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MULTI-ATTRIBUTE ASSESSMENT OF THE SUSTAINABILITY OF INNOVATIVE BANANA CROPPING SYSTEMS IN GUADELOUPE: ADAPTATION AND IMPLEMENTATION OF THE MASC METHOD

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ABSTRACT: Banana production in Guadeloupe was developed on intensive monoculture design with high level of inputs. Currently, this production is cutting through an economic and an environmental crisis. With this crisis, solution possibility lies in proposing sustainable innovative cropping systems. Evaluation and design of innovative systems require the use of tools for modeling and assessment. The research unit ASTRO of the French National Institute for Agricultural Research has developed a program to design banana innovative cropping systems. First results modelized the existing farm diversity through a typological and systemic approach. Then a panel of experts designed a set of innovative cropping systems. Assessment is a key step in a prototyping framework (i) to provide action effects (ex ante assessment); (ii) to identify causes (diagnosis); (iii) to monitor a process; (iv) to take stock of actions (ex post assessment). These assessments are essential in order to make a decision (piloting, proposed actions, improvements) or to communicate. For our case, we chose a qualitative model to assess the overall sustainability of analternative cropping system: the model MASC (Multi-Attribute Assessment of the Sustainability of Cropping systems) (Sadok *et al*., 2009). First, we adapted MASC to banana production in Guadeloupe, changing the decision tree structure (representing sustainability), the utility functions, some methods used to calculate the input attributes, and the threshold for qualitative transformation of inputs. The sustainability of 18 prototypes was assessed taking into account the six-class typology. The data needed came from interviews and results from the mechanistic model BANAD (Blazy *et al*., 2010). MASC allowed identifying different sustainable issues through each farm type. Among the 108 pairs "prototype*farm type" assessed, 51 scored a low level of sustainability, 54 a medium level, and three a high level of sustainability. One of the prototypes gets a high level of sustainability in a farm type whereas this same prototype scores a low level in another farm type. Also, two prototypes seem promising, scoring at least a medium level of sustainability among all the farm types. Our results show that considering the diversity of farms is important in the assessment process. Alternative cropping systems do not generally have the same effects through different farm types. Furthermore, the promising prototypes have to be tested in situ to assess their agronomic and functional performances. Stakeholders should take part in the adapting process of MASC. MASC was appropriate for its flexible structure suitable to be adapted to specific contexts. It can discriminate satisfactorily among a wide range of innovative cropping systems.

Keywords: Banana, banana cropping system, ex ante evaluation, Guadeloupe, innovative cropping system, multicriteria assessment, sustainability assessment

INTRODUCTION

Banana production in Guadeloupe was developed on intensive monoculture logic with high level of inputs (Dulcire and Cattan, 2002). Currently, this production is cutting through an economic and an environmental crisis. With this crisis, solution possibility lies in proposing sustainable innovative cropping systems. The research unit AgroSystèmes Tropicaux of the French National Institute for Agricultural Research has developed a program to design banana innovative cropping systems. A panel of experts designed 18 agro-ecological cropping systems (Blazy *et al.*, 2009). But how can we be sure that the prototypes of cropping systems are sustainable? Testing 18 prototypes on field and/or farm can take a long time and can be very expensive. The *ex ante* assessment is an important step because it allows quick identification of the best sustainable cropping systems. We need methods and tools able to assess the sustainability of cropping systems. This kind of method must have a holistic approach because of the multidimensional aspect of sustainability (Ikerd, 1993; Andreoli *et al.*, 1999; Andreoli and Tellarini, 2000; Espinosa *et al.*, 2008). Several methods and tools were developed to assess the sustainability of agriculture (Sadok *et al.*, 2008; Bockstaller *et al.*, 2009) but they focus on environmental or economic dimensions of sustainability (von Wirén-Lehr, 2001 in Meul *et al.*, 2008). From the different methods available, we chose the MASC (Multi-attribute Assessment of the Sustainability of Cropping systems) method (Sadok *et al.*, 2009) to assess our innovative cropping systems.

In this paper we present how we adapted and used the MASC method to obtain the more suitable innovative cropping systems, taking into account different farming systems.

