Evaluation of prospective cropping system scenarios for managing oilseed rape volunteers and harvest purity using the GENESYS model

Nathalie COLBACH
INRA, UMR 1210 Biologie et Gestion des Adventices, 21000 Dijon, France
(Nathalie.Colbach@dijon.inra.fr)

Background. Oilseed rape (OSR) genes can escape fields in space via pollen and seeds, and in time via volunteers resulting from seeds lost before or during OSR harvest. When varieties co-exist in space and/or in time (e.g. genetically-modified (GM) and non-GM varieties, varieties with different fatty acid contents), this spatio-temporal gene flow can lead to the adventitious presence of extraneous characters in harvests (e.g. GM seeds in non-GM harvests, seeds with a contrasting fatty acid profile in harvests grown for a specific fatty acid content) and thus cause financial losses for farmers and cooperatives. Gene flow depends on crop locations, succession, and management, as well as the location and management of semi-natural areas such as road verges.

Objective. The objective of this study was to develop a simulation methodology using the spatially-explicit cropping system model GENESYS for designing and evaluating prospective cropping systems for managing adventitious presence of extraneous characters in harvests (hence AP). The methodology was developed with case studies on co-existence of GM and non-GM varieties and then adapted to the co-existence of varieties with different contents of α-linolenic acid.

Methods. The GENESYS model (see synthesis by Colbach, 2009a) was chosen for the present study as the only model to date that quantifies cropping system effects (crop succession and crop management techniques) on spatio-temporal OSR volunteers and gene flow. GENESYS synthesizes the results of a large range of analytical experiments, both in controlled conditions and in fields. Its spatial extent is the regional field pattern consisting of fields and any other habitats (e.g. road verges) where feral OSR can grow. In each of these spatial units, the annual life-cycle (Figure 1) of crop, volunteer, and feral OSR is simulated yearly as a succession of stages chosen for their interaction with crops and cultivation practices (or management of road verges) as well as dispersal processes. Pollen flow is calculated daily during flowering and seed dispersal at seed shed for each pair of source and recipient plots (both fields and uncultivated habitats) of the simulated region, based on dispersal kernels. The initial GENESYS version focused on herbicide tolerance; the model has recently been adapted to predict α-linolenic acid content in seeds (Baux *et al.*, submitted). The model was shown to produce satisfactory predictions in most cases except: (1) seed survival was overestimated in directly-drilled fields, probably because predation is neglected in the model, and (2) pollen dispersal between OSR crops was systematically underestimated by approximately 30% when there was low volunteer pressure and OSR fields were more than 50 m apart. In the present study, simulation output was corrected for this underestimation.

The simulation study focused on spatio-temporal co-existence of GM and non-GM varieties. It evaluated pre-sowing OSR seed lot impurity, OSR varieties, local management measures, cropping system components and landscape characteristics. Simulated AP was compared to the EU labelling threshold for the non-GM food chain (i.e. a maximum of 0.9% GM seeds) and analysed at farm and silo level.

