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1           **A model to evaluate the consequences of GM and non-GM**  
2           **segregation scenarios on GM crop placement in the landscape and**  
3           **cross-pollination risk management**

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9           **Abstract**

10 Under European regulations, a product is labelled as GM (genetically modified) if more than  
11 0.9% of one of its ingredients originates from GM material. During collection, crops from  
12 many fields are combined to fill a silo. To avoid the risk of mixing GM and non-GM harvests,  
13 it is possible to dedicate a silo to a given crop or to define specific times for GM and non-GM  
14 product delivery to silos. To evaluate these scenarios for the maize supply chain, we propose  
15 a combination of a model of farmers' varietal choice (based on profit evaluation at the field  
16 level, taking into account transport costs as well as price and cost differences between GM  
17 and non-GM products) and a spatially-explicit gene flow model. Consequences of different  
18 segregation strategies for collection zone organisation can therefore be compared while using  
19 the percentage of GM grain in non-GM crops due to cross-pollination. The 'temporal'  
20 strategy leads to a uniform area of GM or non-GM maize, depending on the prices and the  
21 weather risks. The 'spatial' strategy leads to areas of either GM or non-GM crops surrounding  
22 the corresponding collection silos. GM presence in non-GM batches depends on the size of  
23 the non-GM zone and on the prevailing wind. We show how divergent commercial strategies  
24 of grain merchants could have consequences on GM presence in non-GM batches.

25 *Keywords* : GMO, co-existence, decision model, landscape, farming system

26           **1. Introduction**

27 The introduction of GM crops into Europe generated conflict between proponents and  
28 opponents of this technology (Levidow et al., 2000). Moreover, as a majority of European  
29 consumers is reluctant to eat GM foods (Eurobarometer, 2006), there is a demand for more  
30 stringent purity thresholds than those currently operating in existing crops grown in isolation,

31 such as waxy maize or high erucic rapeseed. To satisfy this demand, while allowing farmers  
32 to make a practical choice between conventional, organic, and GM crop production, the  
33 European Commission has proposed several recommendations for ensuring coexistence at the  
34 field scale (EC, 2003a) and promulgated regulations controlling segregation of GM and non-  
35 GM products “from farm to fork” (EC, 2003b and c).

36 Within the food-processing industry, traceability of GM products has to be implemented  
37 throughout the whole supply chain. Indeed, positive labelling is compulsory when a product  
38 contains more than 0.9% of GM material per ingredient (EC, 2003c). In order to avoid such a  
39 positive labelling, PCR tests (Lüthy, 1999) can be used to assess the presence of GM material  
40 when DNA is present in the product. Moreover, the food industry uses risk management  
41 methods to identify critical points and to propose quality control methods such as the Hazard  
42 Analysis Critical Control Point (HACCP) method (Scipioni et al., 2005). As a consequence of  
43 potential cumulative risks in the food chain and to guarantee a level lower than 0.9% of GM  
44 material in non-GM products, a 0.1% maximum level of GM presence is required by the  
45 industry for non-GM batches delivered by farmers and grain merchants (Raveneau, 2005).

46 In this paper, we consider the consequences of the introduction of Bt maize (resistant to corn  
47 stalk borer) into European cropping systems. Indeed, Bt maize is the only GM crop grown  
48 commercially in the EU, mainly in Spain, where 60,000 hectares of it were grown in 2006  
49 (James, 2006).

50 In the field, adventitious presence of GM material can have several sources: pollen flow,  
51 impurities in seed lots, and volunteer plants (Colbach et al., 2001). Due to the cold winter  
52 climate as well as ploughing in the majority of cropping systems including maize, this latter  
53 source can be considered negligible (Angevin et al., 2008). According to European  
54 recommendations (EC, 2003a), a farmer using GM seed has to use technical measures to  
55 avoid adventitious presence in the neighbouring non-GM fields, such as ensuring isolation  
56 distances and flowering time-lags (Beckmann et al., 2006), whose efficiency in decreasing  
57 cross-pollination risk is known (Halsey et al., 2005).

58 At the farm scale, the use of the same agricultural machinery (such as a seed drill or  
59 harvester) for both GM and conventional production increases the risk of admixture (Jank et  
60 al., 2006; Messéan et al., 2006). For grain merchants, the problem is to ensure segregation of  
61 the two products in their supply chain and, as far as possible, to manage cross-pollination risk  
62 between GM and non-GM fields in their collecting area.

63 Several European studies on segregation made in collaboration with grain merchants resulted  
64 in the identification of two possible management strategies (Miraglia et al., 2004):

- 65       • A ‘temporal strategy’ where the two products are separated by the timing of the  
66       collection period. In this case, each product is delivered to the collection silo nearest to  
67       the farm, but within a given period. It is therefore not necessary to manage product  
68       separation in collection silos. Besides, by concentrating the collection of a product  
69       over a short period of time it is possible to have a sufficient flow of material to be able  
70       to dedicate a drying line to this product and to fill one or more storage bins. The  
71       inconvenience of this strategy for the grain merchant is that farmers can choose to  
72       deliver to a more flexible competitor when they want to harvest. This leads to a loss of  
73       volume collected and thus a loss of market share.
- 74       • A ‘spatial strategy’ based on a geographic grouping decided before sowing. Each  
75       collection silo and accompanying dryer(s) receives only one type of product, thereby  
76       defining an independent supply chain for each product. The risk of mixing between  
77       GM and non-GM products is therefore controlled. Moreover, farmers are informed  
78       about this allocation before sowing, so they can choose their crop type taking into  
79       account the product accepted by the nearest collection silo and the cost of  
80       transportation to other collection silos. This strategy indirectly encourages farmers to  
81       choose a particular crop type, but it does not protect grain merchants from farmers that  
82       deliver to a competitor closer to their farm who would accept both products.

83 Both of these strategies have implications for the allocation of GM and non-GM varieties over  
84 the agricultural landscape. While the second allows a homogeneous zone of each cultivar  
85 around silos, the first lets farmers choose their varieties.

86 Such strategies have not been developed in Europe, and specifically in France, because of the  
87 small GM maize area sown (James et al., 2006). In this paper, we evaluate the efficiency of  
88 these strategies to minimize cross-pollination of non-GM by GM crops. Such an evaluation is  
89 necessary to elaborate co-existence scenarios at the scale of the collection zone. We used a  
90 modelling approach by combining a model of farmer’s choice between GM and non-GM  
91 varieties for each field in a zone (Coléno, 2008a) with a spatially-explicit model of gene flow,  
92 MAPOD® (Angevin et al, 2008).

## 93    **2. Methods**

### 94    **2.1. The farmer’s choice model**

95 The model used is based on maximisation of the farmer’s profit at the field level (Coléno,  
96 2008a). To calculate this profit, we took into account the yield (Y); the product price (P); a

97 potential quality loss (L) which is an estimate of the decrease in product quality, when the  
98 farmer is compelled to delay harvesting because of collection firm constraints; the seed costs  
99 ( $C_s$ ); the pesticide costs ( $C_p$ ) linked to the nature of the GM variety; the transportation costs  
100 ( $C_{tr}$ ); and the distance of the field from the silo where the product is accepted (d).

