A simulation model to evaluate the consequences of Genetic Modification and non-Genetic Modification segregation rules on landscape organisation

F.C. Coléno

INRA, UMR 1048 SAD-APT,
Bâtiment EGER, Site de Grignon, BP 1 78850 Thiverval-Grignon France.
e-mail : francois.coleno@grignon.inra.fr

Dr François Coléno is a senior researcher in Management Science and farm management in the French National Institute of Agronomic Research (INRA). His principal research topics are land use governance and firm strategy in the case of Genetically Modified (GM) and non-GM crops, crop co-existence, food safety and sustainability of agricultural production.

Abstract

In Europe, a product is GM if it contains more than 0.9% of GM material. During harvesting, crops from many fields are combined to fill a silo. To avoid the risk of mixing GM and non-GM crops it is possible to specify GM and non-GM silos or to define times for GM and non-GM delivery at silos. A model of farmers' variety choice, based on profit and taking into account transport cost and the price and cost difference between GM and non GM crops, is proposed to determine the consequences of these strategies for agricultural land. The delivery timing strategy leads to a uniform area of GM or non-GM crops depending on prices and weather risks. The spatial strategy leads to areas of either GM or non-GM crops around the corresponding collection silos. The size of these zones depends on yields, price differences and transport costs.

Keywords: GM, co-existence, supply chain, land use

1. Introduction

GM implementation in Europe generated conflict between proponents and opponents of this technology (Levidow et al., 2000). This conflict led at first to a moratorium on GM, which ended in 2004, and later to the principle of coexistence between the different types of production. The rules for coexistence are defined in European regulations. At the farm level the regulations aim to avoid cross-pollination of conventional crops by GM crops (EC, 2003a). At the food-processing industry level the aim is traceability of GM products throughout the supply chain (from farm to fork) (EC, 2003b) ensuring labelling of a product if it contains more than 0.9 % of GM material (Arvanitoyannis et al., 2006; Beckmann et al., 2006; Jank et al., 2005). For the food industry the problem is to guarantee the level of GM material using PCR tests (Lüthy, 1999) and to implement risk management methods

identifying critical points and proposing quality control methods such as the HACCP method (Scipioni et al., 2005).
For agricultural producers, coexistence generates several problems. On a farm, use of the same agricultural machinery, such as a seed drill or harvester, for both GM and conventional production, increases the risk of admixture (Jank et al., 2006). Moreover, a farmer using GM seed has to be sure that his fields will not contaminate any conventional production of his neighbours. There are two procedures to avoid this. The first is a minimum isolation distance between GM and non-GM fields (Byrnes et al., 2003) because maize pollen has a short flight range (Della Porta et al, 2008). The second is to stagger planting dates so the flowering of GM and non-GM crops will not occur at the same time (Angevin et al, 2008).
For country elevators the problem is to ensure segregation of the two products in their supply chain and to avoid risk of mixing GM and non GM-fields when crops are harvested.
Concerning the first point, there are two possible management strategies (Miraglia et al., 2004):

- A temporal strategy where the two products are separated by the timing of collection. In this case, each product is delivered to the nearest collection silo to the farm, but at separate times. It is therefore not necessary to manage separation of the product in the collection silos. Besides, by concentrating the collection of a product over a short period of time it is possible to have sufficient material to dedicate a drying line to a product and to fill one or more storage bins. The inconvenience of this scenario for the country elevator is that the farmers can choose to deliver to a competitor who is more flexible when they want to harvest. This leads to a loss of volume collected and thus a reduced market share.
- A spatial strategy based on a geographical grouping decided before sowing. Each collection silo and accompanying dryer(s) receives only one type of product. This leads to an independent supply chains for each product. The risk of mixing between GM and non-GM products is avoided. Farmers are informed about this allocation before sowing, so they can choose their crop type taking into account the product accepted by the nearest collection silo and the cost of transport to other collection silos. Hence, this strategy indirectly encourages farmers to choose a particular crop type, but it does not prevent farmers from delivering to a competitor closer to their farm who accepts both products.

