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Sustainability assessment of agricultural systems: The validity of expert opinion and robustness of a multi-criteria analysis

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ABSTRACT

Sustainability assessment of agricultural systems is frequently hampered by data availability. Elicitation of expert opinions combined with multi-criteria assessment (MCA) could be a useful approach for sustainability assessments in data-scarce situations. To our knowledge, the validity of expert opinion used to score sustainability performance of agricultural systems, however, has not been addressed. Also, robustness of the overall outcome of MCA to uncertainty about scores obtained from expert elicitation and weights used to aggregate scores is generally not addressed. The objectives of this study were to evaluate the validity of expert opinion, and to evaluate the robustness of the overall MCA outcome to uncertainty about scores and weights. The case study considers three soybean agricultural systems in Latin America: conventional agricultural system, with either genetically modified (GM) or non-genetically modified (non-GM) soybeans, and organic agricultural system. The validation was carried out by comparing the sustainability scores of experts with values from scientific studies. The robustness of the overall outcome of the MCA to uncertainty about scores and weights was assessed using Monte Carlo simulation. The comparison of expert opinion with reviewed studies showed that expert opinions are a potential alternative to extensive data-rich methods. The validity of expert opinions can be increased by considering a larger group of experts, with a high level of knowledge about agricultural systems and sustainability issues. With regard to robustness, the overall outcome of the MCA showed higher variation for organic soybean agricultural systems compared with GM and non-GM, in both Brazil and Argentina.

1. Introduction

Worldwide, there is increasing concern about the consequences of economic development, which often has detrimental effects on social progress and environmental protection (Vasileiou and Morris, 2006). This concern finds expression in the concept of sustainable development, further referred to as sustainability. "Sustainability attempts to balance the three dimensions of development, which define the quality of human life in its broadest sense, namely: environmental, economic, and social objectives" (Vasileiou and Morris, 2006 P317). Given the importance of agriculture as the crucial provider of food, fibre, fuel and shelter for humans, sustainable development of this sector is of utmost importance. A large number of sustainability assessment methods, therefore, have been developed to gain insight into the sustainability performance of agricultural systems. Some examples published in the scientific literature are the response-inducing sustainability evaluation (RISE), indicateurs de durabilité des Exploitations agricoles' or farm sustainability indicators (IDEA), sustainability assessment of food and agriculture systems (SAFA), sustainability monitoring and assessment routine (SMART), (Briquel et al., 2001; Grenz et al., 2009; Castoldi and Bechini, 2010; FAO, 2012; Pelzer et al. 2012; Jawtrusch et al., 2013). For a complete overview of methods published in scientific literature see De Olde et al. (2016).

Measuring the sustainability performance of agricultural systems using these methods, however, requires technical data, such as cost prices for feed or labour, and nutrient import via feed or synthetic fertilizer. These data is often costly to collect, in terms of finances and time. Elicitation of expert opinions could provide a solution in situations where data is scarce. Multi-criteria analysis (MCA) is a method that can incorporate expert opinions in sustainability assessments. MCA has become increasingly popular in agricultural sustainability studies, due to its ability to address the multi-dimensionality of sustainability (Linkov et al., 2004; Pohekar and Ramachandran, 2004; Mourits et al., 2006; Huang et al., 2011; Michalopoulos et al., 2013). Furthermore,

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MCA gives an overall outcome by aggregating sustainability scores, and by using relative importance weights (a weight can be defined as a value assigned to a criterion that indicates its importance relatively to the other criteria under consideration) provided by stakeholders. Such an overall outcome can inform decision makers at strategic and operational levels about the potential for improving sustainability.

A number of studies have incorporated expert opinions in MCA to assess sustainability of agricultural systems (Sydorovych and Wossink, 2008; Engels et al., 2010; Mourona et al., 2010; Reig et al., 2010; Michalopoulos et al., 2013; Craheix et al., 2016; Wohlfender-Bühler et al., 2016). Engels et al. (2010) used MCA, for instance, to develop a sustainability label for food products, whereas Reig et al. (2010) used MCA to assess sustainability of rice cultivation technologies. Craheix et al. (2016) used MCA to evaluate the sustainability of different cropping systems. These MCA studies have two shortcomings. First, most of them use expert elicitation to obtain weights or scores, however, they did not evaluate the validity of the expert opinion. Clearly, if scores for an issue obtained from expert elicitation are not in line with scores found in scientific literature, then the overall outcome provided by MCA may be erroneous. Second, existing MCA studies generally do not evaluate the robustness of the overall MCA outcome to uncertainty about scores and weights. Uncertainty about scores and weights imply considering variability of scores and weights in the MCA, which results in a distribution of overall MCA outcomes, rather than to a single outcome. A distribution of overall MCA outcomes gives insight into the range of outcomes and enables more informed decision-making.