101 Thus, we have:

$$102 \quad \text{Profit}_{GM} = Y_{GM} * P_{GM} * L_{GM} - C_s - C_{tr} * d \quad (1)$$

$$103 \quad \text{Profit}_{nonGM} = Y_{nonGM} * P_{nonGM} * L_{nonGM} - C_s - C_p - C_{tr} * d \quad (2)$$

104 In the case of spatial separation, L is equal to 0. Farmers can deliver their crop whenever they  
105 want to the silo dedicated to the appropriate crop.

## 106 **2.2. The MAPOD® model**

107 In the case of maize, gene flow is mainly due to intra-specific cross-pollination in crop and  
108 seed production fields. Indeed, under normal European conditions, because of the cold winter  
109 climate as well as ploughing in the majority of cropping systems including maize, volunteer  
110 plants from previous maize crops are rare and may be controlled easily by agricultural  
111 techniques.

112 MAPOD® is a spatially-explicit model that estimates the percentage of varietal impurities  
113 due to cross-pollination in maize as well as changes in these percentages due to modifications  
114 in cropping techniques (Angevin et al., 2008). It consists of two modules.

115 The first module determines the flowering date for female flowers, expressed in degree-days,  
116 as a function of climate and sowing date (Durand, 1969; Derieux and Bonhomme, 1982,  
117 1990). Most of the varieties currently used display protandry, which means that male  
118 flowering begins several days before female flowering. The duration (in days) of this time lag  
119 can be used to calculate the flowering time for male flowers. Drought stress and sowing  
120 density affect protandry. Modelling the dynamics of male and female flowering then makes it  
121 possible to estimate the amounts of pollen produced by GM and non-GM varieties and the  
122 number of receptive silks for non-GM maize varieties. Factors affecting the viability of pollen  
123 and the receptivity of silks are taken into account. The composition of the pollen cloud in the  
124 air around the plants is therefore known on a day-to-day basis for the entire flowering period.

125 Pollen dispersal is simulated in the second module by a Normal Inverse Gaussian function  
126 (NIG; Klein et al., 2003). It is a function of distance from the emitter, and its parameters are  
127 the direction and mean speed of the wind during the course of flowering and the difference in  
128 height between the panicle from which the pollen is emitted and the receptive silks. The

129 composition of the pollen cloud at a given site in a non-GM field is determined by the pollen  
130 dispersal curves for all the plants in the neighbourhood, whether close by or further away.  
131 Each day, the frequency of GM seeds is calculated as the ratio of the number of non-GM  
132 ovules fertilised by GM pollen to the total number of ovules fertilised. These daily results are  
133 pooled to provide the extent of GM impurities in the non-GM crop.  
134 The input variables for MAPOD® include certain traits of the varieties and certain  
135 agricultural practices for each maize field as well as climatic factors for the region studied  
136 (Table 1). The output is the percentage of GM impurities in the non-GM harvest on the scale  
137 of a field, a group of fields, or a collection area. This model has been used to carry out several  
138 co-existence studies (Angevin et al., 2002; Messéan et al., 2006).  
139 The preliminary evaluation of MAPOD® was carried out by comparing simulation results  
140 with data from two French and one American gene flow field trials. MAPOD® was found to  
141 provide good average predictive values (Angevin et al., 2008). An indirect evaluation was  
142 also performed by simulating the French seed production rules with the model. These  
143 simulation results are consistent with the rates of impurities measured in commercial seed  
144 lots. The effect of sowing male sterile maize rows to diminish risks of cross-pollination,  
145 which was empirically tested as efficient by seed growers, appears to be correctly simulated  
146 (See Messéan et al., 2006, for details). Further evaluation of the overall predictive quality of  
147 the model is on-going in the case of several real agricultural contexts of GM commercial  
148 releases in Spain.

### 149 **2.3. Input data and work assumption**

150 The farmer's choice model was used on a 100 km<sup>2</sup> area (Figure 1), assuming that a field  
151 would be sown with GM maize if this were be more profitable than a non-GM variety. All the  
152 agricultural area was sown with maize. Four silos are located in this area.

153 We simulated both separation strategies, assuming that one firm owns silos 1, 2 and 3, and  
154 another owns silo 4. For the spatial strategy, silo 3 is dedicated to non-GM harvests and the  
155 competing firm would accept all products, whether GM or not, at the same price.

156 Table 2 shows the values used for the calculation of profit in the farmer's choice models. We  
157 choose a 7% difference in price between GM and non-GM products. This difference allows  
158 there to be a partition between GM and non-GM production. Using a higher or a lower price  
159 difference would lead to a homogeneous landscape. As shown in Figure 2, the effect of a  
160 price difference is very large, and all farmers can change their choice quickly depending on  
161 price changes (Coléno, 2008a).

162 For the temporal strategy we tested two assumptions: in one case, the GM crop is collected  
163 when maize quality is at its optimum ( $L_{GM} = 0$ ), and in the other, we assumed that non-GM  
164 production is collected when maize quality is optimal ( $L_{nonGM}=0$ ). The simulation was carried  
165 out with a loss of quality causing a 10% fall in price, which is consistent with the actions of  
166 grain merchants (Raveneau, 2005).

167 With this model, on the level of an agricultural landscape, we can show the type of variety  
168 (GM or non-GM) chosen for every field. The field allocation obtained is one of the input  
169 variables of the MAPOD® model (Table 1). To run simulations calculating cross-pollination  
170 between fields we assume that non-GM seeds do not contain GM impurities, that GM and  
171 non-GM cultivars have similar morphological and phenological characteristics (a risky  
172 situation), and that crop management is the same for both cultivars. We tested three types of  
173 wind: a north wind, a west wind, and the wind distribution obtained from the meteorological  
174 station located at Colmar (48°05' N 7°21'E), which is shown in Figure 3.

175 Finally, to properly evaluate the efficiency of the various collection strategies on GM  
176 impurity rates in non-GM silos, we have simulated one more situation in which the farmers  
177 freely choose the type of variety they will sow ('case with no collection strategy'). We  
178 represented this situation by a random allocation of both varieties in the agricultural  
179 landscape. We assumed a proportion of 60 % of GM maize in the total cultivated area, which  
180 is equivalent to the GM proportion in the spatial strategy with one grain merchant, with the  
181 values of the variables defined above.

## 182 **3. Results**

### 183 **3.1. Case with no collection strategy**

184 The first line of Table 3 presents the weighted mean of GM impurity levels in non-GM  
185 batches due to cross-pollination for ten random distributions of GM crops in the zone. In all  
186 cases, the maize collection did not comply with the 0.9% legal threshold, so it would not have  
187 been possible to sell this maize to the non-GM market.

