Multicriteria assessment of the sustainability of cropping systems: A case study of farmer involvement using the MASC model

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Keywords: Multicriteria assessment, Sustainability, Cropping systems, Farmers involvment, MASC

Abstract

Current changes in the field of agriculture (e.g., food shortages, market globalization, and environmental concerns) are encouraging stakeholders to consider new and more sustainable production methods. To this end, tools are needed to assess the newly designed solutions, before taking them to the field (ex ante assessment), or after being implemented by farmers or by researchers on experimental sites (ex post assessment). MASC is a multi-criteria assessment tool designed to assess the performance of cropping systems in terms of their sustainability. It is based on a decision support system (DEXi) and aggregates 39 qualitative evaluation criteria arranged in a tree-like structure. In this paper, we present a case study involving farmers from Normandy (north-western France). MASC was used in a participatory approach with these farmers who were already working on reducing pesticide use. The overall performance of the different farmer's cropping systems was evaluated. In comparison to similar models, MASC allowed the farmers to become involved in determining the weights allocated to different criteria, thereby enabling them to introduce their personal vision of sustainability into parameter settings. Moreover, rather than assessing at the farm or landscape scale, MASC made it possible to exchange and collectively work on the concept of sustainability at the field scale. In addition, the results provided by the model were collectively examined in order to identify the strengths and weaknesses as well as propose improvements on the assessed cropping systems.

Introduction

Farmers, researchers and extension agents in the field of agriculture are currently facing a growing number of challenges such as coping with market volatility, increasing the production of raw materials and reducing the impacts of agricultural practices on the environment. They are working hard to put into practice production systems that address these key issues at the local level. The concept of sustainability may be used as a framework for assessing and selecting innovative systems in agriculture (Sadok *et al.*, 2008). Several definitions of sustainability have been proposed but most authors agree on its holistic nature what is referred to as the economic, social and environmental pillars (Hansen, 1996). Furthermore, due to this three-fold view, the practical application of the concept of sustainability is complex decision-making process. Indeed, it has:

- to take into account the multiple and sometimes conflicting objectives related with the economic, social and environmental facets of sustainability (Dent *et al.,* 1995);
- to consider various time scales ranging from the short term (ex: profitability) to the long term (ex: global warming) (Meyer-Aurich, 2005);
- to deal with the concerns arising at the various levels of organizations interrelated with agricultural activity such as food processing industries and the society at large (Lichtfouse *et al.*, 2009).

Several authors highlighted that, at the local level, the success of a project oriented toward sustainable development is strongly influenced by a real involvement of socio-economic actors in the decision-making process. Indeed, sustainability is partly subjective and the use of a participatory approach allows the different actors to reach a decision that may be acceptable and legitimate for all of them (Dent *et al*., 1995; Park and Seaton, 1996). Therefore, tools adapted to take into account various points of view as well as the local pedo-climatic context are deemed to be more relevant than “ready to use” technical packages (Sadok *et al*, 2008).

The aim of this paper is to explain how the MASC model has been used in Normandy, north-western France, by a group of farmers interested in decreasing pesticide use on their farms This model has been developped to carry out assessments according to the given pillars of sustainable development at the cropping system (CS) level defined as “a set of management procedures applied to a given, uniformly treated area, which may be a field, part of a field or a group of fields” (Sebillotte, 1990). It includes the crop sequence (rotation) and the crop management (tillage, sowing, cultivar, fertilisation and protection) of each crop in the crop sequence (including cover crops). In accordance with the European Water Framework Directive, these farmers have applied different innovative CSs, based on a redesign strategy (Hill and Mac Rae, 1996). These innovative CSs have been implemented on farms and have already shown their effectiveness in reducing pesticide use.

After providing a brief description of the most recent version of the MASC model (MASC 2.0), we describe the context of the assessment study and how the participatory assessment was implemented. Results are then presented and discussed in terms of the assessment provided by the model, how farmers came to weigh criteria in the assessment of their CSs and the impact of this on the outcomes as well as the added value of MASC compared to similar models.