MATERIALS AND METHODS

Innovative cropping systems. We assessed 18 prototypes of cropping systems: single innovations (concerning only one component of the cropping system) and a combination of single innovations. The aim of the innovative cropping systems is to reduce the use of pesticides and to use natural methods of pest control and/or mineral nutrition. Table 1 presents the different innovations.

Innovations 1, 2 and 3 consist of stopping the use of pesticides (nematicides and herbicides). They can be considered innovations based on extreme societal regulation in comparison with current practices. Innovations 4, 5 and 6 consist of crop rotations that are aimed at durably regulating nematode populations: an 8-month fallow with *Crotalaria juncea*; a 12-month fallow chemically controlled to avoid the development of nematode host-plants; and a 24-month rotation with pineapple. These rotations involve additional operations for ploughing, sowing and managing the rotation crop. Innovations 10, 11, and 12 are based on intercropping with *Canavalia ensiformis*, *Brachiaria decumbens* and *Impatiens* sp. Their aim is first to reduce herbicide use, and second to improve soil nitrogen status. Innovations 13, 14, and 15 are modifications of decision rules for application of nematicides, herbicides and nitrogen supplies according to a monitoring threshold of plant-parasitic nematodes, a percentage of soil covered by weeds and a level of nitrogen nutrition. Innovations 16 and 17 are based on resistant cultivars (Variety 91X and Variety 91Y). These two types have been defined as resistant to the Sigatoka Disease and Black Leaf Streak Disease caused by *Mycosphaerella musicola* and *Mycosphaerella fijiensis*, respectively. In addition to having these desired features, they are less susceptible to plant-parasitic nematodes, mostly burrowing (*Radopholus similis*) and lesion (*Pratylenchus coffeae*) nematodes than the classic Cavendish cultivars (Quénéhervé *et al.*, 2009). Finally, they have a different development and growth pattern, with a shorter cropping cycle and smaller weight of fruit bunches. They differ from each other in the level of these two characteristics. Innovations 7 and 8 were designed with a combination of previous innovations in order to regulate nematode population and reduce herbicide uses. Innovations 9 and 18 consist of a combination of previous innovation in an organic farming system, respectively, with classic Cavendish and resistant cultivars.

All of these innovations comprise a reduction of or total avoidance of pesticides. All the biophysical, technical and economic parameters for describing these innovations were derived from expert knowledge and experiments (Ternisien, 1989; Ternisien and Melin, 1989; Mateille *et al.*, 1994; Chabrier and Quénéhervé, 2003; Clermont-Dauphin *et al.*, 2004; Quénéhervé *et al.*, 2006; Motisi *et al.*, 2007; Thammaiah *et al.*, 2007; Tixier *et al.*, 2008b).

Type of innovative system	#	Description
Regulation of pesticide use	1	No use of nematicides
	2	No use of herbicides (manual or mechanical weeding)
	3	No use of nematicides and herbicides (manual or mechanical weeding)
Rotations	4	Rotation with *Crotalaria juncea* (8 months)
	5	Rotation with fallow chemically controlled (12 months)
	6	Rotation with Pineapple (24 months)
Integrateds systems	7	Integrated system 1: rotation with *Brachiaria decumbens* (12 months) + intercropping with *B. decumbens*
	8	Integrated system 2: rotation with fallow chemically controlled (12 months) + intercropping with *Impatiens* sp.
	9	Organic system: rotation with *C. juncea* + intercropping with *Canavalia ensiformis* + organic manure
Intercropping	10	Intercropping with *C. ensiformis*
	11	Intercropping with *B. decumbens*
	12	Intercropping with *Impatiens* sp.
Conditional application	13	Treatment nematicides according to a monitoring of nematodes
	14	Herbicide based on a threshold of land cover in weeds
	15	Contributions of chemical fertilizers as needed
Resistant cultivars	16	Variety 91X
	17	Variety 91Y
	18	Variety 91Y in organic system rotation with *C. juncea* + intercropping with *Canavalia ensiformis* + organic manure

Table 1. Description of innovative cropping systems

Farm typology. Each innovation was simulated on six different types of farms. This typology was derived from a cluster analysis based on data collected from 25% of banana growers of Guadeloupe (Blazy *et al.*, 2008). Table 2 presents the main characteristics of farms types.