In order to avoid cross-pollination between GM and non-GM crops at field level one possibility is to create homogeneous zones for each crop. Another one is to let farmers manage coexistence on their own, but this could lead to an increased the risk of cross-pollination supported by the farmer. This risk can be counteracted by the use of minimum isolation distances. In that case a domino-effect could occur which would lead to a decrease of GM production and an increasing cost of coexistence (Demont et al., 2008).
As there are very few GM maize crops planted in Europe, and especially in France (22000 ha of GM maize and 3300000 ha of maize) it is not possible to evaluate how farmers would react to these strategies. In this paper, we propose a simulation model of farmer choice between

GM and non-GM crops to evaluate the consequences of different country elevators strategies in the landscape organisation.

2. Presentation of the model

The focus of the simulation model is on farmer choice between GM and non-GM crops. We consider that the choice between GM and non-GM crops is based on the profit from the adoption (or the non-adoption) of GM technology. We take into account any extra costs for farmers coming from the country elevator management strategies.

The variables, which distinguish GM from non-GM crops, arise from differences in production costs and yields. These variables concern:

- difference in seed prices. Studies show a difference in seed cost between GM and non-GM in favour of non-GM partly offset by the treatment cost (Brookes, 2002).
- the seed treatment cost. If a farmer decides to not use GM technology, he has to use pesticide to limit the risk that GM technology allows him to avoid.
- the yield difference between GM and non-GM maize. GM crops have an increased yield compared to non-GM maize that vary from 3 to 9% according to Brookes (2002) and from 3 to 7.5 % as claimed by Betbesé (2006).

The variables of importance for country elevator strategy are:

- transport costs and the distance between the field and the silo accepting the crop.
- the price paid to the farmer for the crop. In Europe, the price paid for non-GM crops will be higher as the food market rejects GM crops (Kalaitzandonakes, 2005).
- the probability of quality loss. When maize with a high moisture content is delivered, the country elevator pays a lower price. Farmers are encouraged to harvest their crops at the lowest possible moisture content, but since country elevators impose delivery periods for a given crop type, it may be difficult to do this. If it is raining over this period there will be loss of quality for the farmer.

For each field the best choice is to grow GM maize if Δ_p is positive and non-GM maize if Δ_p is negative:

If $\Delta_p > 0$ then grow GM maize; otherwise grow non-GM maize

$\Delta_p = profit_{GM} - profit_{nonGM}$ (1)

$Profit = Y*P*(1\text{-}loss) + Y*P*loss - C_s - C_t - C_{tr}*d_{silo}$ (2)

Where Y is the yield of the crop in t/ha, P is the maize price in € paid by the country elevator, C_s the price of the seed, C_t the cost for pesticide (in €/ha), C_{tr} the transportation cost (in €/t/km) to deliver the crop to the collection silo and d_{silo} the distance between the field and the silo in km. Loss is the probability of a loss in quality if the maize is not harvested at its optimal date. In the case of the spatial strategy, loss=0. For a GM crop the treatment cost is taken as zero, the GM crop being pest-resistant. For each field in the area the model maximizes profit by choosing a GM or a non-GM crop type. To evaluate the consequences of these variables on an area's production we used this model on an area of 100 km^2 (figure 1) chosen because of its substantial size, which was sufficient to take into account transport costs. We identified three collection silos, numbered 1-3, within the area. For each field the model chose between GM or non-GM maize, taking into account the field's distance from the various silos. It was then possible to calculate the proportion of land cultivated in GM in the area concerned.

Figure 1: map of the area used for the model[1]

In order to analyse the consequences for country elevators collection strategies on GM and non-GM maize production we focus the analysis on the variables linked to these strategies. For some variables, directly linked to the technology, we used values found in the literature (see table 1). Concerning the yield difference between GM and non-GM maize several authors considered that it could vary from 3 to 7.5 or 9% in favour of GM maize (Brookes, 2002; Betbesé, 2006). Farmers seem to adopt such technology if the yield increase is higher than 6% (Fernandez-Cornejo and McBride, 2002). For the calculations, we used a yield difference of 7% in favour of GM to have a yield difference higher than 6%.