The objectives of this study are to evaluate the validity of scores for sustainability issues obtained from expert elicitation, and to evaluate the robustness of the overall MCA outcome to uncertainty about scores and weights. The validation is carried out by comparing expert scores with values from empirical studies found in scientific literature. The robustness of the overall MCA outcome to uncertainty about scores and weights is assessed using Monte Carlo (MC) simulation. This study uses the case of soybean production in two countries in Latin American (LA), Brazil and Argentina, as these are main producers and exporters of soybean.

2. Materials and methods

To answer our research objectives, Section 2.1 first presents how MCA scores were obtained. Section 2.2, subsequently, presents the validity (i.e., comparison of MSC scores with empirical data from literature) and robustness (i.e., including uncertainty in scores and weights) of MCA results.

2.1. Multi criteria assessment

Most studies that compare alternative production systems based on MCA literature use a simple average of performance scores of various issues (Eq. (1)). Using such a simple average implicitly assumes an equal weight for each sustainability issue, which might not reflect reality. Alternatively, a preference weight can be assigned to each sustainability issue, that reflects the relative importance of each issue to the decision maker.

To compute MCA scores, the following steps were taken: (1) selection of key issues (criteria); (2) scoring of issues by experts for different agricultural systems (referred to as alternatives); (3) weighting of issues by different stakeholders; and (4) analysis and interpretation of scores and weights based on Eq. (1) (Linares and Romero, 2000; Mourits et al., 2006).

$$MCA_j = \sum_{ij} W_i^* S_{ij} \quad (1)$$

where MCA_j is the overall outcome for system j, W_i is the weight for the issue i and S_{ij} is the score for issue i in system j.

2.1.1. Selection of issues

The first step in MCA is the selection of sustainability issues. The relevance of sustainability issues varies across studies because of differences between agricultural sectors (e.g., the issue of animal welfare is specific for animal systems), differences in socio-cultural and geographical context (Cornelissen et al., 2001; Mollenhorst and De Boer, 2004; Van Calker et al., 2005; Pashaei Kamali et al., 2016), and because issues emerge at various levels (i.e., farm level versus chain level) (Yakovleva, 2007; Pashaei Kamali et al., 2014). In this study first selection of issues for environmental, economic, and social sustainability was based on various surveys with stakeholders (as described in Pashaei Kamali et al.). Subsequently, we included only those issues that were considered relevant in LA. Water deprivation, for instance, was excluded because soybeans are not irrigated in LA. Moreover, all issues mentioned by the stakeholders are typically related to soybean production. The following issues were selected: global warming, primary energy use, land use (i.e., yield per ha, biodiversity, profitability, barriers to entry into chain (based on economies of scale), employment, working conditions (labour rights and working circumstances), and human health and safety (local community, employees, and risk).

2.1.2. Scores

Experts were asked to score the issues for different soybean agricultural systems at the chain level, using an ordinal Likert scale, ranging from 1 (worst) to 7 (best). The boundary of the chain was defined as the farm in LA to the harbor in Europe. We included organic and conventional soybean production, where conventional production includes genetically modified (GM), and non-genetically modified (non-GM) production. The GM soybean system was used as a benchmark (represented by "4" in the ordinal Likert scale), because it is the mainstream system in LA and has a higher volume of trade than the other types of soybean (i.e., non-GM and organic soybean). It means that this practice represents the best-known practice (MVO, 2011). Scores indicate experts' opinions about the performance of one agricultural system compared to the benchmark system. Scores below the benchmark system indicate that the performance of the soybean agricultural system on that issue is perceived to be lower than the benchmark system. In contrast, scores above the benchmark system indicate that the performance of the soybean system on that issue is perceived to be better than the benchmark system.

In total 33 experts answered the questionnaire (18 non-GM and 15 organic). The knowledge of experts was evaluated based on their scientific publications and scientific reports regarding different agricultural systems. The experts were assumed to have the potential to provide assessments (scores) for the sustainability issues. In practice, experts in the organic system have also experience and knowledge in GMO and non-GMO systems. Therefore, it does not mean that they have knowledge only on one system. The experts, however, were more specialized in one system. The experts originated from Argentina, Belgium, Brazil, Hungary, Italy, Mexico, and the Netherlands. The Mann–Whitney U test for independent random samples was used to compare whether the scores obtained from experts differed between the agricultural systems. The questionnaire sent to the experts is presented in Appendix A.

2.1.3. Weights

The weights were provided by stakeholders who participated in a survey using a written questionnaire. Weights represented stakeholders' perceptions of the relative importance of sustainability issues, as well as sustainability dimensions (i.e., environmental, economic, and social) for soybean agricultural systems. Stakeholders are defined as any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system (Grimble and Wellard, 1997). In this study, stakeholders were selected from Brazil and Argentina. These countries are representative of soybean production in LA (Sterman et al., 2010; USDA-FAS, 2010). Stakeholders included were farmers and