Types 1 and 2 are small farms with mainly familiar, abundant, and low-cost manpower. It is a banana monocrop farm with replanting every five years. The current banana management system is of medium intensity. Types 3 and 4 represent large farms with mainly full-time permanent employees. On these farms, banana trees are currently rotated every five years with a fallow or sugar cane. It is a relatively intensive system. Types 5 and 6 are small farms with steep slopes and abundant rainfall. This farm type is very extensive with perennial management practices of the banana.

Models. The crop model used is the SIMBA model, which simulates banana cropping systems at field level over several cropping cycles. It includes sub-models that simulate soil structure, water balance, root nematode populations, yield, and economic outputs with a sound balance between representing the major processes of the system in the region and keeping the model simple to reduce the parameterization costs under a large range of conditions (Tixier *et al.*, 2008a).

The mechanistic BANAD model (Blazy *et al.*, 2010) allowed simulating the impact of innovative cropping systems on production, economic performances, workload and use of pesticides, taking into account the diversity of farming contexts and different policy and market conditions.

Farm Type	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Banana field management	Banana field replanted every 5 to 8 years				Perennial banana	
	Continuous		Rotation sugar cane or fallow		Continuous	
System area (ha)	4,2	8	82	28	8	5
Average altitude (m)	80	115	123	250	550	380
Type of soil	Nitisol	Ferralsol	Nitisol	Andosol	Andosol	Andosol
Surface mechanized	100%	100%	100%	75%	0%	0%
Average yield (t/ha/yr)	21,4	22,5	45,2	38,5	17,3	18,6
Percentage of family labor	74%	42%	2%	9%	37%	70%
Selling Price banana (€/kg)	0,56	0,54	0,57	0,57	0,45	0,46

Table 2. Main characteristics of farm types

Assessment method. The MASC method (Sadok *et al.*, 2009) was chosen because it deals with cropping system scale; it allows an *ex ante* evaluation; and it takes into account the economic, social and environmental dimensions of sustainability.

MASC is implemented in the decision support system DEXi (Jereb *et al.*, 2003 in Bohanec *et al.*, 2004). In MASC, the sustainability is conceptualized as a hierarchical decision tree. It makes it possible to break down a problem (concept of sustainability) in smaller subproblems represented by criteria (attributes or indicators).

The input criteria are calculated or estimated for each year of the rotation and then averaged. Input criteria are estimated quantitatively by formalisms and models or are estimated qualitatively (linguistic or ordinal) by indicators based on bibliographic or expertise-based guidelines. All values obtained in input criteria are homogenized by converting them into qualitative-linguistic variable (e.g., ‘Low’, ‘Medium’, ‘High’). Input criteria are aggregated in order to obtain a single criterion by ‘If-Then’ decision rules. In the aggregating process, criteria can have a relative importance representing them by the percentage given to each one.

For our needs the MASC method was adapted to the production of bananas in Guadeloupe. Figure 1 shows the decision tree of ‘MASC-Banane’, the adapted version of MASC, where we make modifications in the way to use this method. We modified the original structure of the decision tree because we had other criteria that were more relevant. Also, we adapted weightings given to a criterion in order to respect our strategic vision of the sustainability. For example, in ‘Overall Sustainability’, the three dimensions, economic, social and environmental sustainability, have to be balanced. By contrast, in ‘Water Pollution Risk’, ‘Pesticide Losses’ was the most important criterion. Then, we change the way to calculate/estimate criteria that were not suitable in our context. Adaptations were also made in the transformation process because the interpretation of qualitative values and their transformation into qualitative-linguistic values is locally specific.