Materials & methods

The MASC model

MASC, developped with the DEXi software (Bohanec, 2008), conceptualizes the sustainability assessment problem through a decisional approach based on a division of the overall problem into the three dimensions that make up sustainability (social, economic and environmental). Each dimension represents a hierarchy of sustainability objectives organized into sub-models. This conceptualization makes it possible to realistically represent the problem in a model that provides a graphical representation of the whole hierarchy, thereby allowing the users to trace the effects of changes in a single criterion on the overall result (Sadok et al., 2009). MASC has a hierarchical tree structure formed by 65 variables (Figure 1). Each variable has a number of qualitative values (i.e., modalities), from 3 to 7, that typically takes the form of a ”Low→Medium→High” progression with the addition of ”Very Low” and ”Very High” in some cases. Variables can be distinguished as input variables (i.e., basic criteria; 39 variables) and aggregated variables (i.e., aggregated criteria; 26 variables).

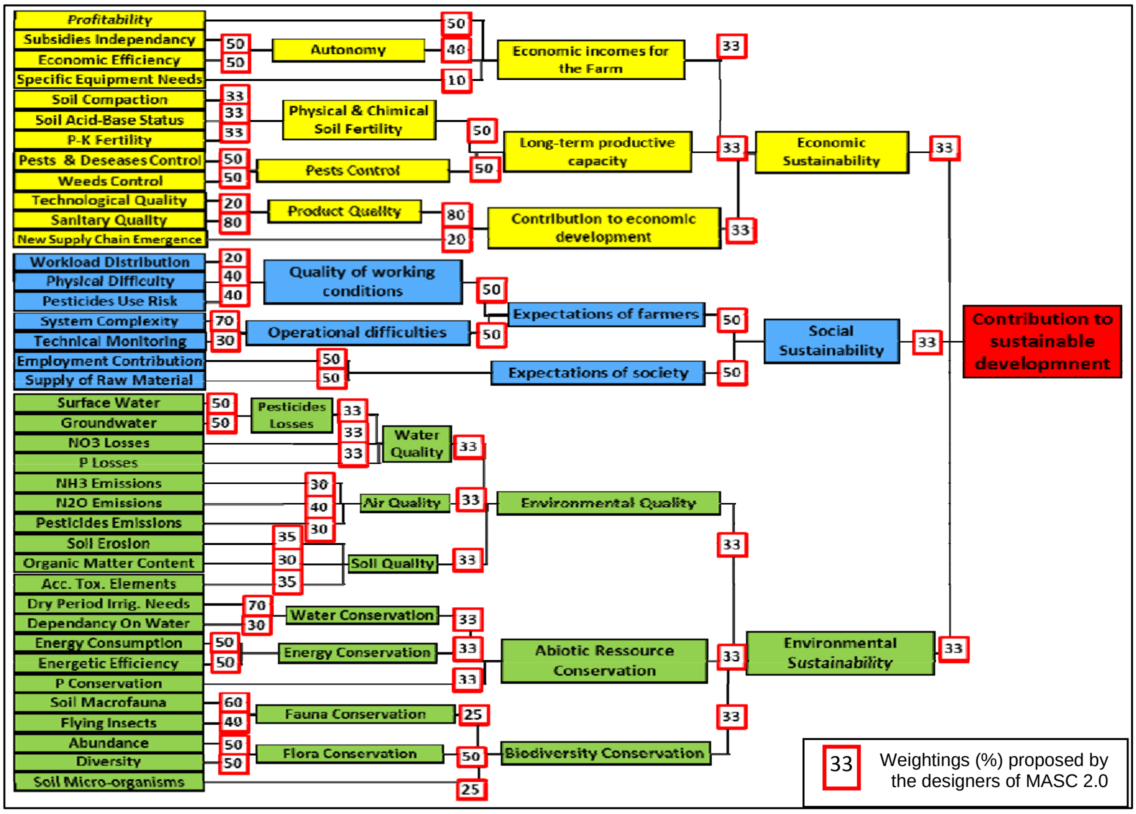

Figure 1: MASC 2.0 decision tree and weighting pattern for the calculation of aggregate criteria from basic criteria

Basic criteria refer to elementary concerns of sustainable development (e.g., profitability, nitrate losses and soil erosion). These criteria are populated by specific indicators proposed by the model designers with the MASC model. These indicators are not compulsory and can be replaced by local measurements or by operational models better adapted to the local context. In MASC, three types of indicators are proposed:

