Relative impacts of closest fields and background pollen on GM adventitious presence rates in non-GM harvests

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Abstract

In Europe, isolation strategies are the most common rules proposed to ensure the coexistence of GM and conventional crops. Spatial strategies are usually based on distance from the closest GM field, and on empirical data from two-plot experiments. However, long distance pollen dispersal produces a background pollen cloud in numerous plant species which impact depends on a complex interaction between the spatial distribution of pollen sources and the short- and long-distance components of dispersal. We thus investigated under which conditions there would be a need to account for the multiplicity of pollen sources over landscapes in the case of maize.

Introduction

The regulations concerning coexistence of GM and conventional crops in European countries are mainly based on keeping a minimum distance from conventional to the closest GM field (EC, 2009) but there is a margin for regional adaptation of rules (EC, 2003a; 2009). Efficiency of isolation distances are mainly tested by carrying out two-plot experiments (emitter/receiver). However, long distance pollen dispersal produces a background pollen cloud in numerous plant species. In natural populations, its impact depends on a complex interaction between the spatial distribution of pollen sources and the short- and long-distance components of dispersal. Two major differences between agricultural landscapes and natural populations are (i) that sources have shapes and areas and (ii) that two sources may have the same genetic composition. Thus, results from point sources cannot be directly extrapolated and a better understanding of the interactions between the spatial pattern of pollen sources and the components of the dispersal kernel would help design isolation strategies. We investigate how characteristics of pollen dispersal kernels and field patterns affect GM rates in harvests of conventional fields by first simulating such rates over realistic landscapes using two dispersal kernels that differ in their amount of long distance dispersal (LDD). We then compare these simulated GM rates to those obtained assuming conventional plots only receive pollen from their closest GM neighbour, using a two-field approach. Finally, we fit linear models including or excluding landscape factors on simulated GM rates and assess their ability to correctly predict classification of fields as regards GM adventitious presence (AP) threshold values.

Material and methods

Simulation of field patterns

To simulate realistic maps in terms of field sizes and distances among fields and to test whether GM rates were sensitive to systematic variation among maps (i.e. largely different field sizes) as well as small random variations, we characterised five real contrasted French landscapes thanks to spatial descriptors. We used these descriptors as input data of a model, GenExP-Landsites (Le Ber et al., in press). This model is based on Voronoï tesselation method. Random variation was introduced with respect to the spatial distribution of field centroids in the original maps. This procedure has been shown to simulate different maps with numbers of fields and distribution of distances among field centroids close to those of the original map (Adamczyk et al., 2007). We thus obtained 10 (5 original maps x 2 replicates) 1.5kmx 1.5km simulated maps that were set in a raster format with 5m x 5 m cells.

Maize allocation to fields

The total proportion of maize area was either 70% or 20%, simulating production areas where maize is either a major crop or not. The proportion of GM maize was set either to 10% or 50%, simulating low or high farmer acceptance of GM crop. The resulting proportions of GM crop over the landscape were thus 2%, 7%, 10% and 35%. GM and conventional fields were randomly allocated. Two replicate allocations of crops were performed per proportion of GM crop per simulated map. We thus obtained 80 (8x10) field patterns. To clearly see the impact of long distance dispersal and to avoid border effects due to the fewer neighbours edge fields have, we transformed each 1.5km x 1.5km field pattern into a 6km x 6km field pattern by pasting it 16 (4 x4) times.

Simulations of pollen dispersal and cross-pollination

Pollen dispersal was simulated with a modified version of the MAPOD software used for estimate cross-pollination in maize (Angevin et al., 2008). To keep the focus on the impact of spatial characteristics of landscapes, we kept agronomic and climatic inputs constant and identical for the GM and conventional varieties. GM adventitious presence (AP) rates were simulated over each 6km x 6km field pattern but they were only recorded within the 3km x 3km central area to avoid border effects.

