Consequently, the co-existence between different types of crops has become a major issue and has to be addressed per se whatever are the actual ecological, agronomic and safety impacts.

Adventitious presence of GM highly depends on crop biology, farming practices and regional environments

On-farm gene flow occurs through pollen flow as well as through seed dispersal. Several factors are involved: crop biology, environmental conditions, crop management and post-harvesting practices.

Adventitious presence of GM seeds in non-GM production could have several causes:

- Crop-to-crop pollination between neighboured fields;
- Presence of volunteers in conventional fields resulting from former GM crop cultivation in the field;
- Pollination from feral GM plants occurring in field borders and resulting from seed dispersal during transportation;
- GM impurities in seed lots (cross-pollination during seed production or admixture in the post-harvest process).

Soybean is a self-pollinating crop and adventitious presence is only due to GM impurities. Maize is an open-pollinating crop and crop-to-crop pollen flow also contributes to the GM presence. For rapeseed, gene flow occurs both in time and in space and all these processes have to be considered: seed persistence and dispersal – especially volunteers in subsequent crops – have a major impact on adventitious presence.

Those crop characteristics interact with cropping practices (sowing date, soil tillage, crop protection strategies), with farming systems as well as with local environmental conditions.

Admixture also occurs in the downstream chain (crushing, etc) as well as in the upstream chain (seed production).

Models are necessary for helping decision-makers

Forecasting the fate of GM plants at the landscape level by taking into account the various cropping systems and the agricultural practices is thus necessary for helping in the elaboration of co-existence rules as well as for assessing their feasibility and their consequences as well as for setting up monitoring and control schemes. For such a perspective, specific field experiments are not sufficient even if several studies have been carried out in order to broaden the scope of the evaluation: the inter-institute platforms in France (Champolivier et al., 1999) or the Farm Scale Evaluation programme in the UK (Firbank, 2003).

For forecasting the spread and behaviour of GM plants and seeds as well as their impacts in a wide range of agro-ecosystems, modelling is a key element.

Models help in:

- structuring knowledge, identifying gaps and reducing the research fragmentation;
- ranking farming systems according to adventitious presence in non-GM production;
- forecasting the behaviour of transgenes in cultivated and non-cultivated lands;
- testing *a priori* the efficiency of mitigation measures or regulation schemes;
- implementing monitoring schemes by identifying high risk situations;
- re-assessing the overall balance of the impacts of GM crops when new results are available (from trials as well as from monitoring).

Modelling for forecasting the behaviour of transgenes has been in development for some years. It has been focused mainly on crop-to-crop gene flow and six models have been published so far. However, only two of them, GENESYS® for rapeseed (Colbach *et al*, 2001a & b) and MAPOD® for corn (Angevin *et al*, 2001), actually take into account the spatial patterns and are thus able to forecast the behaviour of transgenes at the landscape level. GeneSys as well as MAPOD for maize have been used to underpin the co-existence studies carried out by INRA in France (Relevance and feasibility of non-GM chain, 2001) and by JRC/IPTS study (Scenarios for co-existence, 2002).

**Using Genesys to adapt cropping systems**

GENESYS®-rape aims at forecasting the effects, both in time and in space, of cropping systems and of rapeseed varieties on gene flow from rapeseed crops to rapeseed volunteers (Colbach *et al*, 2001a & b). The input variables of the model are (1) the regional field pattern including waysides, field edges and fields; (2) the crop succession of each field; (3) the agricultural (stubble breaking, tillage, sowing date and density, herbicides, harvest conditions) and (4) rapeseed variety characteristics (genotype, self-pollination rates, differences between GM and non-GM varieties in pollen emission and yield). The main output variables are, for each year, adult rapeseed plants, newly produced seeds, seed bank as well as the proportion of GM in each. The model is presently being evaluated. The first results show that it correctly ranks cropping systems according to their rapeseed volunteer infestation. However, pollen and seed dispersal is frequently underestimated and this must be kept in mind when analysing the results.

GENESYS has been used:
- to identify the **cropping systems with high/low GM presence**
- to test management practices and rules for the combination in space of **cropping systems** aiming at reducing the GM presence and/or their impacts
- to identify **cultivar characteristics** increasing/decreasing the GM presence as well as the impacts of gene flow.

**Simulation examples.** In the JRC-IPTS study, four farms have been designed. Each farm is defined as a combination of a typical field pattern (Fig. 1), agricultural practices and farm equipment in order to cover a wide range of representative situations: use of certified seeds or not, organic vs conventional practices, crop rotation, soil tillage, etc. Two kinds of simulation were carried out over a 13 year-period by considering these farms as non GM-farms while either 10% or 50% of the neighbouring rapeseed fields are considered as GM fields:
- Comparing the farming systems in terms of resulting proportion of GM seeds (hence "harvest pollution") in hybrid seed production as well as in non-GM rape harvests;
- Assessing the impacts on adventitious presence of GM seeds when changing farming systems and farmer practices.
Some results. When analysing GM presence in harvested non-GM fields on the various farms, field sizes turn out to be a major factor. Small fields as on farm 2a were very sensitive to GM pollen inflow whereas the large fields of farms 3 and 4 were only slightly affected despite they use farm-saved instead of certified seeds. The lower efficiency of mechanical volunteer control in organic farms leads to a slight increase in harvest pollution. Whatever the farm, the pollution rate of hybrid seed production exceeded the 0.3% threshold proposed by the EU for conventional seeds. Therefore, co-existence rules should be more drastic for hybrids than for classical varieties.

Table 1 gives simulation results of the impact of changing some farming practices on the adventitious presence of GM seeds in hybrid seed production on farm 1. These results indicate that cropping practices have a great influence on GM presence. Some practices are susceptible to help in reducing this presence, e.g. ploughing before rape crops, systematic cutting of borders or adding spring crops to farm rotations.

Table 1. Simulated effect of changes in cropping system on rate of varietal impurities in hybrid seed production for intensive farm 1 (relative values).
Conclusions

Results from these co-existence studies have raised several issues that should be further addressed:

- The landscape fragmentation has a great influence on gene flow and ecological impacts and its effect should be taken into account in modelling.

- Induced costs due to indirect effects of co-existence rules are difficult to estimate and are highly dependent on the local regional variability of landscapes and on agricultural farming systems.

- Available models for gene flow and ecological impacts focus mainly on the field level or on a small region (group of fields). However, mitigation measures and monitoring schemes should involve at least three different decision levels: the field level with crop management practices, the “cropping system” within the farming systems strategy, the landscape or the regional level. Up-scaling of models at different biogeographical levels should thus be made possible and easy to handle.

More generally:

- Gene flow occurs both in time and in space, its impacts highly depend on farming practices and regional variability and co-existence rules should be designed on a local basis and dynamic;

- Models are necessary for addressing the landscape fragmentation and the regional diversity of cropping systems and practices;

- Models are tools for helping decision-makers (farmers, regulation bodies) in evaluating the impacts of various scenarios, management rules as well as for setting up monitoring systems;

- Most of the results and models would be useful for other innovations