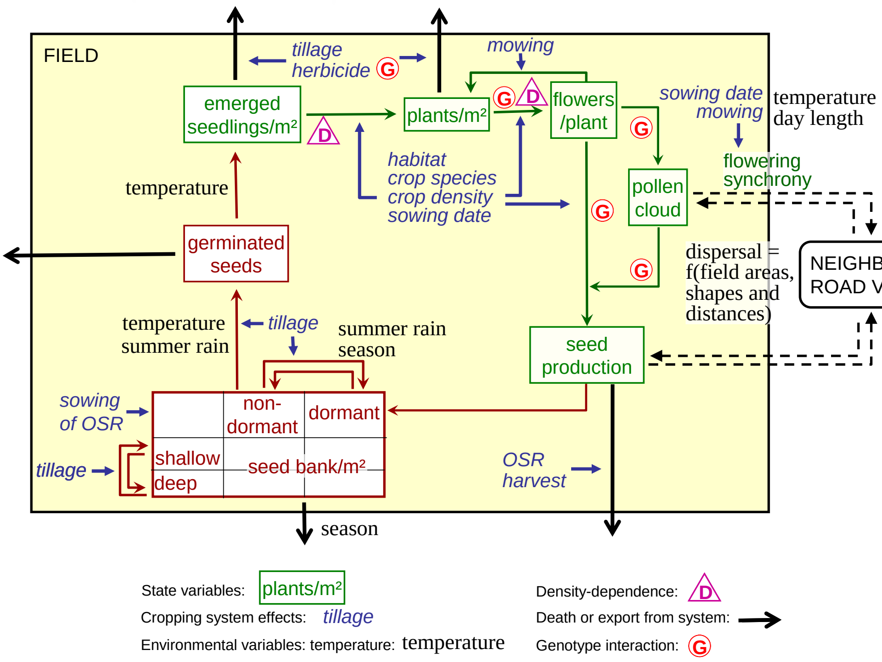


Figure 1. Spatiotemporal structure of the GENESYS model quantifying the effect of cropping systems on population dynamics and gene flow for oilseed rape volunteers in agricultural landscapes (taken from Colbach, 2009b)

Results. Seed lot purity was crucial but insufficient to control AP. Cleistogameous non-GM varieties presented a high AP despite an increased self-pollination rate; AP decreased most when GM varieties were semi-dwarf; non-GM varietal associations comprising male-sterile plants presented the highest AP (Figure 2). Local measures (non-GM buffer zones around GM fields, harvest discarding in non-GM fields) were either inefficient or needless. Controlling OSR volunteers in landscapes was the key for limiting AP; the most efficient measures were though expensive and/or difficult to carry out (e.g. sow setaside fields, change rotations, cluster farm fields); in fact, a combination of management measures was necessary to control AP (Table 1). The management effects were most noticeable and necessary for farms consisting of small and/or scattered fields. If volunteers were insufficiently managed, AP was difficult or impossible to achieve.

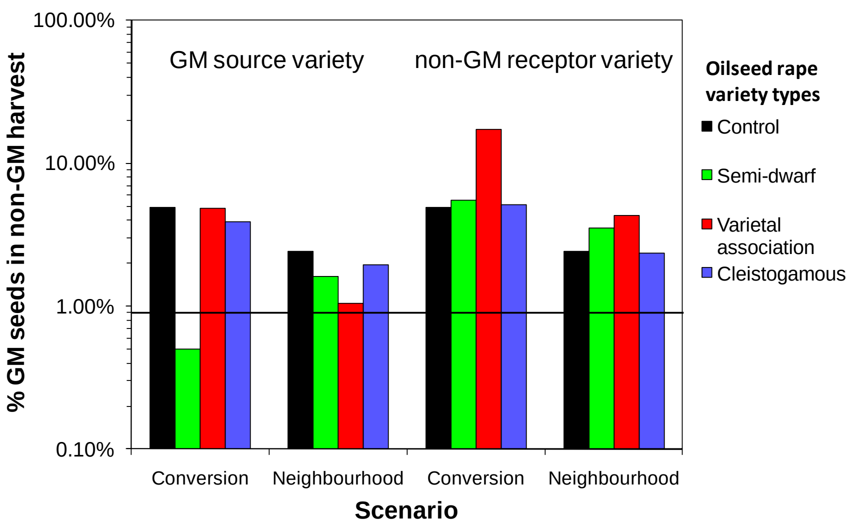


Figure 2. Effect of varietal characteristics of GM and non-GM oilseed rape (OSR) on the adventitious presence of GM seeds in non-GM OSR grown either 3 years after GM OSR in the same field (conversion scenario) or simultaneously in a field adjacent to a GM field (neighbourhood scenario) (based on Fargue *et al.*, 2005; 2006). The line shows the 0.9% EU labelling threshold for non-GM harvests

Table 1. Effect of changes in farming practices on the adventitious presence of GM seeds in non-GM OSR harvests predicted by the GENESYS model for three contrasted farm-types with 15% of OSR and 50% of GM OSR in the region (average of all farm fields for years 8 to 14 after the introduction of GM varieties) (based on Colbach *et al.*, 2004)

