Crop Protection xxx (2016) 1–10

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Assessing the sustainability of crop production systems: Toward a common framework?

Frédérique Angevin [a,*], Gabriele Fortino [a,1], Christian Bockstaller [b], Elise Pelzer [c], Antoine Messéan [a]

[a] Eco-Innov, INRA, 78850 Thiverval-Grignon, France
[b] LAE, INRA, Université de Lorraine, 68000 Colmar, France
[c] Agronomie, INRA, AgroParisTech, 78850 Thiverval-Grignon, France

A R T I C L E I N F O

Article history:
Received 3 August 2016
Received in revised form
16 November 2016
Accepted 17 November 2016
Available online xxx

Keywords:
Sustainability assessment
Multi-attribute decision-aid methods
Cropping system
Arable crop
Field vegetables
Pomefruit orchards
Grapevine

A B S T R A C T

All three dimensions of sustainability —economic, social and environmental— must be integrated into a holistic assessment framework in the development of sustainable cropping systems (CS). Numerous sustainability assessment methods meet this requirement, but most of them handle only one type of production system (arable crops, fruit or vegetables). We propose here a common framework for sustainability assessment applicable to various types of crop production. The DEXiPM model, which was designed for the *ex ante* assessment of innovative arable CS was adapted to other production systems. Three groups of experts analyzed and modified this model, to develop suitable methods for assessing the sustainability of pomefruit orchards, field vegetable systems, and grapevine systems. We used the resulting models to formalize a sustainability assessment framework, in which a fixed core of hierarchically organized generic agricultural sustainability issues can be weighted according to stakeholder priorities, and a set of basic attributes can be estimated in a flexible manner, depending on the situation to be assessed and the data available. This common framework for sustainability assessment has several advantages. It can facilitate communication between stakeholders involved in the development of innovative production systems. It can also help researchers to identify gaps in knowledge and the means of bridging them. Its results can provide recommendations for policy makers, concerning actions likely to incite the adoption of innovative systems, for example. We also consider the general applicability and limitations of this framework.

1. Introduction

Reducing the side-effects of agriculture has been on the socio-political agenda for several decades. For example, Directive 2009/128/EC (European Commission, 2009) aims to protect human health and the environment by promoting integrated pest management (IPM), to optimize pesticide use, thereby reducing the quantities applied and the risks associated with pesticide application (Lamichhane et al., 2016).

To this end, the research and development community has been asked to design alternative crop production systems satisfying the "*triple bottom line*" of sustainability, its social, economic and environmental pillars (Elkington, 1998). However, the development of sustainable agriculture is highly challenging. On the one hand, there is a lack of consensus concerning the choice and balance of indicators for assessing sustainability (Lichtfouse et al., 2009). On the other, the diversity of assessment situations makes this task very complex, for a number of reasons (Bockstaller et al., 2008). Firstly, the object of the assessment can be delimited by different spatial and temporal boundaries, such as the region, farm or plot, in a particular year or over several years. Secondly, different types of crop production systems, such as arable, vegetable and perennial systems, can be assessed at each scale. Thirdly, the assessment may focus on diagnosis of the current situation (*ex post* assessment) or prospective analyses of the effects of a new scenario (*ex ante* assessment). Consequently, the information available for some assessment attributes may be scarce and may differ considerably between assessment contexts.

* Corresponding author.
E-mail address: Frederique.Angevin@inra.fr (F. Angevin).
[1] Present address: Chambre d'agriculture de La Manche, Maison de l'agriculture, Avenue de Paris, F-50000 Saint Lô, France.

http://dx.doi.org/10.1016/j.cropro.2016.11.018
0261-2194/© 2016 Elsevier Ltd. All rights reserved.

Agronomists often used quantitative indicators to determine whether a set of objectives has been met in their assessments of cropping systems (CS). These indicators generally relate to environmental and productivity aspects (Bockstaller et al., 2009). However, any overall assessment approach must evaluate the impact of the CS on all three pillars of sustainability. This integration of the three pillars of sustainability is often neglected (Traverso et al., 2012). Integrated approaches must provide information about possible synergies, trade-offs and antagonisms between the different goals to be achieved (Post et al., 1998). There is a need to identify suitable indicators and to structure them into an operational framework for assessing existing situations and possible alternative solutions (Alkan Olsson et al., 2009). Theoretical frameworks have been proposed (*e.g.*, Lewandowski et al., 1999), but are difficult to put into practice. For example, the Life Cycle Sustainability Assessment toolbox published by UNEP (2011) suggests ways to combine three life cycle-based techniques (Life Cycle Assessment, Life Cycle Costing and Social Life Cycle Assessment) but does not provide the guidelines for structuring relevant attributes describing sustainability and indicators. In practice, these attributes are always selected under the responsibility of the researcher and the funder of the study (Bare and Gloria, 2006), making it difficult to compare studies.