- **Indicators related to technical and economic references** (e.g., semi-net margin, economic efficiency) or references using operational models (e.g., indicators of INDIGO method; Boscktaller *et al*., 2009). For this type of indicator, calculated quantitative variables are discretized into qualitative values compatible with the MASC model thanks to threshold values.
- **Indicators assessed by expert knowledge**. Several recommendations were made by the designers to facilitate the choice of a qualitative class. These indicators basically concern some aspects of the social dimension which, in essence, is subjective (e.g., the "System complexity" criteria will be evaluated differently by farmers according to their skills and educational level).
- **Composite indicators elaborated as a “satellite tree”** implemented separately on the DEXi software. These indicators are proposed to assess basic criteria that cover a complex domain that cannot be estimated with a simple calculation or for which there is no operational model (For instance “Weed Control”). These “satellite trees” inputs are filled with both expert knowledge and simple calculations.

Aggregations are performed for each aggregated criterion thanks to "utility functions" materialized by tables populated by 'IF-THEN' decision rules such as IF <the criterion ”Expectations of Society” is ”Very *low*”> AND IF <the criterion ”Expectations of Farmers” is *”Very low”*> THEN < the aggregated criterion ”Social Sustainability” is *”Very low”*> (Figure 2).

Decision rules

	Expectations of Society	Expectations of Farmers	Social Sustainability
	50%	50%	
1	**Very low**	<=**Low to medium**	**Very low**
2	<=**Low to medium**	**Very low**	**Very low**
3	**Very low**	***Medium to high***	**Low**
4	**Low to medium**	**Low to medium**	**Low**
5	***Medium to high***	**Very low**	**Low**
6	**Very low**	***Very high***	Medium
7	**Low to medium**	***Medium to high***	Medium
8	***Medium to high***	**Low to medium**	Medium
9	***Very high***	**Very low**	Medium
10	**Low to medium**	***Very high***	***High***
11	***Medium to high***	***Medium to high***	***High***
12	***Very high***	**Low to medium**	***High***
13	>=***Medium to high***	***Very high***	***Very high***
14	***Very high***	>=***Medium to high***	***Very high***

Figure 2: Example of the utility function associated to the criteria : “Social sustainability »

Each utility function can be filled manually or by using a semi-automatically function based on the weight of each criteria. To make this task easier, all the utility functions have been pre-populated by the designers but users can change them to adapt the model to their local context and preferences.

Presentation of the assessment context

CSs implemented by thirteen farmers in Normandy – France were evaluated. These systems are located in a mixed cropping-livestock region characterized by a homogenous pedoclimatic context, a oceanic climate, and deep silty soils. All these innovative CSs combined varying strategies implemented by farmers in order to reduce the agricultural negative externalities and especially pesticides (e.g., shifted sowing dates, mechanical weed control, low nitrogen application and longer crop rotations). The CSs assessed in this case study are presented in table 1. The control CS, representative of the agricultural practices performed in the regional context, was added to facilitate the interpretation by allowing comparisons. In accordance with the targeted reduction of pesticides, the average of the Treatment Frequency Indexes (TFI; Gravesen, 2003) of the 13 innovative CSs is 35% less than the local reference CS.

Table 1: Main agronomical characteristics of the 14 CSs assessed with MASC 2.0 (S. = Spring; W. = Winter)

