The co-existence between transgenic and non-transgenic maize: a risk analysis

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Abstract

One of the major concerns regarding genetically modified crops is the risk of inadvertent admixture of genetically modified organisms (GMOs) with products from conventional and organic farming. Non-GMO growers who are confronted with GMO contamination may end up with prices far lower than expected under normal conditions. In this paper an analytical model is presented to estimate the associated loss distribution.

Two relevant influencing risk factors on the probability of a contamination and its economic consequences are taken into account in the analytical model, namely 1) the uncertainty of the pollen dispersal curve and 2) the uncertainty with respect to the characteristics of adjacent fields. The latter probability distributions were derived from the national geographical information database comprising farm and field data and quantified, among others, the probability that neighbouring fields grow also maize as well as size and distance of the recipient field.

Keywords: risk exposure, technological development, food safety

1 Introduction

On of the major concerns regarding genetically modified (GM) crops is the risk of inadvertent admixture of genetically modified organisms (GMOs) with products from conventional and organic farming. Non-GMO growers who are confronted with GMO contamination may end up with prices far lower than expected under normal conditions.

An important potential source of admixture is outcrossing between neighbouring field plots. The basic pattern of outcrossing is described by the leptokurtic pollen dispersal curve. The essentials of this curve are that most of the outcrossing occurs close to the pollen source with a strong exponential decrease with distance. Outcrossing may continue at a low level over longer distances. The tail of the curve is more difficult to quantify because of the low hybridization rate found, which may vary substantially depending on environmental conditions.

The amount of outcrossing is influenced by various factors, like cultivar, compatibility, flowering synchronization, availability of pollinators (insects) and weather conditions (wind). In addition, field size is an important factor mainly because of the competition between incoming pollen and pollen produced by the field itself. Thus, a relatively small field next to a large field will show a higher level of outcrossing than a field of equal size, due to the smaller amount of competing pollen from the smaller field. Also, the longer the field that borders a source field the more outcrossing it will have (Van de Wiel and Lotz, 2004).

Given the above described mechanisms two relevant influencing risk factors are important, namely 1) the uncertainty of the pollen dispersal curve and 2) the uncertainty with respect to the characteristics of adjacent fields. However, evaluating this emerging risk is very complicated. Since contamination might occur irregularly in time and place, it is difficult to derive general properties and predictive values about the probability of occurrence and magnitude. Therefore the objective of this research is to construct an analytical model quantifying the inherent loss potential at farm and sector level. The analysis focussed on Maize (Zea mays) since this crop is most relevant because of the impending introduction of transgenic varieties and its sensitivity to outcrossing under normal farming conditions.

2 Risk modelling

A Monte Carlo simulation model is used to obtain insight into the distribution of the impact of inadvertent admixture of GMOs with products from conventional and organic farming. Monte Carlo simulation is considered an appropriate and very flexible method of investigating aspects that are stochastic in nature, such as outcrossing. Risks are incorporated by random sampling from a priori specified probability distributions within the model. Many random numbers are drawn which reflect the likelihood of different outcomes of each probability distribution. To establish stable probability distributions 5,000 replications (i.e. annual losses) were run.

The conceptual model is graphically presented by means of a probability tree in Figure 1. For each GMO grower with maize a sequence of chance nodes were accounted for. The full loss distribution can be derived by aggregating the terminal probabilities in the decision tree, which can be found by multiplying the probabilities along the branches leading to each end point (Hardaker et. al., 2004).

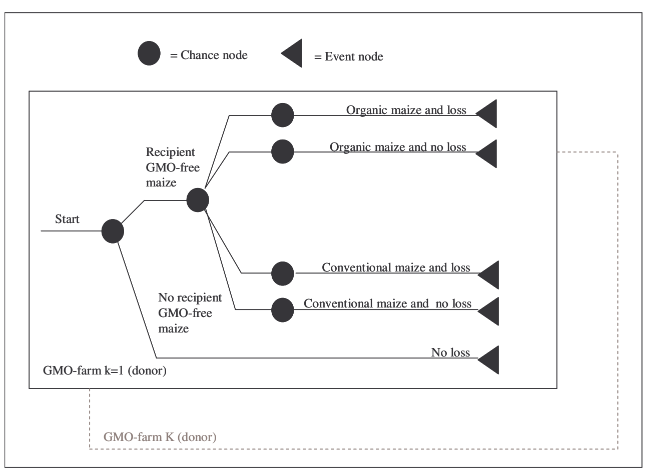

Figure 1: Probability tree of co-existence between transgenic and non-transgenic maize.