188 In view of our working assumptions and the features of the landscape studied (a fairly  
189 uniform field size), we can see that the GM and non-GM field arrangement has little influence  
190 on the GM percentage in non-GM batches. This is shown by the small difference in the  
191 percentage of GM caused by wind direction, as well as by the small standard deviations  
192 between the distributions of GM and non-GM allocations. For a given wind, the variability in  
193 the mean accidental GM presence in the non-GM batches is quite low. On the other hand, the

194 proportion of the non-GM area that is not compliant with the 0.9% threshold varies between  
195 62% and 77% among the 10 crop allocations to fields and the three wind distributions.

### 196 **3.2. Temporal strategy**

197 Figure 4 presents the distribution of GM and non-GM crops in the collection area when the  
198 temporal strategy is implemented. In this case, GM batches are collected at the beginning of  
199 the harvesting period, before the non-GM ones, in order to avoid admixture within silos and  
200 dryers. We find a homogeneous distribution of the variety when this collection strategy is  
201 used. Farmers' incomes are linked to the probability that the optimal maize harvest date is the  
202 period of collection for his crop. This probability depends on the period of the collection  
203 period. If the GM maize collection period is shorter than the non-GM one, the income of  
204 farmers growing GM cultivars is lower. As a result, farmers could therefore choose to only  
205 sow non-GM varieties (Figure 4a). The opposite situation is shown in figure 4b.

### 206 **3.3. Spatial strategy with one grain merchant**

207 We have assumed in this case that there is only one grain merchant in the territory, owning  
208 silos 1, 2 and 3 (Figure 1). The distribution of GM and non-GM varieties obtained by using  
209 the farmer's choice model is presented in Figure 5. The non-GM crops surround silo 3, which  
210 is dedicated to them, while GM crops are located around silos 1 and 2. The size of the non-  
211 GM area can be modified according to the price difference between GM and non-GM maize  
212 paid by the grain merchant.

213 The second line of Table 3 shows the percentage of GM grain in the non-GM silo as affected  
214 by wind direction. In each case, this percentage is relatively low and below the 0.9 %  
215 threshold. It is thus possible to sell the collected batches on the non-GM market. Besides, this  
216 percentage depends on the wind distribution and is higher with a northerly wind. Indeed, in  
217 this case, the wind is blowing from the GM maize area to the non-GM maize area, which is  
218 the worst case. There are two main prevailing winds (north and south) in the Colmar region.  
219 A south wind is the more favourable, because the non-GM fields are upwind. That is why the  
220 cross-pollination rate is lower and closer to 0.1% with the real wind distribution. Taking into  
221 account the most unfavourable wind direction may lead to an overestimate of the risk of GM  
222 admixture due to pollen flow. Grain merchants should thus consider the real wind  
223 distribution.

224 If we compare the first and second lines of Table 3, we notice a large decrease in GM grain  
225 percentage in the non-GM silo. Therefore, the organization of production in the collection



226 zone can reduce the cross-pollination risk not by using isolation distances between GM and  
227 non-GM fields but by indirectly creating field clusters such as those that exist for specific  
228 maize crops such as waxy maize (Meynard and Le Bail, 2001). In this case, the core of the  
229 non-GM zone is isolated from GM sources while harvests of ‘frontier’ fields containing GM  
230 impurities could be diluted by mixing in the silo, or they could be collected separately.

### 231 **3.4. Spatial strategy with two grain merchants**

232 In this case, two grain merchants share the harvest collection within the study zone. The first  
233 merchant owns silos 1, 2, and 3, and collects GM maize in silos 1 and 2 and non-GM maize in  
234 silo 3. The second owns silo 4 and has a different commercial policy. GM and non-GM  
235 harvests are collected in the same silo and the company pays the same price for both products.  
236 Figure 6 shows the distribution of GM and non-GM varieties in the agricultural landscape  
237 resulting from these two competing commercial policies. We see that the second firm’s  
238 strategy leads to the creation of a GM zone around silo 4, inducing a decrease in the non-GM  
239 area to 30% of the total area grown.

240 The third line of Table 3 shows the percentage of GM adventitious presence in the non-GM  
241 silo simulated by MAPOD®. Although GM production has increased in the zone, the  
242 percentage of GM grain in the non-GM batches remains low on average and below 0.9%. It is  
243 therefore possible to sell the collected crops to the non-GM market. If we compare the second  
244 and the third line of Table 3, we see that the GM percentage remains relatively low. It is thus  
245 possible to limit the proportion of GM in the non-GM silo by organising production in the  
246 zone, even if it contains a high proportion of GM maize.

247 However, if we compare the second and the third line of Table 3 we see that the amount of  
248 GM adventitious presence is three times as great in the case of a westerly prevailing wind  
249 blowing from the GM area (Figure 6). This percentage still complies with the 0.9 % threshold.  
250 However, the presence of several competitors in the same zone with different commercial  
251 policies can lead to an increase in GM impurity rates in the non-GM silo. Due to the stringent  
252 requirements of the maize food chain (Raveneau, 2005), this could lead to the loss of potential  
253 outlets for this crop.

### 254 **3.5. Impact of farmers’ behaviour on non-GM silo purity**

255 Table 4 shows the percentage of the non-GM area cultivated in GM necessary to contaminate  
256 the non-GM silo to an extent which would deny access to the non-GM market. It also shows  
257 that a very small area sown with GM in the non-GM zone (from 0.36 to 0.73%) would result

258 in exclusion from the non-GM market. To prevent such a situation, companies would have to  
259 adopt several strategies, such as crop contracts with farmers and information management  
260 about farmers' practices. Such a policy would increase the transaction costs associated with  
261 co-existence.

## 262 **4. Discussion**

### 263 **4.1. Limitations of the farmer's choice model**

264 The model of crop allocation that we have used in this study is based on the maximisation of  
265 profit for each field. It has two assumptions that warrant discussion.

266 The first is that the risk covered by the use of GM maize is uniform over the collection zone.  
267 In fact, the distribution of the agronomic risk due to the corn borer is not uniform throughout  
268 any area, so the farmer's choice between GM and non-GM maize should be linked to this  
269 constraint (Bourguet et al., 2005). The use of agronomic variables in the model of farmers'  
270 choices might put into perspective the results presented here, because they would apply to  
271 larger and more representative geographical zones of the whole collection region of a grain  
272 merchant. Taking into account these agronomic factors and a larger area would allow one to  
273 search for alternative collection strategies. A spatial strategy with different delivery periods  
274 for each product could be considered. It would then be possible to take into account different  
275 flowering times to avoid field-to-field cross-pollination (Halsey et al., 2005; Messéan et al.,  
276 2006).

