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How to Identify Barriers to the Adoption of Sustainable Agriculture? A Study Based on a Multi-Criteria Model

Moisés Barbosa Junior [1,*], Eliane Pinheiro [2], Carla Cristiane Sokulski [1], Diego Alexis Ramos Huarachi [1] and Antonio Carlos de Francisco [1]

[1] Sustainable Production Systems Laboratoy (LESP), Postgraduate Program of Production Engineering (PPGEP), Universidade Tecnológica Federal do Paraná (UTFPR), R. Doutor Washington Subtil Chueire 330—Jardim Carvalho, Ponta Grossa 84017-220, PR, Brazil

[2] Fashion Department, Regional Campus of Cianorte, State University of Maringá, R. Afonso Pena 130, Zona 1, Cianorte 87200-000, PR, Brazil

* Correspondence: moisesjrbarbosa@gmail.com; Tel.: +55-42-991056347

Abstract: The world's population grows yearly, so increasing food production is necessary, to meet consumer demands. This production must be clean; thus, sustainable agriculture seems to represent a solution. However, social, economic, and environmental barriers impede the adoption of this practice. Therefore, this research identified these barriers, according to the sustainability triple-bottom line through a literature review, and analyzed which barriers are more influential and vulnerable to influences, using the Fuzzy DEMATEL method, as well as by considering the opinions of 30 mixed crop producers. As a result, eleven barriers were identified; and "technical knowledge and qualified workforce" was the most influential on not adopting sustainable agriculture. A multi-criteria model was provided and could be replicated in further research. Thus, sustainable practices are provided, to minimize the barriers' negative impacts and assist producers; highlighting investment and policies for training farmers to have the technical knowledge to practice sustainable agriculture. Theoretical implications were reviewed, such as an analysis of the barriers found in the literature and the lack of studies reporting on the difficulty of producers in adopting sustainable agriculture, as well as the practical implications of providing assistance and transferring knowledge, to eliminate these barriers, so that sustainable practices can be efficiently implemented.

Keywords: sustainable agriculture; multi-criteria model; fuzzy DEMATEL; sustainability; barriers

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1. Introduction

In 2050, the global population will reach 9.7 billion [1]; therefore, this greater number of people will demand more food, and food production will have to increase [2]. Consequently, conventional agricultural systems are increasingly being left behind, because their practice severely affects the quality of human life, water, and soil, causing the loss of biodiversity and compromising the characteristics of food over time [3–6]. They also lead to financial problems, because of the lack of control of producers, and social problems, due to the use of resources and practices that are dangerous to human health [7].

The purpose of sustainable agriculture is to meet this exponential demand for food, while reducing negative impacts on the environment, without disregarding the social (e.g., quality of life of every stakeholder) and economic (e.g., cost–benefit, profit, investment) dimensions of sustainability [8,9]. By using cleaner production, sustainable agriculture can expands its benefits, in order to improve the well-being of people and animals, optimizing the use of supplies and preserving the environment [9].

The transition from conventional to sustainable agriculture entails high costs and behavioral changes for companies and consumers [10,11], and these are considered barriers to practicing sustainable agriculture. These barriers influence consumption and affect people's food security, generating a more demanding population, product scarcity, and an unsustainable system [12].

There is a need for recognition of the importance of the criteria involved in studies on sustainable agriculture, especially those that deal with multiple cultures and with a systemic and comprehensive view [13].

Most current studies on sustainable agriculture are oriented towards only one pillar of sustainability. In this sense, Qureshi et al. [2] identified socioeconomic criteria and soil and climate conditions through a literature review; they also listed the main criteria using the Fuzzy TOPSIS method, collecting qualitative data. Skaf et al. [3] proposed biophysical and socioeconomic indicators to improve food production in Lebanon, using a multi-criteria system diagram. For their part, Girardin et al. [14] used the ÉLECTRE TRI method to assess environmental impacts using nine agroecological indicators.