ID code	Crop rotation	TFI[a] $ha^{-1}year^{-1}$	Breeding farm[c] (P/B/.)
CS 1	S. Peas-W. Wheat-*(mustard)*-S. Barley-W.oilseed Rape-W.Wheat-*(mustard)*-Linen-W. wheat-W.Barley-*(mustard)*	2,2	P
CS 2	Grassland[b]-Grassland[b]-Grassland[b]-*(mustard)*-Silage Maize-W.Wheat	0.8	B
CS 3	Grassland[b]-Grassland[b]-Grassland[b]-Grassland[b]-*(mustard)*-Maize-W.Wheat-Linen	0.9	B
CS 4	W. Oilseed Rape-W. Wheat-*(mustard)*-F. Bean-W.Wheat-*(mustard)*-S. Peas-W.Wheat	2.2	.
CS 5	W. Oilseed Rape-W. Wheat-*(mustard)*-Linen-W. Wheat-*(mustard)*-F. Bean-W. Wheat	1.5	B
CS 6	Fescue-Fescue-W. Wheat-W.Barley-F.bean-W.Wheat-Hemp-W.Wheat-S.Barley	1	.
CS 7	Sugar Beet- W. Wheat-Linen-W. Wheat-Maize-W. Wheat-Rape-W. Wheat	3,3	B
CS 8	W.Oilseed Rape -W. Wheat-S. Barley-W. Wheat- F. Bean	2,8	.
CS 9	W.Oilseed Rape -W. Wheat-Hemp-Ray Grass- W.Oilseed Rape -Peas-W. Wheat-S. Barley	2	B
CS 10	Sugar Beet-W. Wheat-*(mustard)*-Maize-W. Wheat-*(mustard)*-S. Barley	1,7	.
CS 11	W.Peas-W. Wheat-W.Barley-W.Oilseed Rape-W. Wheat	2.5	.
CS 12	W.Oilseed Rape-W. Wheat-Fescue-W. Wheat-*(Mustard)*-Maize	2,5	.
CS 13	W.Oilseed Rape-W. Wheat-*(mustard)*-Linen-W.Wheat-F. Bean-W. Wheat	3,4	B
Reference CS	**Maize-W. Wheat-*(mustard)***	**3.4**	**B**

[a] *Treatment frequency index, number of full rate treatment: TFI = (1/n)* $(1-n)\sum_{t=1}^{T}(Dt/DApt)$ *with n: number of years in the crop sequence; T: total number of pesticide treatments; D: applied rate in commercial product; DAp: approved/registered rate for the commercial product.*

[b] *Grassland composed of a mixture of Alfalfa and Dactyl*

[c] *Presence of animal breeding in the farm where the CS is implemented (P=poultry breeding; B= cattle breeding; . = no animal breeding)*

Organization of the participatory approach

A five-step participatory methodology was used. Firstly, two extension workers from the French National Institute of Research in Agronomy along with a farm advisor defined the main objective of this study: involve the thirteen farmers the farm advisor had been working with in the assessment of the sustainability of their innovative CSs based on low pesticide use. Secondly, with the help of the farmers, innovative CSs were selected according to their low consumption of pesticides and described in terms of a set of field-scale agricultural practices. Particular attention was paid to describe these as they are commonly implemented by removing the minor variations caused by the effect of situational factors on the practices performed (e.g., climatic events and sudden increases or decreases in input prices). To handle these descriptions, CSs were reconstructed by balancing the available factual data (obtained from surveys, interviews or available records) and the decision-making system of the farmer (obtained through interviews). Thirdly, the 39 basic criteria were estimated (input values of the model) with both expert knowledge to inform the qualitative criteria and by calculations. Fourthly, a half-day meeting was organized with the advisors and the thirteen farmers to further the participatory feature of this study. During this meeting, the MASC model was presented and discussed with the farmers. Then, results provided by the model were collectively and individually analyzed by following an iterative loop: A first simulation was carried out with the set of weights proposed by the designers of the model followed by a second simulation incorporating, in the upper part of the tree, the specific modifications defined thanks to a consensus reached by the farmers. Thus, this second simulation integrated farmers' preferences in the assessment process. Fifthly, the results were used to identify the strengths and the weaknesses of each evaluated CS. Thanks to a participative approach, organizers sought the expertise and opinions of the farmers in order to find realistic solutions to enhance the overall performances of their CSs.

Results & Discussion

Analysis of the Individual CS under assessment

At first, the performances obtained for each assessed CS were analysed by small groups of farmers supervised by one of the organizers. An example of an individual CS assessment, considering the designers' weights, is given in Figure 3.

This output made it possible for farmers and the advisor to have an overview of the performances of their CSs according to the three facets of sustainability. During this step, each group moved further ahead in its interpretation of results by seeking to pinpoint which of their agricultural practices could have led to the given results. In this respect, the collective analysis emphasized the importance of the adoption of (i) long and diversified crop rotations, (ii) perennial crops (e.g., grassland) and (iii) green manure crops. Consequently, to improve the sustainability of their CSs, participants highlighted the importance of generally enhancing the complementary between crop and animal production.