Firstly, for each GMO grower with maize the following chance events were accounted for: 1) the probability of non-GM equivalent crop (recipient) in the vicinity of GM crop (donor); and 2) the probability that the recipient applied either organic or conventional farming practices. Secondly, the level of contamination of the recipient in the vicinity was assumed to depend on: 1) the expected level of contamination based on the average distance between donor and recipient; and 2) the uncertainty of the pollen dispersal curve. Thirdly, the average level of contamination at farm level was accounted for by including also non exposed fields. The underlying functional forms and corresponding parameter levels are discussed in the subsequent sections

In addition, a number of assumptions and restrictions were made, but only the most important ones are elaborated on. A strict enforcement of coexistence regulation with respect to isolation distances is considered, which is for maize 250 meters if organic producers with an equivalent crop is in the vicinity and otherwise 25 meters. All non-GM equivalent crops in the vicinity of GM crop are monitored and applied tests have optimal sensitivity and specificity. Moreover, if the average contamination level of organic maize at farm level exceeds 0.9% than it will be marketed as conventional maize. The expected price and yield differences between organic and conventional maize were based on a panel data set of the Dutch Agricultural Economics Research Institute. Other costs, for example associated with monitoring and labelling, are ignored in the current analysis.

2.1 Stochastic assumptions

The expected level of outcrossing ($\bar{Y}$) is described by an exponential pollen dispersal curve (Equation 1). This curve was fit with data obtained from the meta-analysis described by Van de Wiel and Lotz (2004). The meta-analysis indicated that a distance larger than 25 meter is needed to keep admixture below the EU labelling threshold of 0.9%, and larger than 250 meter to remain below the 0.1% threshold as favoured by organic farming organizations. Moreover, an admixture of less than 0.3% at 80 meter is expected.

$$\overline{Y}_{outcross} = \beta_0 \exp^{(\beta_1 x)} \quad (1)$$

One of the most extensive large-scale outcrossing experiments was within the FSE (Farm Scale Evaluations) in the UK. There was little variation between years, but considerable variation between sites, mainly depending on wind conditions, but also on flowering synchronization and field form (i.e., length of the border between GM and non-GM field). Re-examining the results of Henry et al. (2003) showed that the coefficient of variation (CV) was fairly constant and amounted 250%. On basis of the expected level of outcrossing and CV the random variable describing deviations of outcrossing was derived by means of a normal distribution (Equation 2).

$$Y_{outcross} = N(\overline{Y}_{outcross}, \overline{Y}_{outcross} * CV) \quad (2)$$

The probability whether or not the adjacent plot was organic (or conventional) was incorporated as a discrete random variable and parameterised on basis of data recorded by Statistics Netherlands. Approximately 2% of agricultural businesses applied organic methods of production. Note that also farms that were in transition from conventional to organic were accounted for as organic farms.

Other farm and field related inputs were derived from a geographical information database. A random selection of 1000 farms which produced maize were selected and analysed. Discrete random variables described: 1) the probability of having a neighbouring field with maize; and 2) the probability that this neighbouring field was the only field with maize or whether there were more fields on the recipient farm with maize. This latter element is important to determine the average farm level of contamination.

Gamma distributions (Equation 3) resembled the following random elements: 1) the field size of a potential recipient; 2) the border length; and 3) the proportion of the size of the recipient adjacent to the donor in relation to the total area with maize cultivated by the recipient.

$$f(x) = \frac{\beta^{-\alpha} x^{\alpha-1} \exp(-\frac{x}{\beta})}{\Gamma(\alpha)} \quad (3)$$

Subsequently, field size of a potential recipient and the border length determined the average distance.

2.2 Scenario analyses

Scenario analyses have been carried out to provide useful insight into deviations of the ‘best guess estimates’ for important variables in the model.

The threshold of admixture with GM material above which a product should be labelled as GM has been set by the EU at 0.9%. However, the organic farming organizations aim at production that is essentially free from GM material. So they are in favour of a threshold of 0.1%, which at present is the most practical detection level for checking whether or not harvests are mixed with GM material. The consequences of both options are explored in the scenario analysis.

The number of organic producers in the Netherlands is currently fairly limited, but policy makers aim at a level of 10% in the near future (in the scenario analysis number of organic producers ranged from 2% to 10%). At the moment there are hardly any GM maize commercially grown (besides field experiments), therefore alternative numbers of GM farms were considered (ranging from 100, 500, 1000 and 2000). Deviations of outcrossing from the expected pollen dispersal curve is an important stochastic element in the model, therefore three alternative levels were considered (CV equalled 100%, 250% and 500%).

3 Annual loss distribution

Farm and field related inputs, which were derived from the national geographical information database, are presented in Figure 2. Estimates of the Gamma distributions parameters (α and β) were highly significant.