Thus, the purpose of this study was to propose a multi-criteria model, to identify the main barriers that impede the adoption of sustainable agriculture using the Fuzzy DEMATEL method. The barriers were considered as criteria, to prioritize them individually and to become facilitators for applying sustainable agriculture.

Furthermore, there is an evident lack of studies reviewing the barriers to adopting sustainable agriculture in theory and practice, both in an international, and a Brazilian, context. This demonstrates the necessity of enabling the utilization of sustainable agriculture, due to the need for environmental, economic, and social criteria that demand cleaner food production, with lower environmental impacts, making production cleaner, and taking into account the three dimensions of sustainability.

This study was motivated by the gaps identified in the literature and aimed to achieve the identification of the barriers that impede the adoption of sustainable agriculture. In order to overcome this limitation, a multi-criteria model was proposed; this model identifies the environmental, economic, and social barriers that, when surpassed, will permit the use of sustainable agriculture. At the same time, this study highlights the main obstacles to the adoption of sustainable agriculture and outlines strategies to avoid them.

The main contributions of this study include identifying a gap in public policies favoring the adoption of sustainable agriculture practices, and this will allow government agencies to implement them. Moreover, in an academic context, this research contributes to the knowledge of which barriers are significant for promoting sustainable agriculture practices, bringing this knowledge to farms, and educating farmers for a proper transition to sustainable agriculture.

The structure of the remaining parts of the study is as follows: The second section presents the barriers identified in the literature review. The third is the methodology of the research. The fourth section contains the analysis of the results. The fifth presents the discussion of results and the means for adopting sustainable practices. Finally, the sixth section describes this research's theoretical and practical implications.

2. Theoretical Background

Regarding cleaner production, sustainable agriculture reconciles the social, economic, and environmental pillars, to ensure societies' well-being, preserve the environment by reducing waste, and decrease production costs [9]. Moreover, agriculture does not involve only workers, but also all the stakeholders involved in a process [10].

Thus, sustainable agriculture originated from the necessity to meet the current and future food demands, but by considering the sustainable triple-bottom line, which benefits society as a whole [15,16], promoting the harmony between the sustainability dimensions and effectiveness when adequately practiced.

However, the context and definitions of sustainable agriculture are vague, because they are often confused with organic agriculture, which is different. Thus, while it is not mandatory to find a definition for sustainable agriculture, a general overview would include factors that benefit everyone, leading to cleaner production, ensuring human and environmental well-being, and reducing exorbitant costs, while achieving the goal of guaranteeing families' food security, without exempting rural communities [17].

2.1. Social Dimension

The social dimension is related to the culture of societies and communities, referring to quality of life, which includes many topics, from physical well-being to people's education level. In this sense, it encompasses the consumers' search for safer food from sustainable producers [18].

Hence, it is imperative to use incentives for producers, because these incentives may influence the system as a whole [15], starting from the attention of government agencies and private entities [19].

The social barriers to sustainable agriculture identified in the literature are shown in Table 1.

Table 1. Barriers identified for the social dimension.

Barriers	Description	References
Culture (beliefs, attitudes, moral values, fear of change)	This criterion involves the willingness of producers to move from traditional to sustainable agriculture.	[7,20–25]
Workforce/techniques to adopt sustainable agriculture	For the adoption of sustainable agriculture, specific techniques must be adopted, and qualified labor is required.	[26,27]
Cooperation (networking)	Cooperation between producers facilitates the adoption of sustainable agriculture.	[5,9,28,29]
Incentives (policy, advertising, inspection)	The means of disseminating the benefits of sustainable agriculture and public policies that encourage its practice can motivate producers.	[4,5,10,16,24,28, 30–38]
Norms and laws to regulate and enforce the implementation of sustainable agriculture	Legislation that promotes sustainable agriculture is a factor that influences its implementation and practice.	[5,10,16,28,29, 31–33,36,37,39]

Human behavior is a important topic, since the change to new management systems in agriculture requires a change of thought and attitudes, which, in consequence, will change the practice of food production and agriculture as a whole [5]. Moreover, farmers lack interest in implementing sustainable agriculture, due to competition between them to increase their production and their ignorance about adopting sustainable agriculture practices [24].

