SMAC Advisor: A Decision-Support Tool on Coexistence of Genetically-Modified and Conventional Maize

Marko Bohanec[1], Antoine Messéan[2], Frédérique Angevin[2], Martin Žnidaršič[1]

[1] Jožef Stefan Institute, Department of Knowledge Technologies, Jamova 39, SI-1000 Ljubljana, Slovenia
Tel: (+386) 1 477 3309, Fax: (+386) 1 477 3315, e-mail: `marko.bohanec@ijs.si`
[2] Institut National de la Recherche Agronomique (INRA), Eco-Innov Unit, Grignon, France

ABSTRACT

This paper presents SMAC Advisor, a decision-support tool for the assessment of coexistence between genetically modified and conventional maize. The assessment is based on a qualitative multi-attribute DEXi model. This model was developed from two sources: (1) extensive simulations of gene flow due to cross-pollination, obtained by a simulator called MAPOD®, and (2) rules provided by experts in agronomy. SMAC Advisor provides a friendly "wizard" interface for its users: farmers, administrative workers and policy makers in agronomy.

1 INTRODUCTION

Modern agronomy is highly innovative. In order to meet the demands for food, ensuring food quality and safety, contributing to sustainable development, and making profit, new innovative production systems are designed. One such recent innovation is the introduction of *genetically modified* (GM) crops. On one hand, GM crops have genetical charateristics, such as resistance to pests and tolerance to herbicides, which make them very convenient for agricultural production. On the other hand, the use of GM crops raises many concerns about their potential ecological and economic impacts. Decision-making about GM crops turns out to be extremely difficult as it involves many factors that are difficult to assess and control, but may have significant long-term or irreversible consequences to the environment and food production.

One of important GM issues is the question of *coexistence*: is it possible, under which conditions and to which extent, to grow both GM and non-GM (conventional) crops simultaneously or in close proximity without affecting each other "too much". In other words, coexistence refers to the ability of farmers to freely choose between conventional, organic or GM-based crop production (Recommendation 2003/556/EC). Currently, coexistence is being studied in two major European research projects: SIGMEA (2004) and Co-Extra (2005).

In this paper, we present a decision-support tool called *SMAC Advisor*. SMAC stands for *SIGMEA MAize Coexistence*, denoting that this software was developed in SIGMEA and specifically addresses the coexistence of *maize*. The aim of this software is to provide advice to farmers and other decision-makers (administrative workers, policy makers) who want to assess the achievable level of coexistence between GM and non-GM maize on a given field and in a given agricultural environment. This assessment is based on a qualitative multi-attribute model, which was constructed from two sources: (1) results of simulation and (2) expert-provided rules.

In what follows, we first define the decision problem addressed by SMAC Advisor. Then, we describe the architecture of this software, which consists of three layers: (1) user interface, (2) multi-attribute model, and (3) simulation results. In sections 4 to 6, these layers are presented in more detail.

2 DECISION PROBLEM

According to the European Commission Recommendation 2003/556/EC, the farmers who introduce a new production type in a region should bear responsibility for implementing the farm management measures necessary to limit gene flow. Accordingly, we have formulated the decision problem as follows:

Suppose a farmer wants to start growing GM maize on some field F. In the neighbourhood, there may be some other fileds, say E_1, E_2, ..., E_n, on which this or other farmers grow (or want to grow) non-GM maize. Then, the question is: to which extent will the plants grown on F genetically interfere with the plants on E's? Will this interference be small enough to allow coexistence?

The "interference" between plants is usually expressed and measured in terms of *adventitious presence* (AP). AP refers to the unintentional and incidental commingling of trace amounts of one type of seed, grain or food product with another (BIO, 2006). AP is an unavoidable reality of plant biology, seed production and the distribution of commodity crops. EU regulations have introduced a 0.9 % labelling threshold for the AP of GM material in non-GM products (Regulation 2003/1830/EC). Thus, in order to approve the coexistence between GM and non-GM crops, we usually require that the achieved AP is 0.9 % or less.