[1] Map: Courtesy of the Institute for the Protection and Security of the Citizen, Joint Research Centre of the European Union and AUP-ONIGC - ex ONIC (Office National Interprofessionnel des céréales/French Interprofessional agency for cereal crops)

Table 1: model variables and their values

	Variables distinguishing GM and non-GM	Variables accounting for collection strategies	Variable name	Value used for GM	Value used for non-GM
Seed price	X		C_s	223€/ha (Brookes, 2002)	192 €/ha (Brookes, 2002)
treatment cost	X		C_t		24 €/ha (Brookes, 2002)
Transportation cost		X	C_{tr}	0.05€/t/km	0.05€/t/km (comité national du transport, 2006)
Harvest price	X	X	P	variable	variable
Yield	X		Y	10.02 t/ha (Betbesé 2006)	9.32 t/ha (Betbesé 2006)
Probability of quality loss		X	loss	variable	variable

3. Results

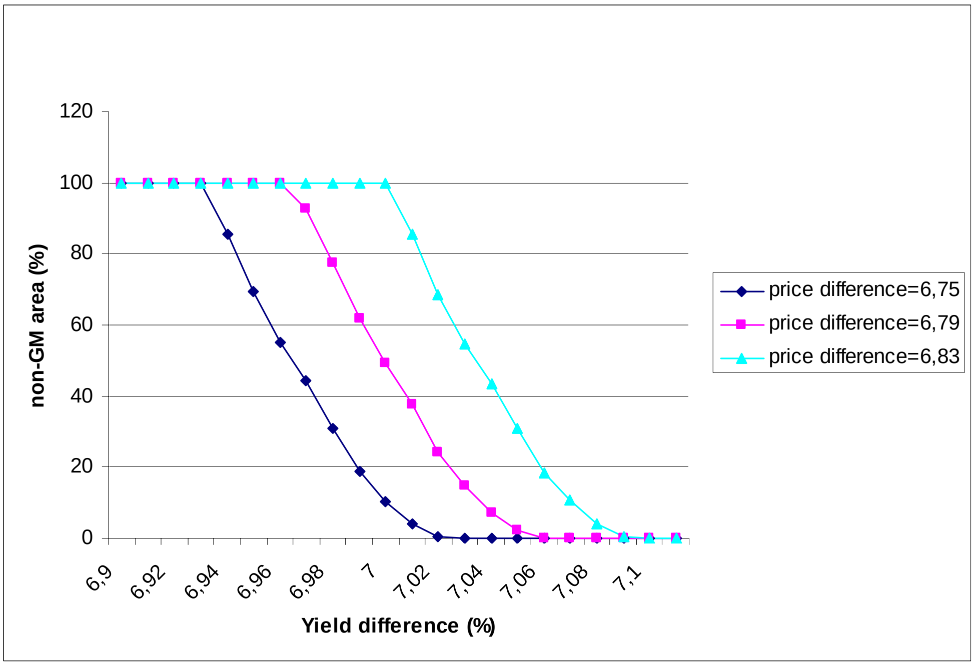
3.1 Consequence of the spatial collection strategy

To estimate the sensitivity of the model to the various parameters we assumed that silo 1 receives the GM crops and that silo 2 the non-GM ones (silo 3 is only used to evaluate the impact of transport costs and receives non GM crops). In the case of the spatial strategy, we focus on the influence of price differences and transport costs on the proportion of non-GM maize in the area.