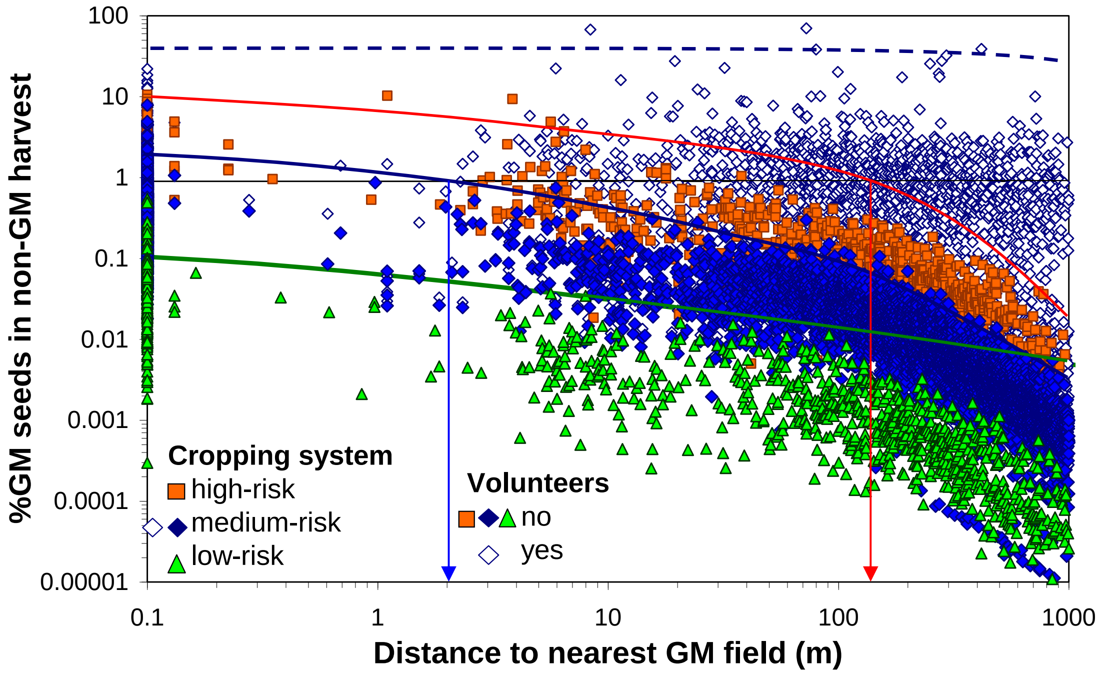
Cropping system component	Current value	Tested value	% GM seeds in non-GM harvests in farm		
			IM	OS	IL
Current farming system (control)			4.1	6.7	0.1
Herbicide efficiency	95%	99%	4.1	nt	0.1
Mechanical weeding efficiency	20%	60%	nt	6.7	nt
OSR harvest loss	5%	10%	4.3	9.2	0.1
OSR frequency in rotation	1/6 years	1/7 years	1.0	1.6	nt
OSR seed lots	Certified	Farm-saved	45.5	nt	nt
	Farm-saved	Certified	nt	nt	0.01
Tillage before OSR	Chisel	Mouldboard plough	2.9	4.7	0.1
Tillage before cereals	Chisel	Mouldboard plough	6.3	nt	nt
Non-GM OSR sowing date	With GM OSR	Later than GM	0.8	1.4	0.08
		Earlier than GM	14.5	nt	nt
Setaside management	Mowing only	Spring-sown + mowing	0.2	0.4	0.1
Roadverge management	Early mowing	Late mowing	3.3	6.7	0.1
		Glyphosate	5.1	6.9	0.5
Farm field location	Scattered	Clustered	0.01	0.4	0.02
Optimal management (increased weeding efficiency, plough before OSR, delayed GM sowing, spring-sown setaside, late-mown roadverges)			0.006	0.06	0.08

I = intensive management, O = organic management; S = farm fields of 1-2 ha, M = of 5-6 ha, L = of ~ 13 ha. nt = not tested