There are a number of factors that contribute to AP: pollen flow, volunteers, feral plants, mixing during harvesting, transport, storage and processing, human error, and accidents (BIO, 2006). These factors are complex. Pollen flow, for example, depends on the distance between fields, their sizes and shapes, climate (especially wind

characteristics), flowering characteristics of crops, etc. Determining the achievable level of AP and assessing the level of coexistence taking into account all these factors is a difficult problem even for experts.

3 SMAC ADVISOR

SMAC Advisor is aimed at providing assistance in solving the above problem. Basically, the program requires information from the user about the:

- emitting field F,
- neighbouring fields E_1, E_2, …, E_n,
- relation between F and each E_i (in terms of distance, relative size, prevalent wind direction, etc.),
- type and characteristics of used seeds,
- environmental characteristics (e.g., background GM pollen pressure),
- use of machinery (e.g., sharing with other farmers).

On this basis, SMAC Advisor determines the *achievable AP*, that is, the expected level of GM impurities in harvests of the neighbouring fields. This achievable AP is compared with the required *target AP* (provided by the user). In principle, when the achievable AP is lower than or equal to the required AP, coexistence is considered to be achieved and, consequently, GM farming on F can be allowed.

Actually, this inference is more complex and takes into account some additional indicators, such as the structure of GM and non-GM production in the neighbourhood. In any case, SMAC Advisor completes the analysis giving one of the following "color-coded" *recommendations*:

- "Green": GM farming allowed (no need to address coexistence at all, e.g., due to existing GM production in the neighbourhood).
- "Red": GM farming dissallowed (e.g. due to an organic farm in close vicinity).
- "Yellow": assess risks (coexistence is possibly achievable, so the farming might be allowed; continue with further analyses not covered in SMAC Advisor).
- "Orange": assess additional measures (target AP is currently not achievable, meaning that the farming is disallowed, but might have been achievable by some small changes, e.g., making an additional agreement with a neighbouring farmer).

Schematically, SMAC Advisor consists of three software layers (Figure 1). On the highest layer, there is a *user interface*. It communicates with the user, guides him or her through the coexistence assessment process and, when necessary, engages the second layer. The second layer performs all the inference (reasoning, evaluation and aggregation) necessary to map the inputs into recommendations. This is done using a *qualitative multi-attribute model*. The essential part of this model has been developed according to pollen-flow simulations provided by a system called MAPOD®; its *simulation results* compose the third layer of SMAC Advisor. In the following sections, these layers are described in more detail in the bottom-up order.
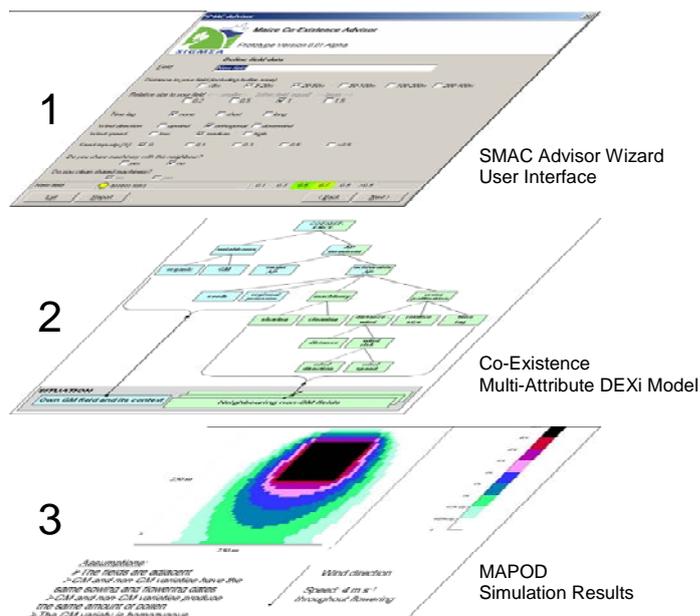

Figure 1: Three layers of SMAC Advisor.

4 MAPOD® SIMULATOR

MAPOD® is an advanced simulator that estimates the rate of varietal impurities due to cross-pollination in maize as well as changes in these rates due to changes in cropping techniques (Angevin et al., 2001). The input variables include certain traits of the varieties and certain agricultural practices for each maize field as well as climatic factors for the given region (Table 1). The output is an estimated amout of pollination in the considered area.