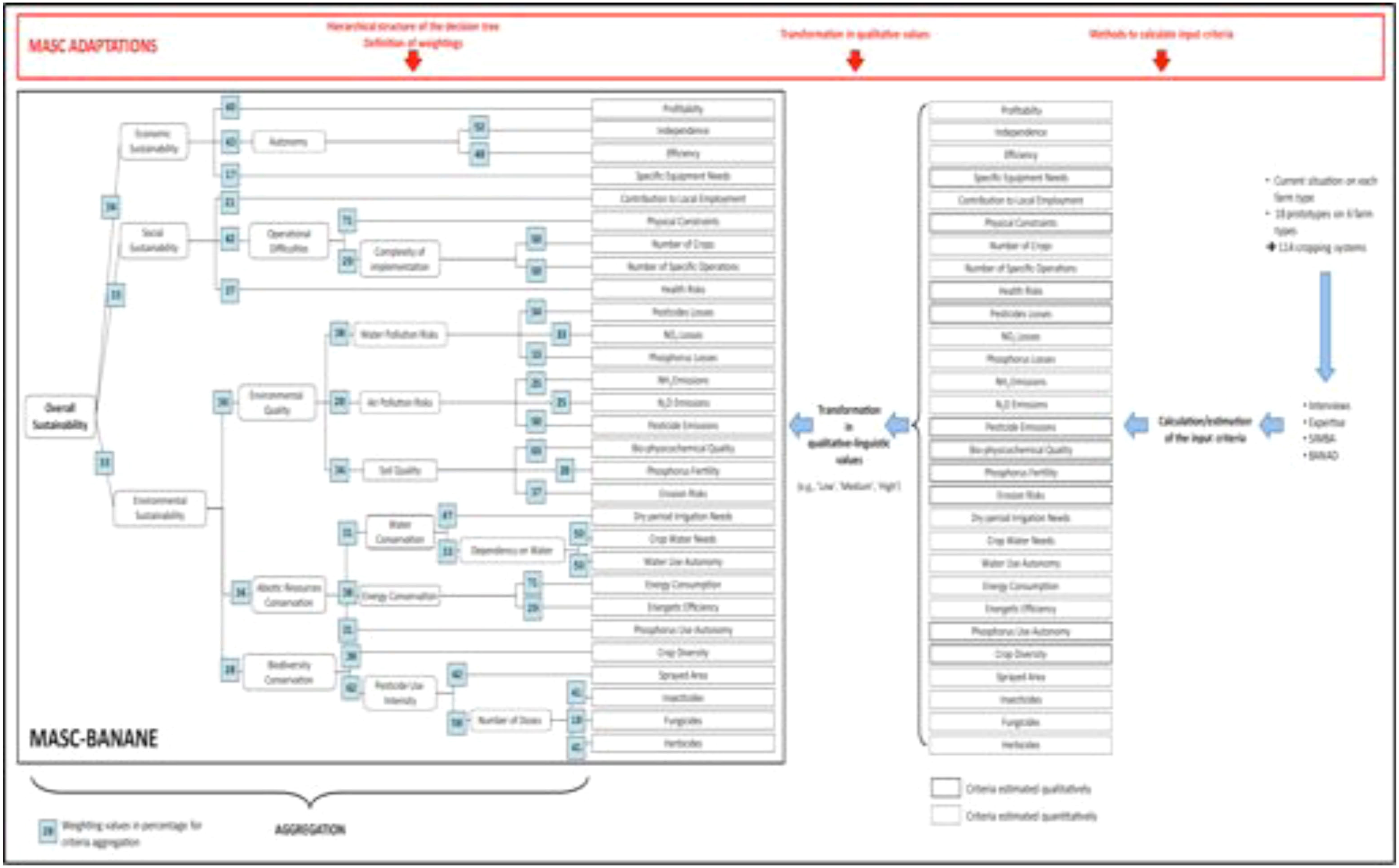

Figure 1. Hierarchical decision tree of MASC-BANANE and the way to use the assessment method.

Assessment of innovative cropping systems. Input information for the assessment process come from interviews, expertise, the SIMBA and the BANAD modelling. We assessed the sustainability of 114 cropping systems:

- the six current cropping systems (six farm types),
- 18 innovative cropping systems on six farm types (108 different cropping systems)

For each of the 114 cropping systems we obtained an overall sustainability score, making it possible to select the most sustainable cropping system for each farm type.

RESULTS

Current situation. The results of the assessment of the current situation are presented in the first rows of Table 3. The variability of the overall sustainability score between the different farm types is low. Farm types 1, 2, 3 and 6 present a low overall sustainability. Farm types 4 and 5 seem more sustainable than others, with a medium overall sustainability.

Breaking down the sustainability score in economic, social and environmental dimensions (Figure 2), we noticed that farm types 1 and 2 do not have good scores for any dimension. Farm types 3 and 4 obtain an acceptable economic sustainability score. Farm types 4 and 5 have a good social sustainability. Finally, the environmental sustainability is high for farm types 5 and 6.