3.1.1 Impact of yield differences on GM and non GM area

Figure 2 presents the impact of yield differences between the two crops for three price differentials (6.75%, 6.79% and 6.83 %) and a 0.05 €/t/km transportation cost. There is an abrupt change in the type of crop grown on the whole area. This phenomenon is the opposite of the one seen for the crop price difference. The yield increase in our hypothesis favours GM crops (Betbesé, 2006). However, the yield difference is weakly compensated for by the price difference. For any price difference, the change from an area totally cultivated with non-GM to one growing only GM occurs with a 0.1% yield increase (from 6.9 to 7 %).

Figure 2: Effect of yield on non-GM area for three hypothetical price differentials.



For the rest of the paper we assume a yield difference of 7 % in favour of GM. This allows us to be over the 6% for adoption of GM technology (Fernandez-Cornejo and McBride, 2002) and to allow a distribution of GM and non-GM in the landscape.

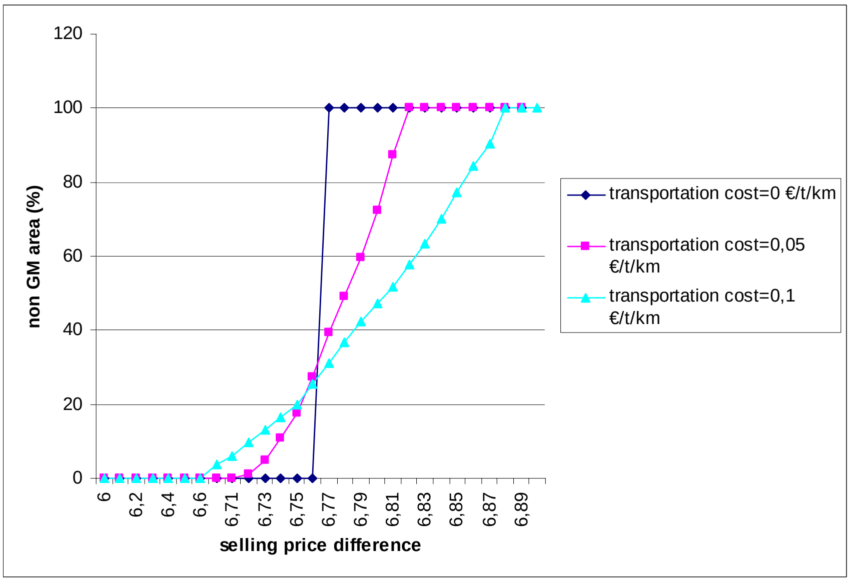
3.1.2Impact of price difference on the distribution of GM and non- GM crops

Figure 3 shows the proportion of the total area in non-GM maize according to the price differential between GM and non-GM for three transport costs.

It is immediately clear that the change from total GM to only non-GM is very abrupt whatever the transport cost. The change from one extreme to the other is made between 6.5 and 6.9 %, because the difference in production costs between GM and non-GM production of 7€/ha is quickly compensated for by the price difference between the two products. A smaller difference in production costs, due for example to a reduction in GM seed costs, would lead to an increase in GM production or require an increase in the non-GM price to compensate for the decline in GM seed costs.

Secondly, we can see that the slopes of the curves vary according to the increase in transport costs, so for a zero cost the change is sudden - 0 to 100 % of the area cultivated in non-GM as soon as the price differential offsets the production cost difference between the two crops (in our hypothesis between 6.76 and 6.77 % of the price difference). On the contrary, for a transport cost of 0.1€/t/km the change from one crop to the other is more gradual. Hence, as soon as we take into account the transport cost the difference in production costs between the two products diminishes. The price to be paid to purchase the non-GM product can then be lower.

Figure 3: Impact of the selling price difference on the proportion of non GM area



3.1.2 Impact of transportation cost on GM and non-GM areas

Figure 4 demonstrates the impact of transport costs on the distribution of GM and non-GM maize for three price differentials between GM and non-GM products.

We notice that when the price difference is below 6.77 % the non-GM area is small or nil according to the transport cost. On the other hand, when the price difference is above this threshold the non-GM area is large and can reach 100% of the area.