Table 1: MAPOD® input data.

Input data	Description
Field plan	Form and size of fields, location of GM and non-GM maize plants
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

The overall structure of the simulation model is shown in Figure 2 (Angevin et al., 2002). The first module determines the flowering date for female flowers, expressed in degree-days, as a function of climate and sowing date. The analysis takes into account protandry (male flowering beginning several days before female flowering) and the factors (drought stress and sowing density) that affect it. Then this module simulates the dynamics of male and female flowering, giving an estimate

of the amounts of pollen produced by GM and non-GM varieties. The second module simulates pollen dispersal as a function of distance from the emitter, direction and mean speed of the wind, and the difference in height between the panicle from which the pollen is emitted and the receptive silks. The composition of the pollen cloud at a given site in a non-GM field is determined by the pollen dispersal curves for all the plants in the neighbourhood. For each day, the frequency of GM seeds is calculated. These daily results are pooled to provide the total frequency of GM seeds in the harvest.
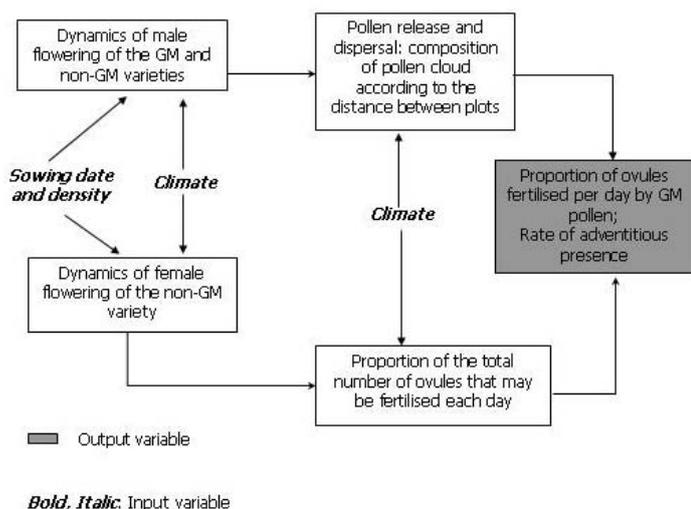
Figure 2: Structure of the MAPOD® model.

This model has been used to carry out several coexistence studies (Angevin et al., 2002; Messéan et al., 2006). In the latter, simulations with MAPOD® were carried out for maize production in Poitou-Charentes (South West of France). Using typical climatic conditions and field patterns, this study aimed at evaluating the impact of current practices as well as the feasibility of alternative practices reducing adventitious presence in non-GM harvests. Different strategies were tested, considering spatial isolation, time isolation, characteristics of GM and non-GM fields, and different buffer zones. In total, 8960 simulations were run to test one or several strategies in combination. Results were synthesised in a database and in decision tables (Messéan et al., 2006). These results were also used to design a part of the DEXi model used at the second layer of SMAC Advisor.

5 MULTI-ATTRIBUTE DEXi MODEL
The second layer of SMAC Advisor contains a qualitative multi-attribute model that was developed according to DEX methodology (Bohanec, 2003), using the software DEXi (Bohanec, 2006). The role of this model is to take the inputs, provided by the user, that describe the decision situation, and to use them to make a final recommendation. This is done according to a hierarchical structure of attributes (Figure 3): inputs are entered at the bottom of the hierarchy and are gradually aggregated in a bottom-up way