In this case study, the farm adviser and extension workers were already rather experimented in the use of the MASC model. This facilitated the presentation of the MASC model and exchanges with the farmers. Nevertheless, although the model is quite simple to understand, its use with another group will require the organizer(s) to dedicate time to becoming familiar with the indicator assessment method.

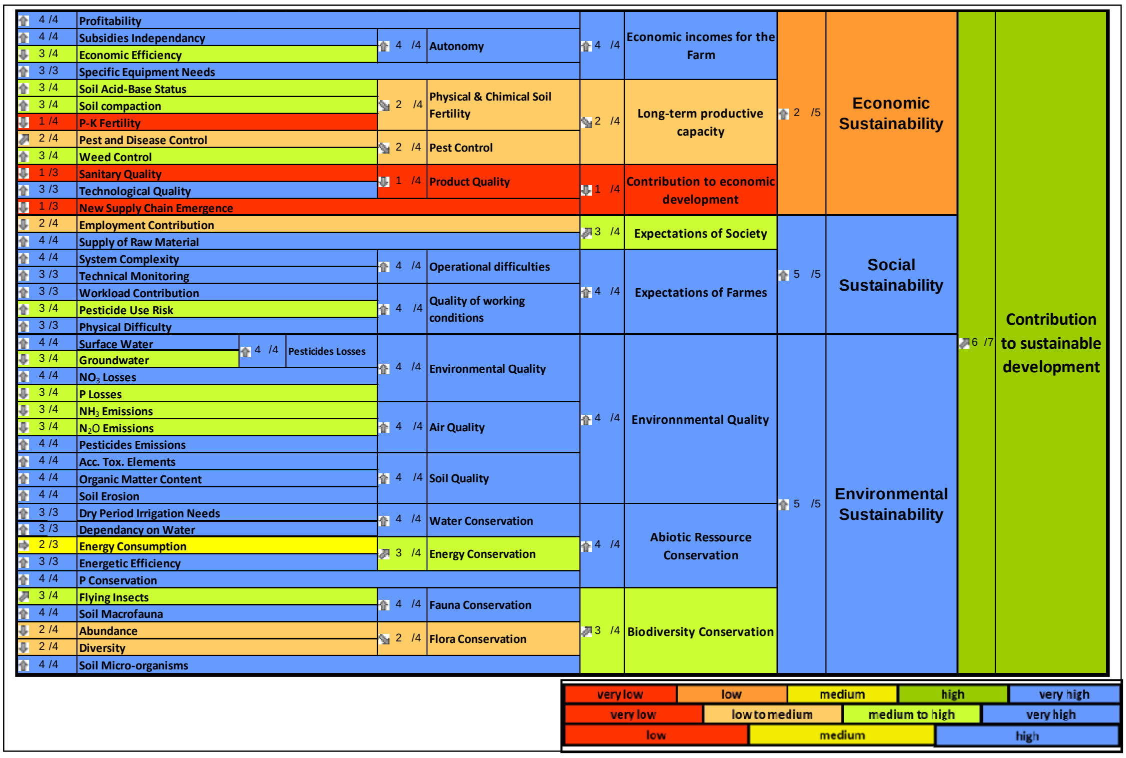

Figure 3: Example of detailed results provided by the MASC model for CS 8 with the set of weights defined by the model designers and discussed with farmers.

Global analysis of the performances of the CS by simulation of different set weights

"Contribution to sustainable development" scores, according to the two sets of simulated weights, are shown in Figure 4. The first set of simulated weights (model designers proposal), can be considered as a well-balanced perception of sustainability given that the weights are in general evenly distributed (Figure 1). The second set of weights (farmers' proposal) increased the weight of the economic dimension (50%) and decreased the weights of the environmental (30%) and the social dimension (20%).