Moreover, the consequence of a transport cost increase is a decrease in the GM area up to a certain stage, which depends on the price difference. Thus in figure 4, for a price difference of 6.83% it is not possible to go below 60 % of the total area of non-GM while for a price difference of 6.79 % it is possible to come down to 40 % of non-GM. The transport cost effect on farmers' choice is thus relative. To counterbalance such an effect, country elevators have two possibilities:

- to use their buying price to increase, or decrease, the quantity of non-GM produced, as shown here, or
- to increase or decrease the number of collection silos in the area that accept GM deliveries. So, when two silos are allocated to non-GM collection, the rate of non-GM in the area increases strongly (figure 5). For a 6.79 % price difference it is possible to go from a maximum of 20 % of non-GM (figure 3) to a maximum of 45 % (figure 5).

Figure 4: Impact of transportation cost on non-GM area with one silo for each product.

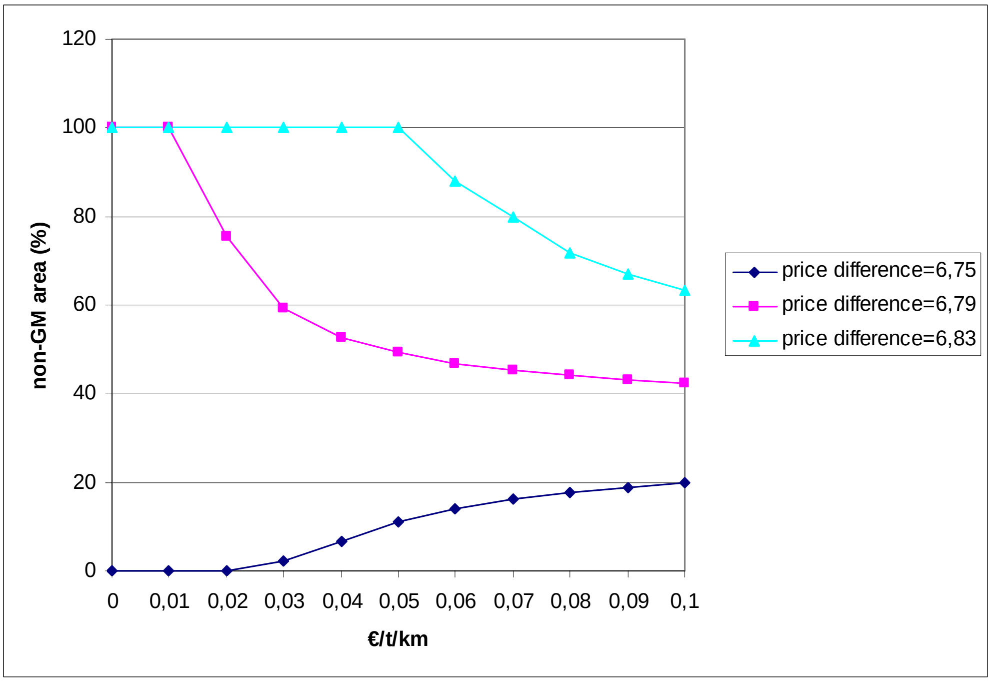
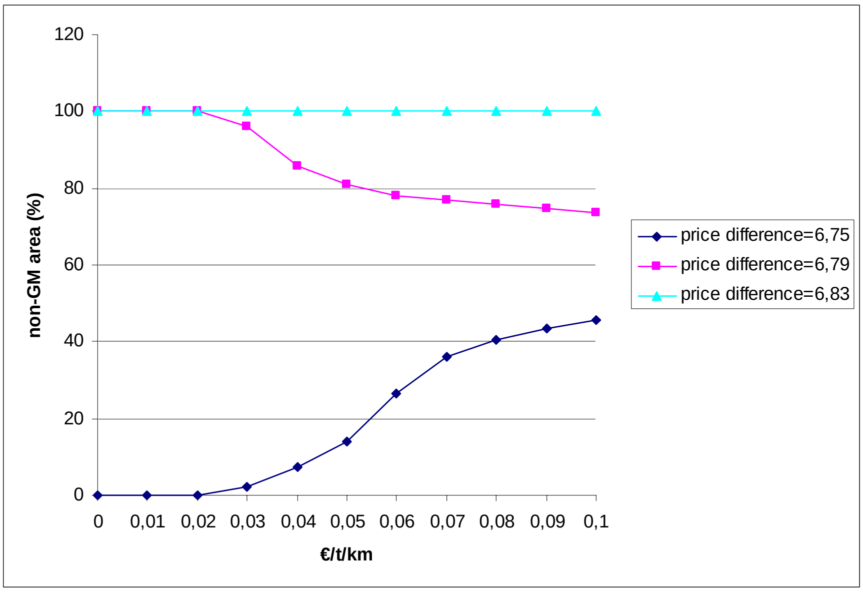