277 The second is that the optimal period for maize harvesting can be relatively short. The  
278 probability of being able to harvest during this period is connected to the total duration of  
279 collection. Such an assumption must be put into perspective. It applies in northern Europe and  
280 in Alsace in particular (Raveneau, 2005). In southern Europe (southwest France or Spain), the  
281 climate is more favourable and the optimal period for maize harvesting lasts longer. It is  
282 therefore possible to consider temporal strategies of collection that have a lower collection  
283 cost (Coléno, 2008b). In this case, farmers would support cross-pollination risk management,  
284 possibly growing GM varieties so as to set up isolation distances or non-GM buffer zones  
285 around their fields to avoid the risks of cross-pollination (EC, 2003a).

### 286 **4.2. Effect of the strategies studied on GM crop planting**

287 Introduction of GM varieties on a landscape scale comes up against regulations based mainly  
288 on the use of isolation distances (Beckmann et al., 2006), whatever the characteristics of the

289 agricultural landscape. In regions where fields are small and fragmented, GM maize can only  
290 be sown in a small number of fields (Devos et al., 2007). Furthermore, when fields are small,  
291 with scattered ownership, non-GM production can lead to prohibition of GM production on  
292 almost all the land because of a domino effect (Demont et al., 2008). But this domino effect  
293 could lead to an exclusion of organic farming in the landscape, because of a greater isolation  
294 distance between GM and organic fields.

295 All this takes only account of farmers' choices at an individual level, and so leads to solution  
296 for co-existence at the field level. Taking into account grain merchants' strategies allows GM  
297 and non-GM co-existence to be considered at the landscape level. It is thus possible to take  
298 into account incentive mechanisms with farmers (contract or price setting) in order to  
299 organise GM and non-GM production at a higher level than that of the field. Hence it is  
300 possible to bypass the problem of isolation distances between GM and conventional fields by  
301 concentrating non-GM production in specific zones. Co-existence of both crops in the zone  
302 may then be possible.

#### 303 **4.3. How should the boundaries of the collection zone be managed?**

304 The definition of homogeneous zones, such as are used for waxy maize production in certain  
305 regions (Meynard and Le Bail, 2001), raises the question of boundary management. Indeed,  
306 we calculated the adventitious presence of GM material for the whole non-GM maize area.  
307 This average percentage masks the disparities between fields in the core of the non-GM zone  
308 and those located near the boundaries.

309 In the case of maize, the quantity of dispersed pollen diminishes with distance (Bateman,  
310 1947a; b; Raynor et al., 1972). Non-GM fields in the border zone are closer to the GM pollen-  
311 emitting source than those in the core, and consequently have a higher GM rate than the  
312 average (results not shown).

313 The management of these fields thus requires:

- 314 • limiting the rate of cross-pollination by implementing co-existence measures such  
315 as isolation distances (Jones and Brookes, 1950), time-lag of flowering (Halsey et  
316 al., 2005), or non-GM buffer zones (Messéan et al., 2006);
- 317 • setting up compensation mechanisms for non-GM crops that would have to be sold  
318 as GM. Such mechanisms can be implemented either via producers' clubs (Furtan  
319 et al., 2007) or they may be provided by grain merchants in order to ensure a low  
320 GM rate in the core of the non-GM zone.

#### 321 **4.4. How to deal with grain merchants with divergent strategies?**

322 Use of appropriate collection strategies realise on the creation of a non-GM production zone  
323 of sufficient size to guarantee a low percentage of GM in non-GM batches. A decrease in the  
324 size of the non-GM zone, because of competitors with different commercial strategies, causes  
325 an increase in the GM percentage in non-GM batches. Consequently, the non-GM zone  
326 should be located in areas where the competition between grain merchants is low. Another  
327 possibility is that grain merchants coordinate GM and non-GM variety allocation in the zone.  
328 This leads to the development of co-opetition strategies (Nalebuff and Brandenburger, 2002)  
329 at the scale of the collection zone. Therefore, GM and non-GM crop co-existence could lead  
330 to new collective strategies of the various firms involved in the supply chain, between clients  
331 and suppliers as well as between competitors.

#### 332 **5. Conclusion**

333 To overcome difficulties in the segregation of GM and non-GM crops in the supply chain, it  
334 is necessary to dedicate silos and dryers to either crop over the course of time or by defining  
335 GM and non-GM zones in the agricultural landscape and collection infrastructure.  
336 These two basic solutions lead to an increase in collection costs due to an increase in transport  
337 costs and a decrease in the flexibility of the collection process (Bullock and Desquilbet, 2002;  
338 Coléno, 2008b). Moreover, these strategies do not have the same effect on landscape  
339 organization and on the risk of cross-pollination between GM and non-GM fields. The spatial  
340 strategy could allocate parts of the landscape to each crop and thus minimize accidental GM  
341 presence. The temporal strategy would lead to uniform GM and non-GM zones while only  
342 considering the farmer's economic benefit. In this case, there is no risk of cross-pollination.  
343 But, from an agronomic point of view in relation to the different exposures to risk concerning  
344 Bt maize, it is possible that the spatial allocation of GM and non-GM crops would no longer  
345 be homogeneous. In such a case, considering European regulations, GM production might  
346 have to be reduced because of the impossibility of producing a GM crop close to non-GM  
347 fields of the same species (Demont et al., 2008; Devos et al., 2007).  
348 Moreover, in order to go further to evaluate collection strategies at the landscape level it is  
349 necessary to improve the two models used there. Concerning the farmer's choice model, it  
350 would be possible to develop a multi-criterion model of farmer's choice that takes into  
351 account economic and agronomic factors. For MAPOD®, the specific effect of canopy  
352 discontinuities (such as other crops, hedges or roads) on pollination patterns at field edges  
353 needs to be better modelled.

354 Considering the difficulties of segregation management, it seems necessary to consider  
355 landscape governance (Byrne and Fromherz, 2003) in order to define an optimal collection  
356 strategy for grain merchants that takes into account the cost management of segregation in the  
357 supply chain as well as the costs of managing GM crop distribution in the agricultural  
358 landscape. Specifically, it seems necessary to evaluate the feasibility of cooperation between  
359 different grain merchant companies in order to manage the collection zone.

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## 368 **References**

- 369 Angevin, F., Colbach N., Meynard, J.M., Roturier, C., 2002. Analysis of necessary  
370 adjustments of farming practices, *In* A.-K. Bock, Lheureux, K., Libeau-Dulos, M., Nilsagard  
371 H., Rodriguez-Cerezo, E., eds. Scenarios for co-existence of genetically modified,  
372 conventional and organic crops in European agriculture. Technical Report Series of the Joint  
373 Research Center of the European Commission. EUR 20394 EN
- 374 Angevin, F., Klein, E.K., Choimet, C., Gauffreteau, A., Lavigne, C., Messéan, A., Meynard,  
375 J.M., 2008. Modelling impacts of cropping systems and climate on maize cross-pollination in  
376 agricultural landscapes: The MAPOD model., *European journal of Agronomy*. 28, 471-484
- 377 Bateman, A. J., 1947a. Contamination in seed crops I: Insect pollination. *J. Genet.* 48, 257-  
378 275.
- 379 Bateman, A. J., 1947b. Contamination in seed crops II: wind pollination. *Heredity*. I, 235-246.
- 380 Beckmann, V., Soregaroli, C., Wesseler, J., 2006. Coexistence rules and regulations in the  
381 European Union. *American Journal of Agricultural Economics*. 88, 1193-1199.
- 382 Betbesé, I., Lucas J.A., 2006. Varietats de panís, Dossier tècnic, Ruralcat. 24p
- 383 Bourguet, B., Desquilbet, M., Lemarié, S., 2005. Regulating insect resistance management:  
384 the case of non-Bt corn refuges in the US. *Journal of Environmental Management*. 76, 210-  
385 220.