The development of multi-attribute decision-aid methods (MADM) has advanced the integrated assessment of agricultural sustainability (Sadok et al., 2008). These methods organize attributes into a hierarchical structure. Given defined "IF-THEN" decision rules, qualitative attributes are aggregated until an overall assessment of sustainability is achieved. In this approach, the output is not limited to a set of values, as it also provides information about interactions (*i.e.*, synergies, trade-offs and antagonisms). The DEX method (Bohanec and Rajkovič, 1990) implemented in DEXi® software (Bohanec, 2015) is a MADM method that has been used to develop models for assessing the sustainability of innovative arable CS (*e.g.*, Pelzer et al., 2012; Sadok et al., 2009; Bohanec et al., 2008). The CS were considered to be a relevant scale for tackling the challenge of innovation in agriculture (Sadok et al., 2009). Some studies have focused on the assessment of sustainability in specific CS (*e.g.*, Vasileiadis et al., 2013 for maize based CS; Mouron et al., 2012 for apple orchards).

The use of the same structured assessment framework for a wide range of crop productions in a given area could help to harmonize the methodology for the setting of regional goals, the identification of bottlenecks and the recommendation for adjustments for different types of crop production systems (arable crops, fruits and vegetables). Standardized approaches of this kind are essential to improve (i) communication between the different stakeholders involved in the development of sustainable farming and (ii) the planning of research and policy-making actions.

DEXiPM (Pelzer et al., 2012) is a hierarchical qualitative multi-attribute model supported by DEXi software. It was initially developed to assess the global sustainability of arable CS. The users of DEXiPM are researchers and advisers involved in the design of innovative CS based on IPM. This model can handle qualitative information and is used for the *ex ante* assessment of CS described by experts and to get around possible problems associated with a lack of data for innovative prototype CS.

Within the PURE research project, this model was used to support the development of IPM for different crop production systems. As such, it was adapted for use with field vegetable, pomefruit orchard and grapevine production systems. Here, we tried to develop a common sustainability assessment framework suitable for use with diverse crop production systems. We first present the DEXiPM model and focus on the approaches adopted for its adaptation to other crops. We then discuss the consequences of such adjustments for the set-up of a generic assessment framework and consider the limitations and utility of such a framework.

2. Materials and methods

2.1. Presentation of DEXiPM

The DEXiPM model (see Pelzer et al., 2012, for a comprehensive description) evaluates the overall sustainability of CS, by breaking this sustainability down into less complex issues, beginning with environmental, social and economic sustainability, and ending with elements characterizing the CS itself and the context of the assessment (pedoclimatic and socioeconomic context; see Fig. 1). All the components of this hierarchical structure, called "attributes", are defined by qualitative classes of values (*e.g.*, *high, medium, low*). The attributes at the bottom of the hierarchy ("basic attributes"), represent the model inputs. Their values are set by the user and then combined with respect to the model structure to determine the value of the upper-layer attributes ("aggregated attributes"). In DEXi® software (Bohanec, 2015) aggregations are performed for each attribute with "utility functions" materialized in tables completed with 'IF-THEN' aggregation rules, such as **IF** <the attribute "Investment capacity" is "Medium"> **AND IF** <the attribute "Autonomy" is "Low "> **THEN** <the aggregate attribute "Viability" is "Low"> (see hierarchical structure of attributes in Fig. 1). These functions are the relative "weights" applied to the underlying-layer attributes, reflecting the influence of these attributes on those of the upper layer. Depending on the nature of the attributes involved, two types of utility functions can be distinguished:

- Knowledge-based utility functions: these functions account for about 60% of the total and are fixed by the model developer on the basis of scientific and technical knowledge (to determine pesticide leaching value, for example); these utility functions occur predominantly in the lowest layers of the hierarchical structure of the model;
- Priority-based utility functions: these functions account for about 40% of the total and can be adapted by users on the basis of stakeholder priorities in terms of sustainability objectives (Pelzer et al., 2012). These objectives may differ between assessment contexts (for example, in dry areas, the user may be more concerned about water use than about land, energy and mineral fertilizer use). Priority-based utility functions tend to be located in the upper layers of the model structure (Fig. 1).

DEXIPM output consists of a set of values associated with all the aggregated attributes included in the model. It represents a wide range of sustainability issues characterized by different levels of complexity (*e.g.*, from "environmental sustainability" to "pesticide leaching risk"). The user can examine the performances of the CS assessed, beginning with overall sustainability and then focusing on intermediate attributes of each pillar of sustainability until all the CS and context elements contributing to the various impact have been identified.

2.2. Principles of DEXiPM adaptation to other crop production systems

Within the PURE project, the assessment of the designed IPM strategies for field vegetables, pomefruit orchards and grapevine systems necessitated the adaptation of DEXiPM to the specific features of these different types of production system. For each type of production system, a working group was established, consisting

Please cite this article in press as: Angevin, F., et al., Assessing the sustainability of crop production systems: Toward a common framework?, Crop Protection (2016), http://dx.doi.org/10.1016/j.cropro.2016.11.018