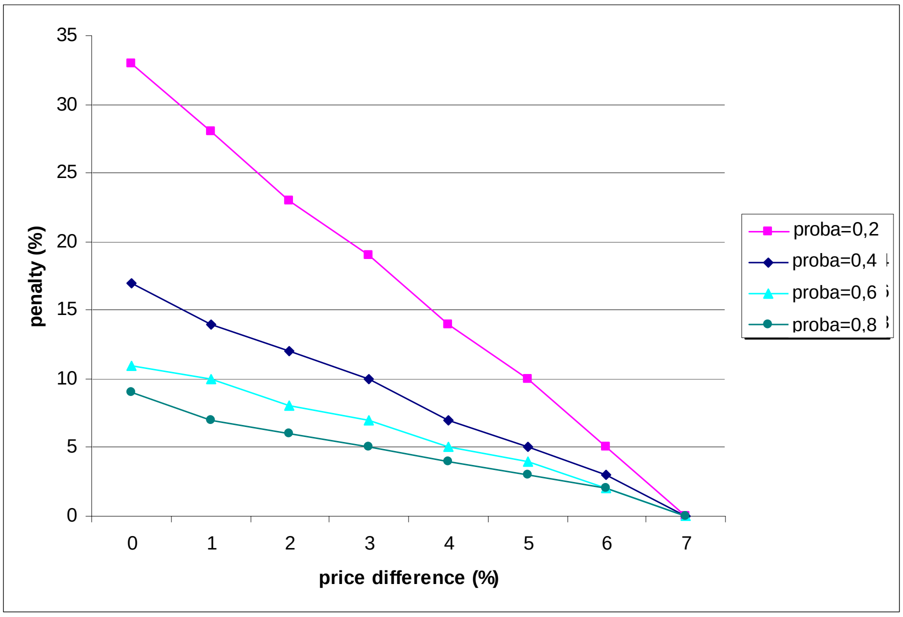
Figure 5: Impact of transportation cost on non- GM area with two silos receiving non- GM deliveries



3.2 Consequence of a temporal collection strategy

For this strategy the transport cost has no effect on the farmer's choice because he delivers to the nearest silo, whichever type of crop he grows. This strategy leads to a uniform area of GM or non-GM maize. Variations in prices and the penalty for loss of quality allows the country elevator to strongly influence the farmer's choice according to the weather risks, notably the probability of rain during the specified collection period. Figure 6 shows, for various probabilities of quality loss, the price differential/penalty combination when there is a change from a total GM area to all non-GM area. So, for a 0.2 probability of quality loss with GM production there will be 100 % of non-GM if the price differential/penalty combination is above the curve and 100 % of GM if it is below it. Hence the greater the price differential between GM and non-GM, the smaller can be the penalty for quality loss to have a uniform non-GM collection if the GM collection period is the shortest one. In the opposite case, the whole of the area would be sown to GM (not shown).