386 Brookes, G., 2002. The farm level impact of using Bt maize in Spain. *PGEconomics*, 23p.  
387 [http://www.pgeconomics.co.uk/pdf/bt\\_maize\\_in\\_spain.pdf](http://www.pgeconomics.co.uk/pdf/bt_maize_in_spain.pdf)

388 Bullock, D.S., Desquilbet, M., 2002. The economics of non-GMO segregation and identity  
389 preservation. *Food Policy* 27, 81-99.

390 Byrne, P. F., Fromherz, S., 2003 Can GM and Non-GM Crops Coexist? Setting a Precedent in  
391 Boulder County, Colorado, USA, *Journal of Food, Agriculture & Environment* 1, 258-261.

392 Colbach, N., Clermont-Dauphin, C., Meynard, J. M., 2001. GENESYS: a model of the  
393 influence of cropping system on gene escape from herbicide tolerant rapeseed crops to rape  
394 volunteers. II. Genetic exchanges among volunteer and cropped populations in a small region.  
395 *Agric. Ecosyst. Environ.* 83, 255-270.

396 Coléno, F.C., 2008a. A simulation model to evaluate the consequences of GM and non-GM  
397 segregation rules on landscape organization. *Journal of International Farm management*. 4-3  
398 ([www.ifmaonline.org/pdf/journals/Vol4\\_Ed3\\_Coleno.pdf](http://www.ifmaonline.org/pdf/journals/Vol4_Ed3_Coleno.pdf))

399 Coléno, F.C., 2008b. Simulation and evaluation of GM and non-GM segregation management  
400 strategies among European grain merchants. *Journal of Food Engineering*. 88; 306-314

401 Comité National du Transport. 2006. Simulateur de prix de revient transport régionaux  
402 ([www.cnt.fr](http://www.cnt.fr)).

403 Demont, M., Daems, W., Dillen, K., Mathijs, E., Sausse, C., Tollens, E., 2008. Regulating  
404 coexistence in Europe: Beware of the domino-effect!. *Ecological Economics*, 64, 683-689.

405 Derieux, M., Bonhomme, R. 1982. Heat unit requirements for maize hybrids in Europe.  
406 Results of the European FAO sub-network. I. Sowing-silking period. *Maydica*. 27, 59-77.

407 Derieux, M., Bonhomme, R. 1990. Heat units requirements of maize inbred lines for pollen  
408 shedding and silking: results of the European FAO network. *Maydica*. 35, 41-46.

409 Devos, Y., Reheul, D., Thas, O., De Clercq, E. M., Cougnon, M., Cordemans, K., 2007.  
410 Implementing isolation perimeters around genetically modified maize fields. *Agronomy For*  
411 *Sustainable Development*, 27, 155-165.

412 Durand, R. 1969. Signification et portée des sommes de températures. *Bull. tech. inf.* 238,  
413 185-190.

414 Eurobarometer. 2006. Europeans and biotechnology in 2005: Patterns and trends. European  
415 Commission's Directorate General for Research, Eurobarometer 64.3, 85 p.

416 European Commission. 2003a. Commission recommendations of 23 July 2003 on guidelines  
417 for the development of national strategies and best practices to ensure the co-existence of  
418 genetically modified crops with conventional and organic farming, 2003/556/EC (notified

419 under document number C(2003) 2624), , pp. pp 36-47. Official Journal of the European  
420 Union, 29/07/2003, vol. 46, L189.

421 European Commission. 2003b. Regulation (EC) N° 1829 / 2003 of the European Parliament  
422 and of the Council of 22 September 2003 on genetically food and feed, pp. pp1–23. Official  
423 Journal of the European Union, 18/10/2003, vol. 46, L268.

424 European Commission. 2003c. Regulation (EC) N° 1830 / 2003 of the European Parliament  
425 and of the Council of 22 September 03 concerning the traceability and labelling of genetically  
426 modified organisms and the traceability of food and feed products produced from genetically  
427 modified organisms and amending Directive 2001/18/EC, pp. pp 24-28. Official Journal of  
428 the European Union, L268, 18/10/2003, vol. 46, L268.

429 Furtan, W.H., Güzel, A., Weseen, A.S., 2007. Landscape clubs: co-existence of genetically  
430 modified and organic crops. *Canadian Journal of Agricultural Economics*, 55, 185-195.

431 Halsey, M.E., Remund, K.M., Davis, C.A., Qualls, M., Eppard, P.J., Berberich, S.A., 2005.  
432 Isolation of maize from pollen-mediated gene flow by time and distance. *Crop Science*, 45,  
433 2172-2185.

434 James, C., 2006. Global Status of Commercialized Biotech/GM Crops: 2006. ISAAA Brief  
435 No. 35. ISAAA: Ithaca, NY.

436 Jank, B., Rath, J., Gaugitsch, H., 2006. Co-existence of agricultural production systems.  
437 *Trends in Biotechnology*, 24, 198-200.

438 Jones, J. M., Brooks, J. S., 1950. Effectiveness and distance of border rows in preventing  
439 outcrossing in corn. *Oklahoma Agric. Exp. Sta. Tech. Bull.*T-38: 1-18

440 Klein, E. K., Lavigne, C., Foueillassar, X., Gouyon, P. H., Laredo, C. 2003. Corn pollen  
441 dispersal: Quasi-mechanistic models and field experiments. *Ecol. Mon.* 73, 131-150.

442 Levidow, L., Carr, S., Wield, D., 2000. Gentically modified crops in the European Union:  
443 regulatory conflicts as precautionary opportunities. *Journal of Risk Research* 3, 189-208.

444 Lüthy, J., 1999. Detection strategies for food authenticity and genetically modified foods.  
445 *Food control*, 10, 259-361.

446 Messéan, A., Angevin, F., Gómez-Barbero, M., Menrad, K., Rodríguez-Cerezo, E., 2006.  
447 New case studies on the coexistence of GM and non-GM crops in European agriculture,  
448 Technical Report Series of the Joint Research Center of the European Commission, EUR  
449 22102 En, 112 p.

450 Meynard, J. M., Le Bail, M., 2001. Isolement des collectes et maîtrise des disséminations au  
451 champ, Rapport du groupe 3 du programme de recherche Pertinence économique et faisabilité  
452 d'une filière sans utilisation d'OGM. INRA – FNSEA, 56 p.