through a series of internal attributes, until the final recommendation is eventually obtained at the root attribute (COEXISTENCE). The reasoning at each attribute is performed according to 'if-then' rules. The rules that occur in the attribute "cross pollination" and below, were obtained from the results of MAPOD® simulations. All the remaining rules in the model were provided by the experts.
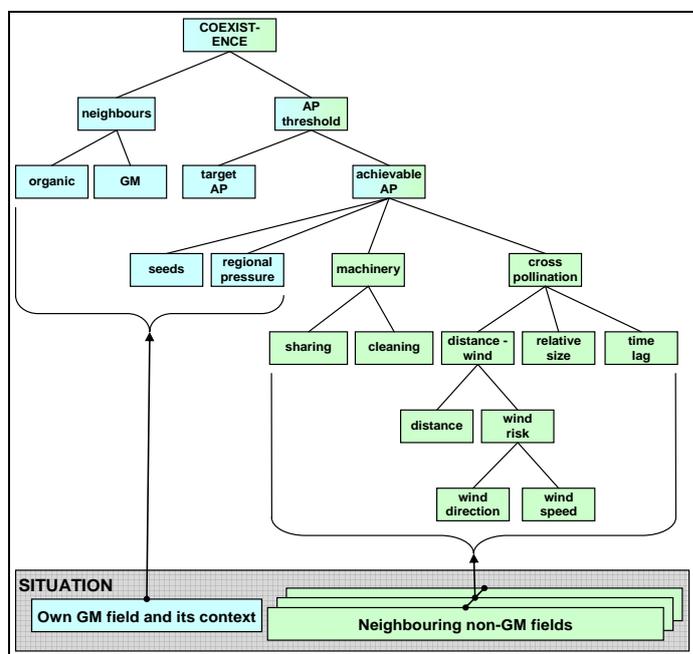

Figure 3: Hierarchical strucure of the DEXi model.

This DEXi model consists of two essential parts. The left-hand part in Figure 3 assesses the characteristics related to the field F itself and its environment: % of seed impurity, existing regional GM-pollen pressure, existing farms in the neighbourhood, target AP to be achieved. The right-hand part, which consists of the subtrees "machinery" and "cross pollination", assesses the relation between the field F and each of its neighbouring fields E_i. For each such pair, the model determines the achievable AP. The total achievable AP is then the maximum of the AP's achievable pairwise.

6 USER INTERFACE
SMAC Advisor has a user-friendly wizard-type user interface, implemented in Borland Delphi. The interface contains a series of dialogs that guide the user through logical steps of the decision-making process:
1. obtaining data related to the field F;
2. for each E_i: obtaining data related to E_i (Figure 4);
3. making and presenting the recommendation (Figure 5).
If necessary, these steps are repeated until the decision situation has been sufficiently analysed.

Figure 4 shows one of the SMAC Advisor's windows, which is used for obtaining data about E_i fields. The data items in this window directly correspond to the right-hand input attributes of the DEXi model (Figure 3). Notice that

they are qualitative: they have descriptive values (such as 'low', 'medium', 'high'), or they are divided into numerical intervals (see the attributes "Distance", "Relative size" and "Seed impurity"). It is also worth noticing that the attributes may be assigned more than just a single qualitative value. In Figure 4, the attribute "Seed impurity" has two values (0.1 and 0.3). These two values cause a dual assessment of achievable AP: 0.5 and 0.7 (Figure 5).
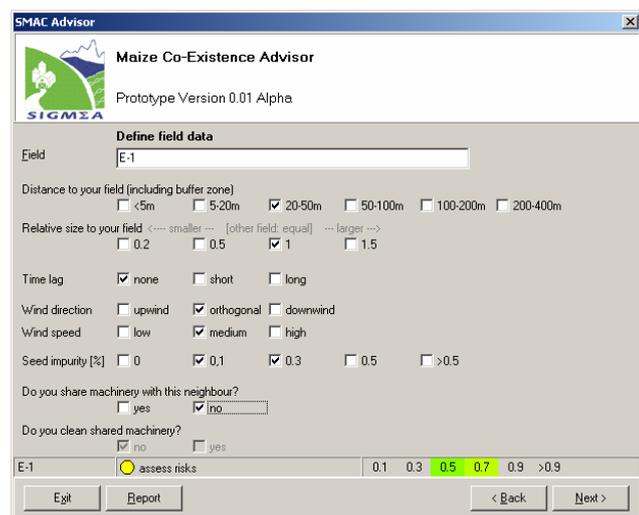
Figure 4: SMAC Advisor: A data-entry window.