Figure 6: price difference/penalty combination when landscape changes from 100% GM to 100% non-GM



4. Discussion

4.1 Comparison of the strategies

Both strategies which we evaluated using this model arise from descriptive work based on case studies made in various regions of France (Coléno et al., 2005; Le Bail and Valceschini, 2004). These two strategies result in different collection costs, which lead the country elevators to prefer the temporal strategy (Coléno, 2008). The model proposed shows that the spatial strategy leads to production of both GM and non-GM maize. It is therefore possible to satisfy both the food industry with non-GM maize and the animal feed market, which accepts GM products if they cost less. On the other hand, the temporal strategy leads to a uniform area. Hence these results reveal a contradiction between the interest of the country elevators which is to satisfy both markets at the lowest cost, and that of the farmers, which is to maximize their profit, taking into account transport costs. Nevertheless, this analysis has one limitation. The hypothesis underlying this work is that the risk covered by the use of GM maize is uniform over the collection zone. But in fact the distribution of the agronomic risk due to the corn borer is not uniform throughout any area, so the farmer's choice between GM and non-GM maize is linked to the distribution of the risk (Bourguet et al., 2005). Use of agronomic variables in the model of farmers' choices might put into perspective the results presented here, since they would apply to larger and more representative geographical zones of the whole collection area of a country elevator. Taking into account these agronomic constraints and a bigger area would allow one to search for alternative collection strategies. A spatial strategy with different delivery periods for each product could be considered. It would then be possible to take into account different flowering times to avoid field-to-field contamination (Messean et al., 2006).

4.2 Influence of collection on coexistence management

The collection strategies evaluated in this paper organised the agricultural landscape around the collection silos. In the case of a spatial strategy, fields sown with a particular type of crop are clustered together around the collection silo accepting this production, whereas the temporal strategy results in a uniform area. Considering country elevators management strategies of coexistence, this leads to homogeneous zones for each type of crop, bypassing the difficulties of coexistence associated with minimum isolation distances that constrain one farmer choice in using GM technology to the choice made by neighbouring farmers (Devos et al., 2007; Demont et al, 2008).

5. Conclusion

The model proposed in this paper illustrates the landscape organisation resulting from country elevators collection strategy decisions. We show that using a spatial segregation of GM and non-GM crops during the collection leads to define homogeneous zone for GM production. This allows farmers to simplify their work organisation, as they don't have to use isolation distances between their GM fields and non-GM fields (there are no non-GM fields in the GM zone). Moreover, cross-pollination between GM and non-GM fields is reduced and so is the risk of non-GM harvest containing more than 0.9% of GM. Another step would be now to evaluate the level of cross-pollination in the landscape with such strategies. To do so, it is possible to combine the model presented here with a model to calculate gene flow from field to field (Angevin et al., in press). This combination would make it possible to calculate the level of GM in the non-GM batches delivered and thus to calculate the proportion of GM in the non-GM collection silos.

Acknowledgment

This research was founded by the French Ministry of Research true through the national program "ACI OGM et environnement".

References

Angevin, F., Klein, E.K., Choimet, C. , Gauffreteau, A. , Lavigne, C., Messéan, A., Meynard, J.M. (2008). Modelling impacts of cropping systems and climate on maize cross pollination in agricultural landscapes: The MAPOD model. *European Journal of Agronomy*, Vol 28, pp. 471-484.

Arvanitoyannis, I. S., Choreftaki, S., Tserkezou, P. (2006). Presentation and comments on EU legislation related to food industries-environment interactions: sustainable development, and protection of nature biodiversity- genetically modified organisms, *International journal of food science and technology*, vol. 41, pp. 813-832.

Beckmann, V., Soregaroli, C., Wesseler, J. (2006). Coexistence rules and regulations in the european union, *American Journal of Agricultural Economics*, vol. 88, no. 5, pp. 1193-1199.

Betbesé I Lucas J.A. (2006). Varietats de panís (*Maize varieties*). DOSSIER TÈCNIC, Ruralcat

Bourguet, B., Desquilbet, M., Lemarié, S. (2005). Regulating insect resistance management: the case of non-Bt corn refuges in the US. *Journal of Environmental Management*. Vol 76, no. 3, pp. 210-220.