453 Miraglia, M., Berdal, K.G., Brera, C., Corbisier, P., Holst-Jensen, A., Kok, E.J., Marvin,  
454 H.J.P., Schimmel, H., Rentsch, J., Van Rie, J.P.P.F., Zagon, J., 2004. Detection and  
455 traceability of genetically modified organisms in the food production chain. *Food and*  
456 *Chemical Toxicology*. 42, 1157-1180.

457 Nalebuff, B.J., Brandenburger, A.M., 2002. "Co-opetition". Profilebooks, London. 275p.

458 Raveneau, A., 2005. Stratégies de séparation des filières OGM et non OGM en amont de la  
459 chaîne logistique d'approvisionnement. Mémoire de fin d'étude de l'ENESAD. 33p

460 Raynor, G. S., Ogden, E. C., Hayes, J. V. 1972. Dispersion and deposition of corn pollen from  
461 experimental sources. *Agron. J.* 64, 420-427.

462 Scipioni, A., Saccarola, G., Arena, F., Alberto, S., 2005. Strategies to assure the absence of  
463 GMO in food products application process in a confectionery firm. *Food control* 16, 569-578.



464 **Figures**

465

466 Figure 1: Map of the region used for simulations (region of Selomes, Loir et cher department,  
467 France). Silo locations are shown by circles. (Courtesy of the Institute for the Protection and Security of  
468 the Citizen, Joint Research Centre of the European Union and AUP-ONIGC - ex ONIC, Office National  
469 Interprofessionnel des céréales/French Interprofessional agency for cereal crops)

470 Figure 2: effect of price difference between GM and non-GM production on landscape use  
471 with a 7.15% yield difference

472 Figure 3: Wind distribution at Colmar

473 Figure 4: Allocation of GM and non-GM varieties. Temporal strategy

474 (a) with GM harvest duration shorter than non-GM harvest duration, (b) with GM harvest  
475 duration longer than non-GM harvest duration

476 Figure 5: Allocation of GM and non-GM varieties, spatial strategy with one grain merchant

477 Figure 6: Allocation of GM and non-GM varieties, spatial strategy with two grain merchants

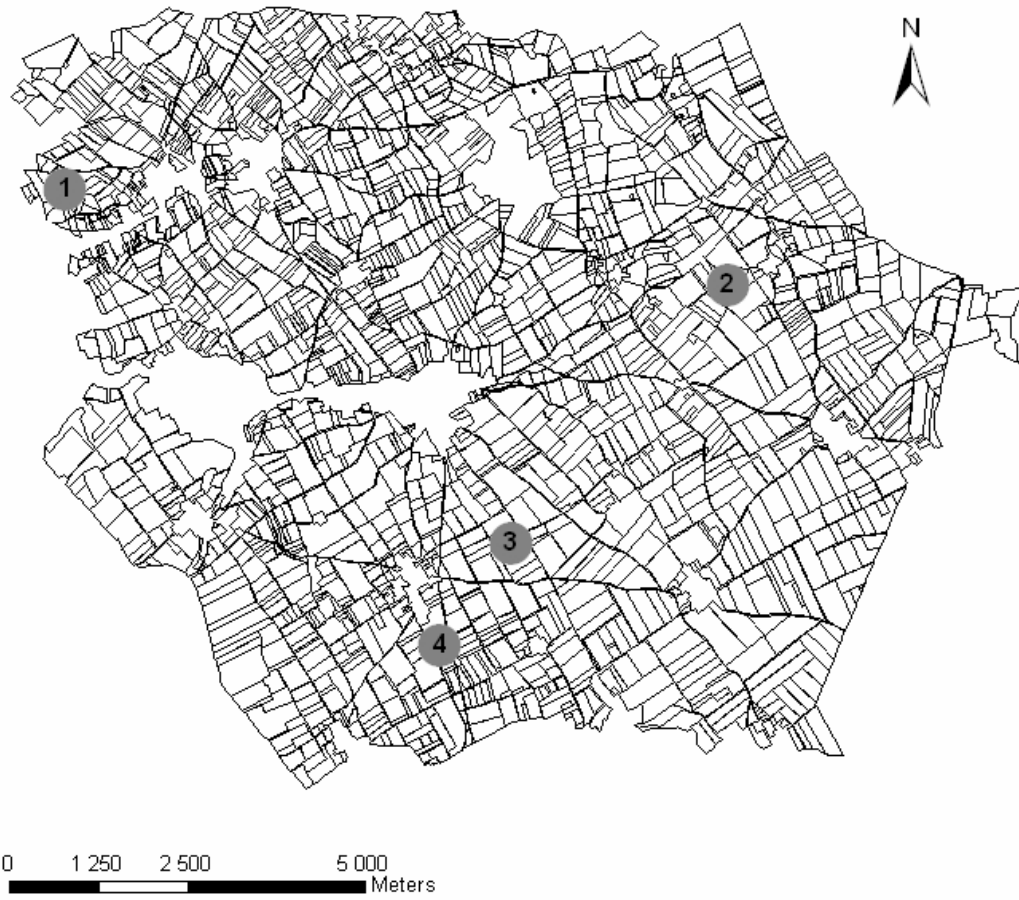
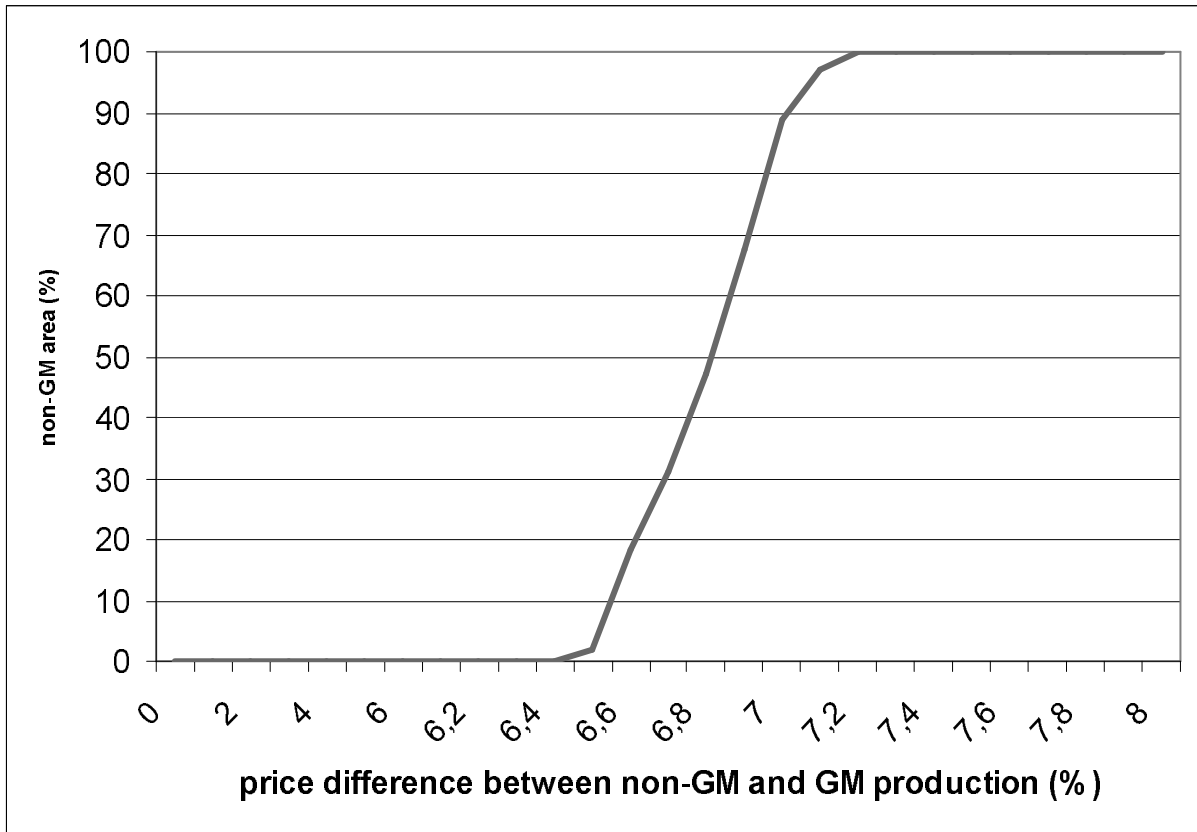