We used two dispersal kernels differing in their behaviour over long distances (Lavigne et al., 2008). The first kernel is a NIG (Normal Inverse Gaussian; Klein et al., 2003). This is the default kernel in MAPOD which was used in coexistence studies (e.g, Messéan et al., 2006). It has a power-law decrease at short distances and an exponential decrease at long distance.The second kernel is a 2Dt (bivariate Student) (Clark, 1998). Contrarily to the NIG, this kernel is fat-tailed, with a power-law decrease at every distance. The NIG and 2Dt only differ at very short and very long distances.

Statistical analyses

To compare field AP rates obtained over field patterns to those obtained considering only the closest GM field, all fields were erased from field patterns except one pair involving a conventional field and its closest GM neighbour. AP rates were thus simulated by considering only two fields. This was repeated for each conventional field in a 1.5km x 1.5 km central area of the 80 field patterns

The relative importance of landscape versus field characteristics on AP rates was assessed through the fit of linear models accounting for landscape effects (Proc Mixed in SAS 8.01, SAS Institute). Models were run independently for each dispersal kernel. AP rates were log transformed to stabilise the variance. In the most complete models, landscape factors were original map (5 levels), simulated map (2 levels per original map, nested within original map), proportion of maize (2 levels), proportion of GM maize (2 levels) and their interaction as well as field pattern (nested within all landscape factors). Local variables were: target field size (quantitative), size of closest GM field (quantitative) and distance to the closest GM crop (quantitative). Both distance and log(distance) were introduced in the model which allowed modelling both a power-law and an exponential component to the decrease of AP rates with distance to the closest GM field (Lavigne et al. 2008).

We also checked how correctly the fields were classified with respect to threshold values, when comparing simulated AP rates used as a reference to either (i) simulations based on two plots only, or linear predictions based on (ii) local variables only or (iii) all variables and their interactions. We used 0.01%, 0.05%, 0.1% and 0.9% threshold values. Values 0.05% and 0.1% approximate the detection and quantification limits of 0.045% and 0.09%[i]. Value 0.9% corresponds to the EU labelling threshold (EU, 2003b) and 0.01% was used for a better understanding of model behaviour.

Results

Simulated maps differed in field numbers, ranging from 42 to 180 per 1.5km x 1.5 km, field size and variability of field size. Voronoï tessellations homogenised field sizes within a landscape. Distances between conventional and closest GM field were comparable among maps and depended largely on crop allocation, increasing with decreasing proportion of maize or GM among maize. In most configurations, the closest GM field of a target conventional field was farther than 100m, except for landscapes with the highest proportion of GM maize where closest GM fields were on average at distances ~ 15m.

The average landscape AP rates varied mainly with the dispersal kernels and with proportions of maize and GM maize but little with the original map. Average landscape AP rates increased linearly with the proportion of GM maize over the landscape. The increase was twice faster with the NIG than with the 2Dt and was governed by the short-distance dispersal component.

Field AP rates were systematically lower when simulated with the 2Dt (mean ± sd = $0.87\ 10^{-3} \pm 1.13\ 10^{-3}$ for the 2Dt and $1.71\ 10^{-3} \pm 2.03\ 10^{-3}$ for the NIG) and presented larger variation (CV=1.30 for the 2Dt and CV=0.84 for the NIG).
Absolute differences between predictions with 2Dt and with NIG kernels decreased with increasing distance between the target conventional field and the nearest GM crop because the predicted values decreased. However, the ratio NIG/2Dt, that indicates if the difference is in the order of magnitude of the predicted AP rate, increased until distances were about 300 m and then stabilised around 3.3.
Field GM AP rates were much smaller when simulated only from the closest GM field rather than from the whole landscape. Despite the large difference in predicted rates mentioned above, underestimation of the NIG and the 2Dt kernels was almost similar. As expected, underestimation was stronger (smaller ratios) when there was more GM maize in the landscape and when the closest GM field did not neighbour the target conventional field. Surprisingly, even when the closest GM field was neighbouring the target field, ratios were much smaller than 1 as soon as there was more than 2% GM maize over the landscape. As a consequence, when considering pairs of fields instead of all fields, error rates, regarding whether AP rates were above or not the defined thresholds, were high, in particular for small thresholds.

Local variables were more important than landscape variables in the linear models on field log-AP rates as indicated by a much larger reduction in AIC (Table 1). When considering the most complete model (Table 2), distance to the closest GM field was the main local factor affecting these rates. As expected, rates decreased with increasing distance to the closest GM field.