Some propositions can be made to enhance the scores obtained:

- Reduce or stop pesticides use for environmental sustainability.
- Stop toxic pesticides use, improve mechanization for lower painful work for social sustainability.
- Reduce costs, increase yields, decrease sorting losses, obtain a better selling price for economic sustainability.

Innovative cropping systems. On 108 pairs 'farm type*innovation' assessed, the overall sustainability is (Table 3):

- Low for 51 cases
- Medium for 54 cases
- High for three cases

Compared to the current situation, innovative cropping systems (Table 3):

- increase overall sustainability score of two levels in three cases
- increase overall sustainability score of one level in 23 cases
- leave overall sustainability score at the same level in 77 cases
- decrease overall sustainability score of one level in five cases

Two innovative cropping systems, organic systems in classic Cavendish and new cultivar, obtained a high overall sustainability score but only on farm types 1 and 2. On farm types 4 and 5, no innovation increased the overall sustainability score. Some of them decreased this score. Intercropping and conditional application generally had a low overall sustainability score among all farm types. Regulation of pesticides use and crop rotations obtained better scores in half of the farm types. Integrated systems allowed a medium overall sustainability score on almost all farm types. The results show that with at least a medium score among all farm types, innovations 7 and 9 are the most promising ones.

Our goal was to sort innovation among farm types. We chose to select innovation increasing overall sustainability score compared to current situation (plus signs in Table 3). We had six innovative cropping systems for farm type 1 and seven for farm types 2, 3 and 6. There were no suitable innovative cropping systems for farm types 4 and 5.

		# Innovation	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
No Innovation		0	**Low**	**Low**	**Low**	**Medium**	**Medium**	**Low**
Regulation of pesticide use	No nematicides	1	=	+	=	=	=	+
	No Herbicides	2	=	=	=	=	=	=
	No Nematicides + No Herbicides	3	+	=	+	=	=	=
Rotations	*Crotalaria juncea*	4	=	+	=	=	=	+
	Fallow	5	+	+	=	=	=	=
	Pineapple	6	=	=	=	-	=	=
Integrated systems	Integrated system 1	7	+	+	+	=	=	+
	Integrated system 2	8	+	+	+	=	=	=
	Organic system	9	+ +	+ +	+	=	=	+
Intercropping	*Canavalia ensiformis*	10	=	=	=	=	=	=
	Brachiaria decumbens	11	=	=	+	=	=	=
	Impatiens sp.	12	=	=	=	=	-	=
Conditional application	Nematicides	13	=	=	=	=	=	+
	Herbicides	14	=	=	=	=	=	=
	Fertilizers	15	=	=	=	-	=	=
Resistant cultivar	91X	16	=	=	=	-	=	=
	91Y	17	=	=	+	=	=	+
	91Y in organic farming	18	+ +	+	+	=	-	=

Overall Sustainability score: Very High; High; Medium; Low; Very Low

Increase of: + + + 3 levels; + + 2 levels; + 1 level

= No evolution

Decrease of: - 1 level; - - 2 levels

Table 3. Assessment results and evolution of overall sustainability score compared to current situation without innovation