Brookes G. (2002). The farm level impact of using Bt maize in Spain. Report of PG Economics, 23p. http://www.pgeconomics.co.uk/pdf/bt_maize_in_spain.pdf

Byrne, P. F., Fromherz, S. (2003). Can GM and Non-GM Crops Coexist? Setting a Precedent in Boulder County, Colorado, USA, *Journal of Food, Agriculture & Environment*, vol. 1, no. 2, pp. 258-261.

Comité National du Transport (2006). simulateur de prix de revient transport régionaux (*simulation of transport cost in France*).

Coléno, F. C., Le Bail, M., Raveneau, A. (2005). Segregation of GM and non GM production at the primary production level. In Proceeding of the Second International Conference on Co-existence between GM and non GM based agricultural supply chain (GMCC 05) A. Messean (ed) 14-15 November Montpellier (FRA). Pp. 169-172.

Coléno F.C. (2008). Simulation and evaluation of GM and non-GM segregation management strategies among European grain merchants. *Journal of Food Engineering,* Vol 88, pp. 306-314.

Della Porta G., Ederle D., Bucchini L., Prandi, M., Verderio A. & Pozzi C. (2008). Maize pollen mediated gene flow in the Po valley (Italy): Source-recipient distance and effect of flowering time. *European Journal of Agronomy*, Vol 28, pp. 255-265.

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

Devos Y., Reheul, D., Thas, O., De Clercq, E. M., Cougnon, M., Cordemans, K. (2007). Implementing isolation perimeters around genetically modified maize fields. *Agronomy For Sustainable Development*, vol. 27, pp. 1-11.

European Commission, (2003a). Commission recommendations of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the coexistence of genetically modified crops with conventional and organic farming, 2003/556/EC (notified under document number C(2003) 2624). Official Journal of the European Union, 29/07/2003, vol. 46, L189, pp 36-47.

European Commission, (2003b). Regulation (EC) N° 1829 / 2003 of the European Parliament and of the Council of 22 September 03 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC. Official Journal of the European Union, 18/10/2003, vol. 46, L268, pp. 1-23.

Fernandez-Cornejo J. and McBride D. (2002). Adoption of Bioengineered Crops. USDA ERS. Agricultural Economics Report no. 810.

Jank, B., Rath, J., Spok, A. (2005). Genetically modified organisms and the EU. *Trends in Biotechnology*, vol. 23, no. 5, pp. 222-224.

Jank, B., Rath, J., Gaugitsch, H. (2006). Co-existence of agricultural production systems. *Trends in Biotechnology*, vol. 24, no. 5, pp. 198-200.

Kalaitzandonakes, N. (2005). Technical and economic issues related to co-existence supply chain: Proceedings of the Second International Conference on Co-existence between GM and non GM based agricultural supply chain (GMCC 05) A. Messean (ed) 14-15 November Montpellier (FRA). p. 29-30.

Le Bail, M. and Valceschini, E. (2004). Efficacité et organisation de la séparation OGM/non OGM. (*Efficiency and organisation of GM/non GM segregation*) *Economie et Société. Série «systèmes agroalimentaires»*, vol. 12, no. 4, pp. 18-29.

Levidow, L., Carr, S., Wield, D. (2000.) Genetically modified crops in the European Union: regulatory conflicts as precautionary opportunities. *Journal of Risk Research*, vol. 3, no. 3, pp. 189-208.

Lüthy, J. (1999) Detection strategies for food authenticity and genetically modified foods. *Food control*, vol. 10, pp. 259-361.

Messean, A., Angevin, F., Gomez-Barbero, M., Menrad, K., Rodiguez-Cerezo, E. (2006) New case studies on the coexistence of GM and non-GM crops in European Agriculture. Technical Report of the European Commission Joint Research Center. 112p.

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

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