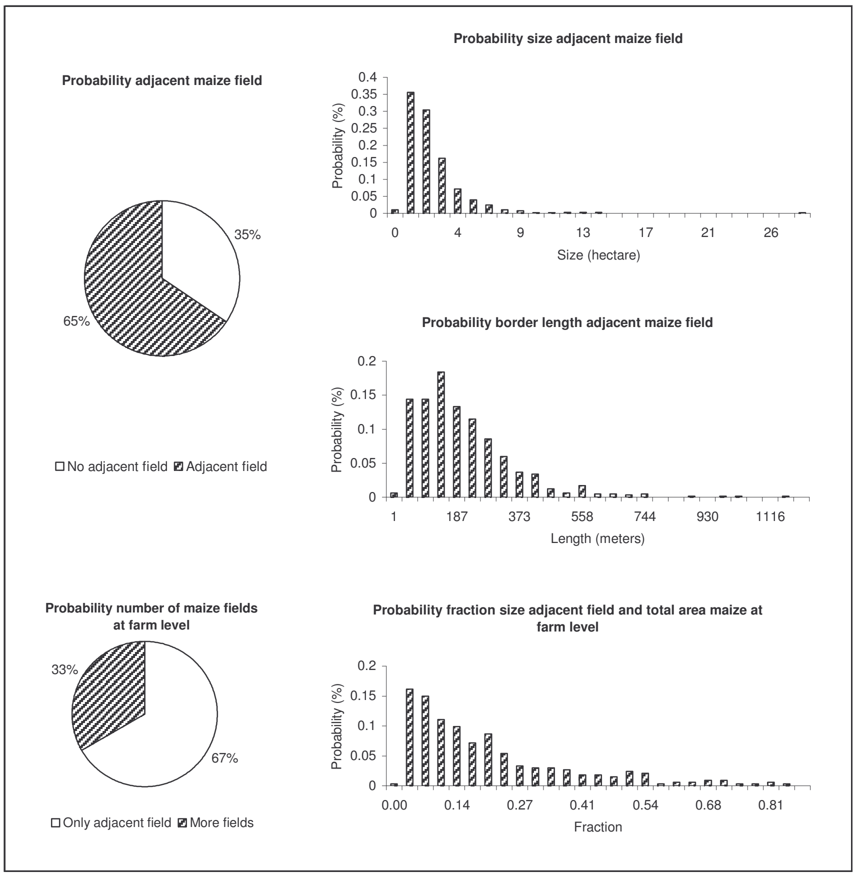

Figure 2: Histograms of input data obtained from geographical information database.

The average number of contaminated farms differed between the scenarios (not presented). These differences are also present with respect to the annual loss (Table 1). For example, average losses accrue up to €5,349 per year if the number of GMO farms and organic farms are set at 2000 and 10% respectively while CV equalled 500% and threshold was set at the most stringent level of 0.1%. Even in this unlikely scenario only a small number of farms were confronted with losses. In general, the threshold level could be regarded as an important factor in determining the amount of loss expected. If set at

0.9, which is in line with the Commission's guidelines on co-existence, hardly any losses are likely to occur.

Given the assumption of independent loss exposures the annual loss distribution was fairly narrow (see standard deviations and percentiles) and stable probability distributions were established with relatively limited number of replications.

Table 1: Annual loss for alternative scenario's (euro per year) [1].

Scenario's			Results stochastic simulation model					
Number of GMO farms	Number of organic farms	CV	Average	Std.	Percentile			
					80%	85%	90%	95%
100	2%	250%	8/0	88/0	0/0	0/0	0/0	0/0
500	2%	250%	25/0	205/0	0/0	0/0	0/0	0/0
1000	2%	250%	44/0	268/0	0/0	0/0	0/0	0/0
2000	2%	250%	81/0	332/0	0/0	0/0	0/0	700/0
1000	10%	250%	600/0	969/0	1,192/0	1,550/0	2,039/0	2,661/0
2000	10%	250%	1,225/0	1,377/0	2,209/0	2,609/0	3,116/0	3,970/0
100	2%	100%	0/0	0/0	0/0	0/0	0/0	0/0
500	2%	100%	1/0	16/0	0/0	0/0	0/0	0/0
1000	2%	100%	3/0	43/0	0/0	0/0	0/0	0/0
2000	2%	100%	9/0	91/0	0/0	0/0	0/0	0/0
1000	10%	100%	48/0	205/0	0/0	0/0	0/0	350/0
2000	10%	100%	134/0	339/0	31/0	330/0	586/0	878/0
100	2%	500%	16/0	210/0	0/0	0/0	0/0	0/0
500	2%	500%	105/0	536/0	0/0	0/0	0/0	318/0
1000	2%	500%	211/0	790/0	0/0	0/0	529/0	1,730/0
2000	2%	500%	390/0	1,008/0	393/0	848/0	1,492/0	2,613/0
1000	10%	500%	2,635/0	2,718/10	4,464/0	5,287/0	6,093/0	7,856/0
2000	10%	500%	5,349/0	3,822/10	8,194/0	9,201/0	10,481/0	12,912/0

[1] Threshold 0.1% / 0.9%.

4 Conclusion

Genetic modification is one of the more controversial technologies. Whatever personal views may be, the use of GM technology is spreading, as is the use of GM crops. It is already legal to grow certain GM crops within the European Union, and the list of permitted crops will almost certainly become longer in the years ahead. In the current study the losses of coexistence of GM crops with (genetically) unmodified crops were quantified by means of a stochastic simulation model. Analysis indicated that the expected number of contaminated farms and associated losses were limited even given unlikely scenarios.

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