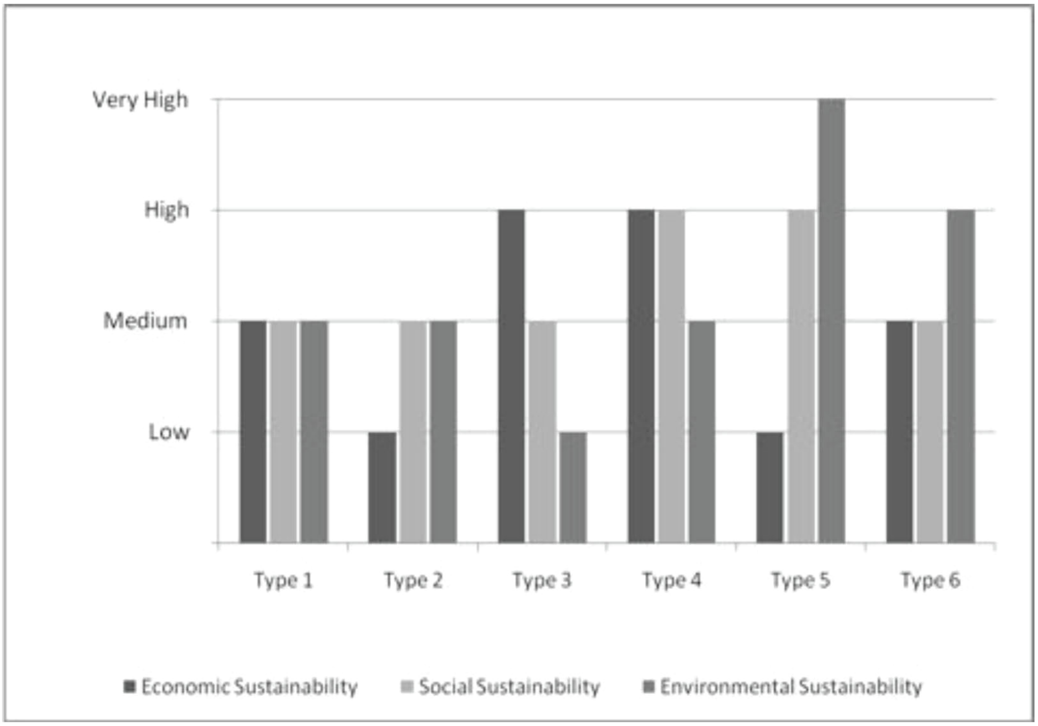

Figure 2. Scores obtained for each dimension of overall sustainability

DISCUSSION

An *ex ante* assessment method of cropping systems, MASC, was adapted to banana production in Guadeloupe. This adapted method, MASC-BANANE, allowed assessing and comparing sustainability of 18 innovative cropping systems taking into account the regional variability of farming systems (six farm types). We selected 27 pairs 'farms type*innovation' more sustainable. These selected innovative cropping systems have to be tested on farm.

Our results show the importance of taking into account the regional diversity of farming systems. Indeed, for a given innovative cropping system the overall sustainability score varies widely within different farm types. For example, cultivar 91Y in organic system (innovation 18) obtained a high score on farm type 1, a medium score on farm types 2, 3, 4 and a low score on farm types 5 and 6. Farm types have specific issues of sustainability and characteristics. This underlines the advantage of proposing a high number of innovations in order to select the most sustainable one for each farm type.

The main limitation of our study lies in the implication of farmers and other professionals involved in banana production in Guadeloupe: they are not involved in the adaptation process. Moreover, the process of transformation in qualitative-linguistic values is subjective. It is the user who chooses which values are low, medium or high. Sometimes we dispose of regional, bibliographic or expert references, sometimes not. In this last case we use the distribution of values to build classes. We also change some methods to calculate input criteria. These methods have to be improved and in one case, have to be validated. Finally, banana selling prices given are questionable. Indeed, in our simulations, the selling price for new cultivars is 50% up compared to classic Cavendish, 40% up for organic classic Cavendish, and 100% up for organic new cultivars. Market studies have to be done in order to determine if premium consumers would be willing to pay for new cultivars and organic bananas.

For the future and to obtain better results different points of our results can be enhanced. First, models used (crop model and farming system model) can be involved to have more accurate results. It would be interesting to test innovation in extreme climatic years, to explore resilience of innovative cropping systems. Moreover, some criteria would be added to the decision tree like resilience, potential adoption by farmers, work demand, land demand, economic risk or quality of products.

CONCLUSION

The method MASC-BANANE allows us assessing sustainability of several innovative cropping systems taking into account different farming systems. This systemic assessment is done through many criteria aggregated in a global sustainability score. Our results demonstrate the importance of farm types in assessing sustainability of innovative cropping systems. Two innovative cropping systems have a positive impact on the sustainability with all farm types:

- The integrated system with *Brachiaria decumbens* in crop rotation, no tillage and intercropping with *B. decumbens*.
- The organic system in classic Cavendish with *Crotalaria juncea* in crop rotation, intercropping with *Canavalia ensiformis* and organic fertilization.

These two cropping systems are the most promising, but would not be adopted by all the farmers. Other innovative cropping systems specifically adapted for each farm type have to be proposed. Then, all the selected innovative cropping systems have to be tested on farm.

Our study underlines the usefulness of models and assessment methods to select a large number of innovative cropping systems among wide range of biophysical and technical farming situations.

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