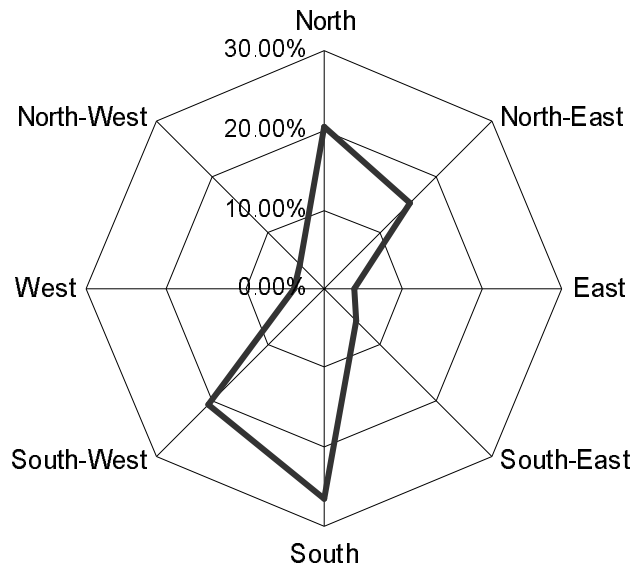
Figure 1



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Figure 2



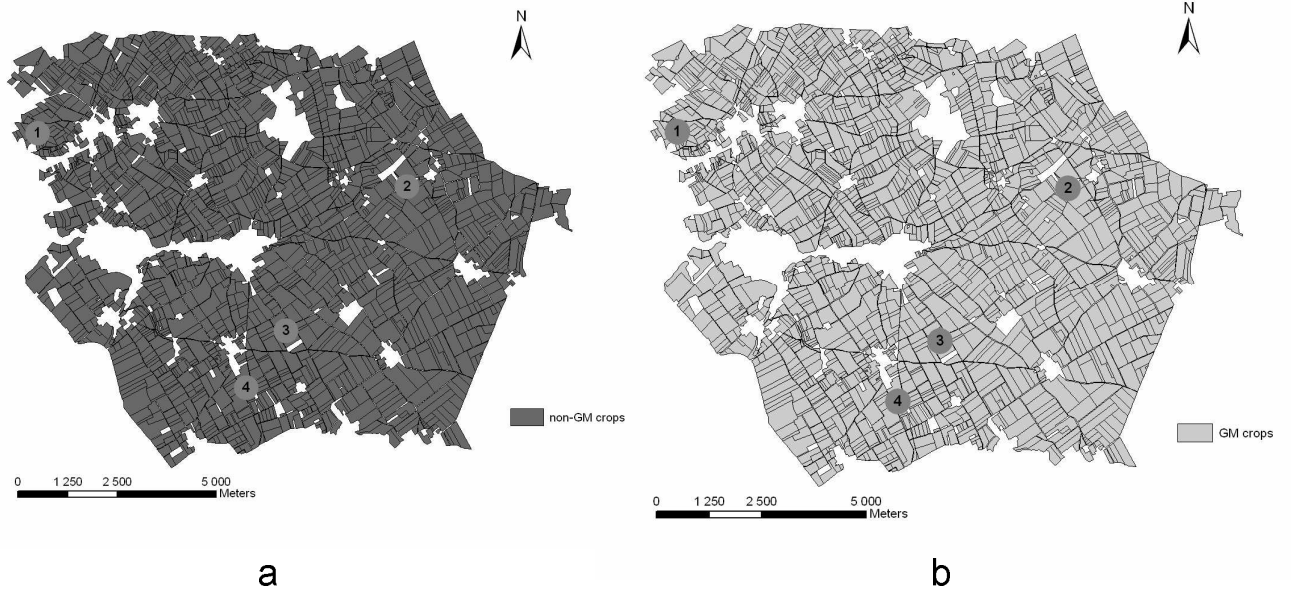
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Figure 3