Conclusion. These simulations can be used to determine regional co-existence measures such as isolation distances (Figure 3) or maximum crop proportions as a function of cropping system type, the accepted risk of field or batch loss, and the harvest impurity thresholds used by the decision-makers. They can also contribute to establish regulation sets and guidelines for farmers aiming at a specific harvest quality or outlet. The level and cost of management constraints depended very much on the AP threshold to respect, and the farm type (e.g. field size and location, intensive vs. organic). In many situations, restrictions are probably superfluous whereas in other, even more stringent modifications would be necessary to limit AP. In the future, it would be helpful to integrate the risk level in individual fields more precisely for determining regulations such as isolation distances to discriminate those situations where regulations are necessary from those where regulations are superfluous (because AP is already low enough) or useless (because AP cannot be sufficiently reduced).

The present simulation study only considered gene flow in fields and landscapes due to "natural" dispersal. Seed dispersal related to farming equipment, trucks and cars was not integrated in the model, though it has been shown to be important for feral populations. Discontinuities such as forests, hedges or roads, and their effect on pollen flow, are also dispersal factors that have not been considered in the present model.

The present study showed how spatially-explicit models are an essential tool to study the effects of cropping systems and landscape patterns on population dynamics and gene flow over a large range of possible situations and over time. Experiments and field monitoring are indispensable for developing the models, to evaluate them before application, and to evaluate the most interesting scenarios identified through simulations. However, these tools on their own are too slow and expensive to test multiple scenarios in different conditions and to understand long-term effects. In addition, models offer the opportunity to understand the outcome of the simulations by analysing intermediate state variables of the simulated system. This approach is not restricted to weed dynamics. Recently, the present spatio-temporal modelling principle for cropping system effects was extrapolated to a crop disease, i.e. phoma stem canker (*Leptosphaeria maculans*) in SIPPOM (Lô-Pelzer *et al.*, 2010).



Fat lines are quantile regression curves for the 99% quantile (without volunteers: continuous lines; with volunteers: broken lines). Arrows indicate the ensuring that the probability of respecting the 0.9% labelling threshold (thin horizontal line) is above the regression quantile.

Figure 3. Relationship between the distance to the nearest GM OSR field and harvest impurity of individual non-GM OSR fields, simulated with GENESYS, without and with volunteer infestation, for three contrasted cropping systems (taken from Colbach, 2009a)

References

Baux A., Colbach N. & Pellet D. (submitted) Crop management for optimal low-linolenic rapeseed oil production - Field experiments and modelling. European Journal of Agronomy.

Colbach N., Angevin F., Meynard J. M. & Messéan A. (2004) Using the GENESYS model quantifying the effect of cropping systems on gene escape from GM rape varieties to evaluate and design cropping systems. OCL 11:11-20.

Colbach N. (2009a) How to model and simulate the effects of cropping systems on population dynamics and gene flow at the landscape level. Example of oilseed rape volunteers and their role for co-existence of GM and non-GM crops. Environmental Sciences & Pollution Research 16:348–360.

Colbach N. (2009b) How to model and simulate the effects of cropping systems on population dynamics and gene flow at the landscape level. Example of oilseed rape volunteers and their role for co-existence of GM and non-GM crops. Environmental Science and Pollution Research 16:348-360.

Fargue A., Colbach N. & Meynard J. M. (2005) Introduction of genotypic effects into GENESYS-RAPE: the example of height and male sterility. Agriculture, Ecosystems & Environment 108:318-328.

Fargue A., Colbach N., Pierre J., Picault H., Renard M. & Meynard J. M. (2006) Predictive study of the advantages of cleistogamy in rapeseed. Euphitica 151:1-13.

Lô-Pelzer E., Bousset L., Jeuffroy M. H., Salam M. U. & Aubertot J. N. (2010) SIPPOM-WOSR: a Simulator for Integrated Pathogen POpulation Management of phoma stem canker on Winter OilSeed Rape. I. Description of the Model. Field Crops Research 118:73-81.