Table 1: AIC values for linear models on log-AP rates including either no factor (Intercept), landscape factors, local factors or both. Models were fitted separately for the two kernels. N=10692 conventional fields.

Model	AIC	
	NIG	2Dt
Intercept	2.72 10^4	3.18 10^4
Landscape only	2.70 10^4	3.17 10^4
Local only	1.19 10^4	1.55 10^4
Local+landscape	1.18 10^4	1.53 10^4
Local+landscape +interactions	1.08 10^4	1.45 10^4

Table 2: Analysis of variance on landscape and local variables affecting log-AP rates.

Model term		df Num	df Den	Mean square ratio	
				NIG	2Dt
Landscape variables	Orig. map	4	67	1.0	1.1
	rep(orig. map)	5	67	1.0	0.8
	% maize	1	67	42	63
	% gm	1	67	70	115
	% maize*% gm	1	67	20	20
Estimated landscape residual variance				0.050	0.052
Local variables	Log(distgm)	1	10602	**13401**	**11360**
	Distgm	1	10602	629	416
	Area target field	1	10602	**804**	**711**
	Area GM field	1	10602	20	41
Interactions	Log(Distgm)*orig. map	4	10602	15	15
	Log(Distgm)* % gm	1	10602	**645**	**731**
	Log(Distgm)*%maize	1	10602	613	499
Estimated local residual variance				0.15	0.22

Largest mean square ratios in bold. Orig. map: original map, Distgm: distance to closest GM field, Df Num: degrees of freedom of numerator, Df Den: degrees of freedom of denominator

Whatever the dispersal kernel, this decrease was a geometric type but somewhat slower than expected under a purely geometric decrease, with, unexpectedly, faster decrease for the 2Dt than for the NIG (not shown). As expected, AP rates also decreased with increasing size of the target field and increased with increasing size of the closest GM field, although this latter effect was very small. Landscape variables had some importance in interaction with distance. The (log) distance effect in particular was more important when there was little GM maize in the landscape, probably because of a lesser variability in distances when the proportion of GM maize was large.

The quality of linear predictions from simple models including only local variables confirmed their adequacy: linear predictions from simple models were most generally correct regarding the defined thresholds and almost as good as predictions from the complete linear model. Error rates are furthermore smaller than those obtained by simulating dispersal from two fields only (Figure 1).

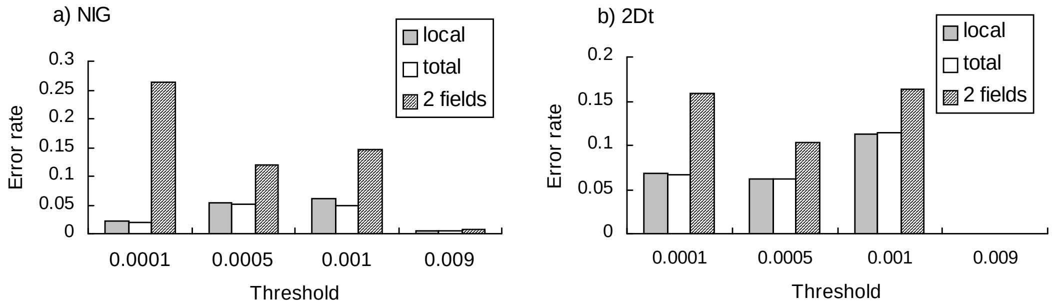

Figure 1: Error rates when classifying fields with respect to four thresholds using simulations at the landscape level as the reference. Classification was based either on linear predictions (model with local variables only (local) or model with all variables (total)) or on values simulated with two fields only (2 fields).

Conclusion

The short-distance component of dispersal had a major impact on AP rates (through a local protection effect and the impact of the closest GM field). However, intermediate- to long-distance dispersal from GM sources farther than the nearest GM field had a significant impact on AP rates, thereby precluding the establishment of isolation distances directly from two-plot experiments.

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[i] http://gmo-crl.jrc.it/doc/Method%20requirements.pdf