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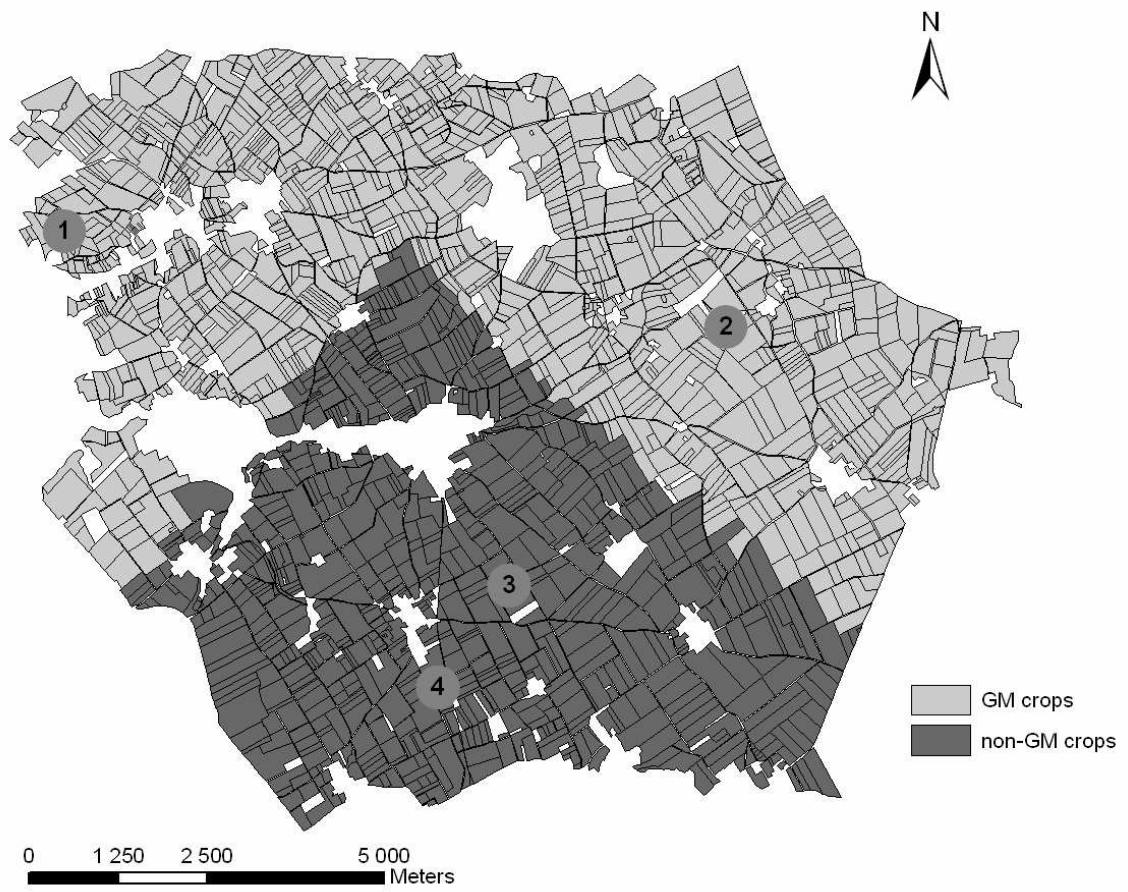
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Figure 4

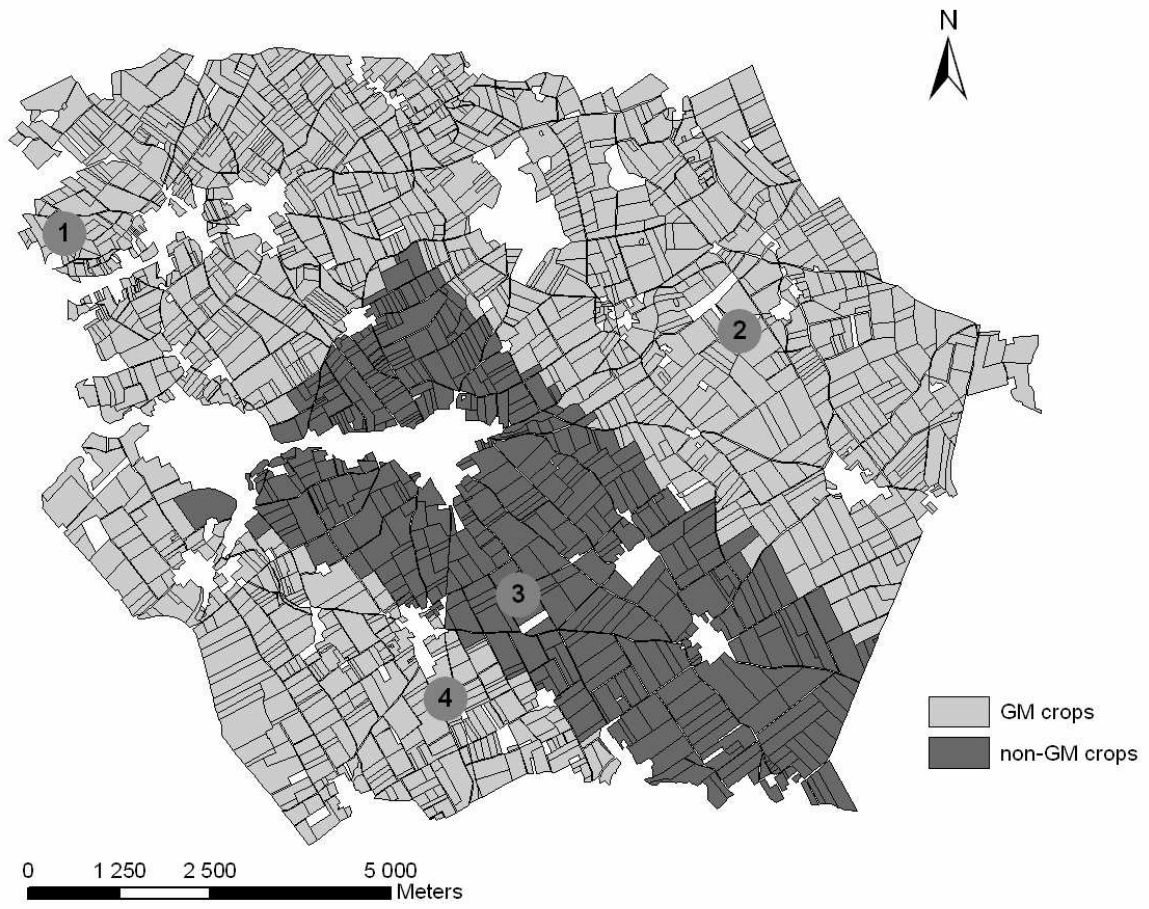


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Figure 5

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Figure 6

495 **Tables**

496

497 Table 1: MAPOD® input data

498 Table 2: Work hypotheses

499 Table 3: GM impurity percentages in non-GM maize batches at the collection silo for the  
500 different scenarios.

501 Table 4: percentage of the non-GM zone cultivated with GM that would lead to loss of the  
502 non-GM market.



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Table 1

Input data	Description
Field plan	Shape and size of fields, location of GM and non-GM maize crops
Climate (per day)	Temperature; rain; wind speed and direction
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 GM: homozygous or heterozygous Tassel height of each variety, Ear height of non-GM variety

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Table 2

	GM maize	Non-GM maize	Sources
Seed price	210/223 €/ha	181/192 €/ha	Brookes, 2002
Treatment	0	24€ / ha	Brookes, 2002
Yield	100%	93%	Betbesé and Lucas, 2006
Price	100 €/t	107€/t	Coléno 2008a
Loss of quality	10 % of the price	10 % of the price	Raveneau, 2005
Transport costs	0.05 €/t/km	0.05 €/t/km	Comité National Routier, 2006

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Table 3

Strategy	Colmar wind distribution	North wind	West wind
60% of GM randomly allocated and standard deviation in bracket “no collection strategy”	1.41 (0.03)	1.42 (0.04)	1.44 (0.04)
Spatial strategy with one grain merchant	0.16	0.25	0.18
Spatial strategy with two grain merchants	0.54	0.27	0.54

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Table 4

Strategy	Colmar wind distribution	North wind	West wind
Spatial strategy with one grain merchant	0.73	0.63	0.70
Spatial strategy with two grain merchants	0.36	0.61	0.36

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