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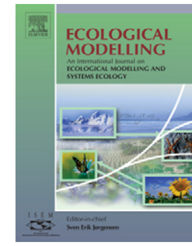

A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops

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ARTICLE INFO

Article history:
Published on line 9 April 2008

Keywords:
Decision support
Qualitative models
Multi-attribute models
Cropping systems
Genetically modified crops
Economy
Ecology

ABSTRACT

Genetically modified (GM) crops have become a real option in modern agriculture. They offer advantages for agricultural production, but they also raise concerns about their ecological and economic impacts. Decisions about GM crops are complex and call for decision support. This paper presents a qualitative multi-attribute model for the assessment of ecological and economic impacts at a farm-level of GM and non-GM maize crops. The model is applied for one agricultural season. This is an ex-ante model developed according to DEX methodology. In this model, cropping systems are defined by four groups of features: (1) crop sub-type, (2) regional and farm-level context, (3) crop protection and crop management strategies, and (4) expected characteristics of the harvest. The impact assessment of cropping systems is based on four groups of ecological and two groups of economic indicators: biodiversity, soil biodiversity, water quality, greenhouse gasses, variable costs and production value. The evaluation of cropping systems is governed by expert-defined rules. The paper describes the structure and components of the model, and presents three practical applications of the model, assessing both hypothetical and real-life cropping systems. In an overall assessment of the ecological and economic outcomes the model ranked cropping systems in the order: organically managed > GM systems including Bt and HT traits > conventionally managed maize. The paper discusses contributions of the model to decision-making practice and highlights methodological lessons learned during its development.

1. Introduction

In agriculture, the role of decision-support systems is becoming more important. New innovative production systems must be designed to meet the demands of ensuring food safety, reducing negative impacts to the environment and contributing to sustainable development. Any change in agricultural practices can lead to changes in the associated ecosystems as well as in the agronomic and economic performance of agricultural production systems (Hails, 2002). Methods and tools are required for assessing the direct and indirect effects of such changes, and for balancing the ecological and eco-

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0304-3800/$ – see front matter
doi:10.1016/j.ecolmodel.2008.02.016

nomic impacts through a multi-criteria approach, to guide decision-makers implementing new agricultural policies as well as providing farmers with decision rules for choosing the best option within a specific context. Modeling is a key element of decision-support, providing formal structure of existing knowledge about impacts, identifying gaps, ranking cropping systems according to their overall performance, and defining the preferences that stakeholders assign to the outputs of agricultural practices (Lavigne et al., 2004; Messean et al., 2005).

Genetically modified (GM) crops represent a recent innovation in agriculture. On the one hand, GM crops have genetic characteristics, such as resistance to pests and tolerance to herbicides, which are beneficial for agricultural production. On the other hand, the use of GM crops raises concerns about their potential ecological and economic consequences (Uzogara, 2000; Hails, 2000). 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 (Hails, 2002).

The authors of this paper are engaged in two projects funded by the European Commission: ECOGEN (2003) and SIGMEA (2004). These projects investigate the impacts of using GM crops in European agriculture and are important for the European Commission, which needs an objective method for assessing the risks associated with growing GM crops, and for the farmers and the public who are concerned about the possible ecological implications. One of the goals of ECOGEN and SIGMEA is to develop computer-based decision support systems (Mallach, 2000; Turban et al., 2004) for the assessment of impacts of using GM crops at field and regional levels. For this purpose, we have developed several models that address specific ecological and agronomic aspects of GM and non-GM cropping systems (Bohanec et al., 2004). These include a model for the assessment of the impact of GM and non-GM cropping systems on soil quality (Bohanec et al., 2007), a model to evaluate the achievable level of coexistence between GM and non-GM maize grown on adjacent fields (Bohanec et al., 2006), and Scatasta et al. (2005) have modeled the economic impacts of GM and non-GM cropping systems.

The aim of the present study was to develop multi-attribute decision models (MADM, described in Section 2) that assessed the economic performance of cropping systems, including GM crops or not, and their environmental impacts. In this paper, we present a MADM for the assessment of ecological and economic impacts of GM and non-GM maize cropping systems at a farm-level for one agricultural season. Cropping systems are described by four groups of features: (1) crop sub-type, (2) regional and farm-level context, (3) crop protection and crop management strategies, and (4) expected characteristics of the harvest. The cropping systems evaluation is based on four groups of ecological and two groups of economic indicators: biodiversity, soil biodiversity, water quality, greenhouse gasses, variable costs and production value.

The paper is structured as follows. Section 2 presents the multi-attribute modeling methodology, which was used to develop the model, and gives some historical remarks. Section 3 describes the components and structure of the model. Section 4 presents three practical applications. The results are discussed in Section 5. Section 6 concludes the paper.

2. Methodology

MADM models evaluate alternatives to determine the best rated one, that is, the one that is most appropriate according to decision-making goals. In our case, we are additionally interested in the comparison of cropping systems and their properties. MADM models are based on a hierarchical decomposition of the problem, where the target goal is decomposed into sub-concepts (represented by aggregate attributes) and finally to a finite set of (measurable) basic attributes. Basic-level descriptions of alternatives are gradually aggregated into the values of higher level attributes, until a final evaluation of each alternative is eventually obtained at the target (root) attribute.

Many methodologies exist for MADM (Saaty, 1980; Keeney and Raiffa, 1993; Triantaphyllou, 2000; Figueira et al., 2005; Bouyssou et al., 2006). In ecological modeling problems, these are often used to represent and combine indicators, evaluate alternatives and provide decision support in general. In some recent applications, MADM methods were used for decision support in recycling (Ardente et al., 2003), forest management (Leskinen et al., 2003; Zadnik Stirn, 2006), aquatic ecosystems (Ríos-Insua et al., 2006), wildfire risk assessment (Kaloudis et al., 2005), and process model development (Komuro et al., 2006). Related approaches include automatic construction of concept hierarchies (Žnidaršič et al., 2006a) and hierarchical qualitative reasoning models (Tullos and Neumann, 2006; Salles et al., 2006).

Most MADM methods provide numeric evaluations of alternatives that are themselves described with numbers. Operations in these models are arithmetic, usually weighted sums. Alternatively, decision problems can be described qualitatively, using non-numeric variables and 'if–then' rules. This is especially useful for problems that are not well formalized—innovative cropping systems are a typical example of such problems. In this paper we used the qualitative methodology called DEX (Bohanec and Rajkovič, 1990), which has been applied to real-world decision problems (Bohanec and Rajkovič, 1999; Kontić et al., 2006).

A multi-attribute DEX model is characterized by the following (Bohanec, 2003):

- the model consists of hierarchically structured variables called attributes;
- all these attributes are qualitative rather than numerical: they can take only a finite (and usually a small) number of discrete symbolic values;
- aggregation of values in the model is defined by rules.

For each attribute, DEX requires a definition of a set of corresponding qualitative values. These are usually descriptive (see examples in Section 3). The aggregation of values is carried out according to aggregation rules, which are usually given in tabular form (for example, see Tables 1 and 2). The attributes at the lowest level are basic descriptors of alternatives; they represent model inputs and must be provided by the user.