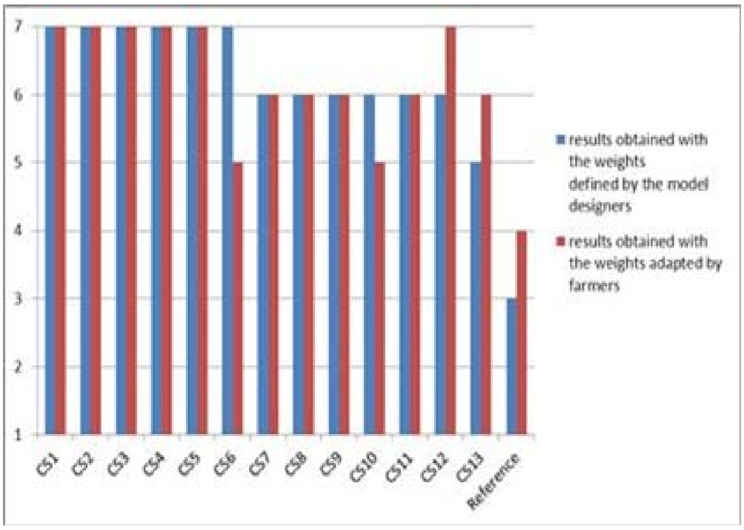

Figure 4: Rank of the CSs regarding "Contribution to sustainable development" depending on the weights given by the model designers (blue) and the farmers (brown) (score 0 = very low sustainability; 7 = very high sustainability).

Overall, no matter the set of weights, all the innovative CSs obtained higher scores of sustainability compared to the reference CS by scoring between 5/7 and 7/7. For five CSs farmers' weights modified the scores. For example, CS 6 obtained the best score the model allows (7/7) if we consider the weights proposed by model designers. However, it earned a score of 5/7 according to the farmers' point of view, mainly due to its lower profitability.

Thanks to the rather easy-to-understand aggregation device farmers had the possibility of sharing among themselves and with the farm advisor their own vision of sustainable development applied to their activity. Despite the fact that a half-day meeting did not provide the time needed to reach a consensus to specify all the utility functions of the model, the farmers were able to express their opinion on several social and environmental issues thanks to the assessment grid proposed in the MASC model (e.g., pesticides toxicity, workload distribution and soil erosion).

Main strengths of the MASC model used in a participatory approach

Several methods to assess agricultural sustainability have already been published (see for instance van der Werf and Petit, 2002; Bockstaller *et al.*, 2009; Binder et al., 2010); however MASC combines several specific interesting features. First of all, in comparison to this other models, MASC allows farmers to modify the weights allocated to each criterion. Thanks to this feature, farmers can easily introduce their personal view of the sustainability into the model and thereby influence the results. This increases farmers' involvement in the assessment process, a step helping farmers more fully appropriate the conclusions they reach. Secondly, assessment at the cropping system level is better adapted than methods designed at larger scales (such as the farm or the landscape scales) accounting more precisely for interactions between the agricultural practices in the field and the pedo-climatic context of that field. This feature is particularly relevant because it permits decision-making at the level of the farmers and it increases the accuracy of the assessment of some agronomic and environmental aspects. Thirdly, unlike a number of existing assessment methods at the cropping system level focused solely on environmental performances (van der Werf and Petit, 2002; Bockstaller et al., 2009), MASC takes a more holistic approach by also assessing the economic and social effectiveness of the CSs. Thanks to this approach, MASC is well adapted to handling the wide range of issues farmers deal with.

Conclusion

The use of MASC within a participative framework allows participants to discuss their concerns and to share knowledge about agricultural impacts on their socioeconomic and biophysical context. Generally speaking, thanks to its simplicity and its flexibility, MASC was a suitable means to get farmers involved in thinking about the concept of sustainability at the cropping system level. A more detailed analysis of the results by small working groups made it possible to identify the strengths and the weaknesses of farmers' CS and led them to propose improvements. In a future study, these improvements could be simulated with the MASC model in an *ex ante* assessment in order to select the more relevant CSs. The results presented here could also be used to inform policy makers and other local farmers about the performances achieved by the innovative CSs assessed here.

In other hands, this case study revealed that the inputting of data and the calculation of the model is rather time-consuming and limit its use within a routine advice session with farmers. The development of a software interface that couples the calculation step (e.g., with the CRITER software; Fortino *et al.,* 2010) and the aggregation step (with the MASC model) would make possible to reach this goal.

Acknowledgments: We wish to thank Dr. S. Tanis-Plant for fruitful discussions in English

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