

A qualitative multi-attribute model for sustainability assessment of agriculture at field crop level

Štraus Saša¹, Rozman Črtomir²

¹ Panvita, d.d., sasa.straus@panvita.si

² Fakulteta za kmetijstvo in biosistemske vede, crt.rozman@uni-mb.si



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Abstract

Sustainable agriculture encompasses economic feasibility, social acceptance, and conservation of the environment. The three agricultural systems (conventional, integrated and organic) are currently in the focus of debate of sustainable agriculture. This paper presents a qualitative multi-attribute model, based on DEX-I methodology, for the assessment of sustainability of agricultural systems at a field level. The data for the implementation was based on field trial. In an overall assessment of the sustainability assessment outcomes the model ranked agricultural systems in the order: organic > integrated > conventional agricultural system. The model gives the decision makers the possibility to assess their decision.

Keywords: sustainability assessment, agricultural systems, qualitative multi-attribute decision models, DEX-i.

Introduction

The concept of sustainable development (SD) has become an important objective of policy makers and in the society. Sustainable agriculture emphasizes environmental quality, long-term economic productivity and social inclusion (Bavec et al., 2009). The sustainability of agriculture should be measured for the purpose of politics, policy makers and also for broader society. Indicators are the basis of different methods for assessing the sustainability of agriculture, because measuring directly sustainability is not possible (Bockstaller et al., 2008).

In a comparative review of the main MCDA families focusing on relevance for sustainability assessment Sadok et al., 2008 suggested that particularly relevant for handling the sustainability constraints are “mixed” or “non classical” MCDA methods. Program using these methods is for instance the DEX (Bohanec and Rajkovič, 1990), which have been used successfully to assess specific problems in agricultural systems. However, to our knowledge, the use of such approaches to assess all aspects of sustainability (economic, agronomic, environmental and social) of a given agricultural systems, has been reported by Sadok et al., 2009, but not on the field level.

The aim of this paper was to assess the sustainability of agricultural systems (conventional (CON), integrated (INT), and organic (ORG)) on field level with multi-attribute decision models (MCDA, described in section 2). The practical application of the model is based on 4 crops, wheat, oil pumpkin, cabbage and red beet. The data are derived from field trial. Agricultural systems are described by four groups of indicators: agronomic indicators (yield, fertilizers, pesticides), economic indicator (economic feasibility), environmental indicators (ecological footprint), food quality as social indicators. The model was developed to assist the decision makers in the context of agricultural companies as Panvita for making the decisions of particular agricultural systems and the integration of individual crops in each agricultural systems.

Material and methods

MCDA 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 agricultural systems and their properties, with the aim to assess sustainability. MCDA 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 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 attribute. In this paper we use the qualitative methodology called DEX (Bohanec and Rajkovič, 1990).

A multi-attribute DEX model consists of hierarchically structured variables (attributes). For each attribute, DEX requires a definition of a set of corresponding qualitative (discrete) values. These are usually descriptive. The aggregation of values is carried out according to aggregation (decision) rules (Bohanec et al., 2008). The principal software tool that implements the DEX methodology is called DEX-i (Bohanec, 2003, 2007). The model requires the iteration of the following four steps (Bohanec, 2003): identifying attributes, structuring attributes, defining attribute scales and defining aggregation rules.

Model structure and components

The goal of DEX-i MCDA development is to provide sustainability assessment of agricultural systems (CON, INT, ORG) and control treatment. The control (without the use of fertilizers and pesticides) is added for the purpose of comparison.

In the first stage of DEX-i decision model development, the possible alternatives (systems) are identified and the problem is dissected into individual less-complex problems. Basic attributes are organized hierarchically into sub attributes and represent the agricultural systems decision sub problems. There are 4 basic attributes; agronomic indicators, environmental indicators, food quality and economic feasibility. The basic attributes are aggregated in to aggregate attributes. The agronomic indicators are composed from yield, fertilizers (type) and pesticides (type). The economic indicator is described by economic feasibility. Economic feasibility is calculated as ratio between total revenue and total costs. The environmental indicators are composed from ecological footprint. The food quality represents the social indicators, because other social indicators cannot be assessed at the field level. The food quality indicator is composed from vitamin C. In the next step, each attribute is assigned with a set of values. Once an agricultural system has been described by the values of input attributes, it is assessed by a bottom-up aggregation according to the hierarchical structure of attributes. The utility functions in DEX-i are described with a set of decision rules. For the development of the model, the attributes for DEX-i analysis were obtained in field trial conducted in years 2009-2011. Attribute values for each alternative were put into the DEX-i assessment model and analysis is performed.

Application and Analysis

Data sources for evaluation of the real-case trial results

The model has been applied for assessment in four applications. All involved the same agricultural systems (CON, INT, ORG) and control. The crops of four applications are: wheat, oil pumpkin, cabbage and red beet. Applications addressed the three years field trial, which was laid out at the research station in Dolenci (Slovenia) near the Hungarian border (46°51'4.43"N 16°17'15.45" E, 302.1 m a.s.l). Three agricultural systems (CON, INT, ORG) and control plots were arranged in a randomized complete block split-plot design with four replications. The agricultural systems differed mostly in plant protection and fertilization strategies, and they were managed in accordance with the laws and rules defining each agricultural system (Bavec et al., 2009). Basic soil cultivation, sowing, and harvesting dates and methods were identical

among the experimental plots and were performed on the same dates and in the same manner to adjacent fields. The same crop variety was used in all production systems under study.