SMAC Advisor's assessment is dynamic: at all times, the program shows the current recommendation (as shown in the status line in Figure 4). Whenever the user makes a change, SMAC Advisor re-evaluates the situation and displays the new assessment. This feature turns out to be very useful for "what-if" analysis of the situation.
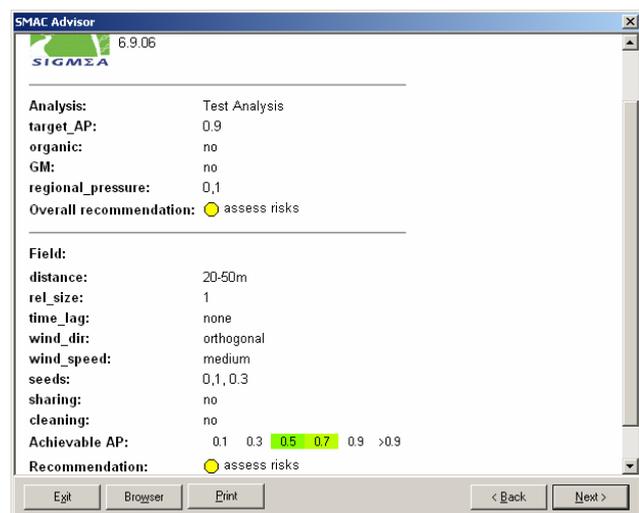
Figure 5: SMAC Advisor: Final report.

6 CONCLUSION
SMAC Advisor is a simple software tool aimed at making advice in a difficult real-life decision problem in agronomy: is it possible to grow genetically modified maize in a given field, achieving coexistence with other fields in a given environment? SMAC Advisor gives recommendations using a knowledge base, which is composed of two parts. The central part is a "shallow" qualitative multi-attribute model, developed according to DEX methodology. It contains rules that aggregate inputs, provided by the user, into final recommendations following a hierarchical structure of attributes. The essential part of this shallow model, which determines the achievable adventitious presence, is however based on a "deep" MAPOD® model, which simulates the biological behavior of maize plants.

Currently, SMAC Advisor has a status of evolving prototype software, which was so far used only on test cases. Within the SIGMEA project, we wish to develop it further towards a useful decision-support tool for farmers, administrative workers and policy makers in the EU.

REFERENCES
Angevin, F., Klein, E. K., Choimet, C., Meynard, J. M., de Rouw, A., Sohbi, Y. (2001). Modélisation des effets des systèmes de culture et du climat sur les pollinisations croisées chez le maïs. In *Pertinence économique et faisabilité d'une filière sans utilisation d'OGM*. Rapport du groupe 3, INRA – FNSEA, pp 21-36.

Angevin, F., Colbach N., Meynard, J. M., Roturier, C. (2002): Analysis of necessary adjustements of farming practices. In: A.-K. Bock, Lheureux, K., Libeau-Dulos, M., Nilsagard H., Rodriguez-Cerezo, E. *Scenarios for coexistence of genetically modified, conventional and organic crops in European agriculture*. Technical Report Series of the Joint Research Center of the European Commission.

BIO (2006): Biotechnology information, advocacy and business support: Adventitious presence. http://www.bio.org/foodag/background/adventitious.asp

Bohanec, M. (2003): Decision support. In: Mladenić, D., Lavrač, N., Bohanec, M., Moyle, S. (eds.): *Data mining and decision support: Integration and collaboration*. Kluwer Academic Publishers, 23–35.

Bohanec, M. (2006): DEXi: A Program for Multi-Attribute Decision Making. http://www-ai.ijs.si/MarkoBohanec/dexi.html

Co-Extra (2005): GM and non-GM supply chains: their CO-EXistence and TRAceability. Integrated Project, funded by the Sixth European Community Framework Programme: Food Quality and Safety Priority. http://www.coextra.org/

Messéan, A., Angevin F, Gómez-Barbero, M., Menrad, K., Rodríguez-Cerezo, E. (2006): *New case studies on the coexistence of GM and non-GM crops in European agriculture*. European Commission , Technical Report EUR 22102 EN.

SIGMEA (2004): SIGMEA*: Sustainable introduction of genetically modified crops into European agricu-ture*. Specific targeted research project, funded by the Sixth European Community Framework Programme: Policy Oriented Research. http://sigmea.dyndns.org/