Table 1. Assessment of agricultural sustainability for different crops.

	Cabbage				Red beet				Oil pumpkin				Wheat			
	CON	INT	ORG	cont	CON	INT	ORG	cont	CON	INT	ORG	cont	CON	INT	ORG	cont
Agricultural system	3	3	1	1	3	3	2	2	3	3	1	2	4	3	2	3
Agronomic indicators	M	M	G	M	M	M	M	M	B	B	M	M	B	M	M	M
Coefficient of economics	M	M	G	G	B	B	M	B	B	B	G	M	B	M	G	M
Environmental indicators	B	M	G	G	B	B	G	G	M	M	G	G	B	B	G	G
Food quality	B	B	G	G	M	M	G	G	M	M	G	M	B	B	B	B

Discussion

The described model integrated findings of different specific disciplines, such as agronomy, ecology, agricultural economics and food quality, and provides a general overview to the sustainability assessment of agricultural systems. The indicators (basic attributes) and their relationships are formally represented by a hierarchical structure and decision rules. The developed model is applicable and can serve as decision tool in practice. The model shows similar results for all four crops. We can conclude that the differences of management of agricultural systems are the key factor for achieving different levels of sustainability.

The agricultural systems for different crops were also presented graphically (Figure 1) using attributes that occur in the model, and where the differences were the highest. Using those charts the weak points of each agricultural system can be identified and suggestions for improvement can be provided.

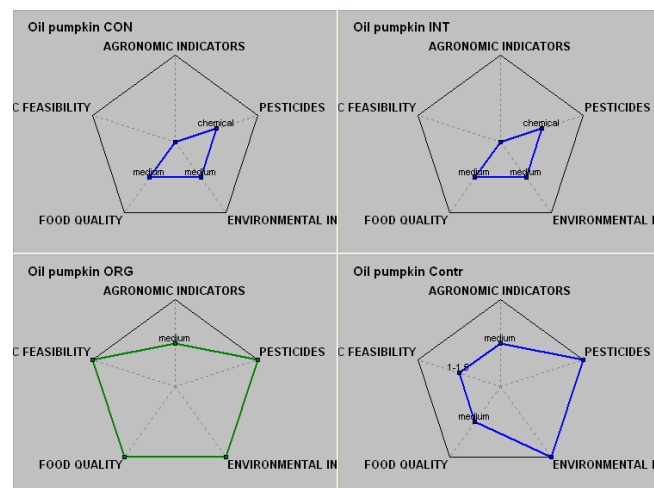


Figure 1. Graphical display of sustainability assessment of agricultural systems for oil pumpkin production.

The overview of individual groups of indicators indicates that all agricultural systems got the worst values for agronomic indicators. They consist of yield, fertilizers and plant

protection means. The yield was above average for all crops except oil pumpkin. The lower yield was attained only for control, which is expected because there were no fertilizers and pesticides applied. The fertilizers were good evaluated for the some cases in CON and INT due to enough available nitrogen for plants. Even though the applied fertilizers where chemical, but due to optimal nutrition of plants, the yields were higher. The pesticides were used in accordance with the laws and requirements. The highest amounts were applied in CON and INT.

Differences in use of fertilizers and pesticides have influenced also economic feasibility of agricultural systems and different crops. The red beet had been the least economically feasible. The production is economically feasible only in ORG, where production values are 100% higher than in CON and INT. The economic feasibility was the highest in ORG also for other crops, due to higher production values and lower variable costs. In ORG the use of pesticides is lower or even does not exist, the organic manure is less expensive, but on the other hand the mechanization has higher costs, also the seeds are more expensive.

Among environmental indicators the ecological footprint was assessed. The ecological footprint was similar for ORG and control, due to absence of fertilizers and pesticides. The footprint was three time higher in INT and CON.

The food quality analysis shows, that between agricultural systems the differences exists. The total evaluation of food quality were the highest in ORG and in control, however the differences between crops were major.

The assessment of sustainability with the model DEXi shows the parameters which can be improved in individual agricultural systems to provide more sustainable agricultural system. The reduction of chemical pesticides and chemical fertilizers in CON and INT would improve their sustainability. Agronomic indicators should be improved for ORG. The higher yield could be achieved with the optimum plant nutrition and thus improved economic feasibility, even with the same prices as in other agricultural systems. The assessments results have shown, ORG system, where we assumed 100 % higher selling prices than other systems, is the most economic feasible. The product price on the market is dependent on the successfully marketing. Despite the deficiencies described (such as the use of qualitative data only), we found that the approach fulfilled most of our expectations and revealed considerable advantages in comparison with other approaches. In particular, we emphasize the use of the qualitative multi-criteria DEXi assessment, which was suitable in a field where judgment prevails, thus making it difficult to give numeric answers.

Conclusions

The model was applied to the real data obtained in field trial on four different crops (wheat, oil pumpkin, cabbage and red bet). It shows that the ORG is commonly the highest evaluated agricultural systems, the lowest is CON. It also shows the good and bad sides of each agricultural system. The model is operational in the sense it can be used for the sustainability assessment, comparison and also shows the possibilities for improvement. The model can be used in a way to propose desirable characteristics of sustainable agriculture system.

The model provides the tool for making decision in agricultural company. Because of the results of this model Panvita has decided that 82 ha are cultivated organically. The advantages of the model are also its transparency, flexibility, easy use and feasibility.

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