The lack of availability of a workforce and its lack of qualifications are other barriers that increase production costs, due to the need to hire more workers or the introduction of improved techniques [36,37,40–42]. These factors are not limited to producers, but affect all the stakeholders involved in the productive process, from suppliers to those who support more sustainable production [33].

Networking and cooperation between producers is a recurring subject in the literature, but it is not practiced. Information and knowledge exchange is crucial, since this can be a way to increase sustainable production through knowledge and technology transfer [4,9,22,28,30,38].

2.2. Environmental Dimension

This dimension is related to the conservation of natural systems, ensuring the preservation of the environment by producers and society. Thus, the quantity and quality of resources used in production must be optimized, to reduce the environmental impact [18].

The barriers identified in the literature for the environmental dimension are presented in Table 2.

Table 2. Barriers identified for the environmental dimension.

Barriers	Description	References
Use of agrochemicals (insecticides, herbicides, pesticides)	Pesticides are commonly used worldwide, to combat pests that destroy production. Alternative products (e.g., green pesticides) can replace them; however, farmers do not use them, due to high costs and a lack of knowledge about their effectiveness.	[23,39,43,44]
Pest control (weeds)	Pests result from not using pesticides, even though other viable solutions exist.	[8,27,45–47]
Climate change/Soil control/Production management	Climate change and soil erosion cause losses of production. These factors, including high costs, impede sustainable agriculture.	[19,33,40,45,48,49]

The use of agrochemicals causes soil erosion due to ignorance about their use and final disposal. Therefore, producers cannot cultivate in eroded soil [5,11].

In addition to these biological factors, another barrier is climate change. However, this cannot be controlled by farmers, so they must have the proper knowledge, in order to be prepared to face climatic adversities [19].

2.3. Economic Dimension

The economic dimension is related to the financial viability of maintaining agriculture, providing continuity of production with the economic resources obtained by sustainable practices. Thus, this is intrinsically related to the social dimension, because it depends on capital to develop techniques that permit the interaction between society and producers [18].

The barriers identified in the literature for the economic dimension are presented in Table 3.

Table 3. Barriers identified for the economic dimension.

Barriers	Description	References
Low financial return/Cost benefit/Maintenance of cash flow	Profit from products from sustainable agriculture does not provide the expected return for producers.	[4,7,10,19,21,24–26,34,37,46,50,51]
Financial incentive	Financial incentives from public and private entities.	[37]
Lack of capital to invest in sustainable agriculture/Financial viability	Training the workforce and suitable materials to implement sustainable agriculture may have high initial costs.	[11,19,21,23,37–39,42,49]

Financial motivation is what motivates the adoption of sustainable practices [32]. Authors such as Guthman [39], Seufert et al. [50], Branca et al. [26], and Knutson et al. [19] argue that the costs of implementing, producing, and selling products from sustainable agriculture are high. Hence, the capital returned is low, discouraging producers from adopting these practices.

In order to raise awareness among producers about the importance of sustainable agriculture, Chowdhury et al. [11] promoted workshops on disaster management; they held meetings with the population, to communicate the benefits of clean production through sustainable agriculture.

Wigboldus et al. [4] and Knutson et al. [19] mentioned that a high level of productivity must be considered to maintain cash flow, so it is necessary to produce a lot to meet the profits of conventional agricultural practices, agreeing with Johnson et al. [51]. Moreover, Fasoula and Tokatlidis [52] explained that sustainable agriculture production systems have a low production capacity, making production almost unfeasible. Therefore, the only alternative to production is to create demand, reminding us that consumer behavior and culture must be changed. Thus, by having a demand to fill, more products are expected to be sold, maintaining the cash flow.

3. Methodology

This section describes the methods utilized in this study, including the workflow and the activities in each step. Figure 1 shows the steps for developing the literature review and the aims of each step. A detailed description of the procedure used for the bibliographic search, selection, and filtering of articles is provided, as well as the aspects considered during the complete analysis of the articles that formed the final portfolio.

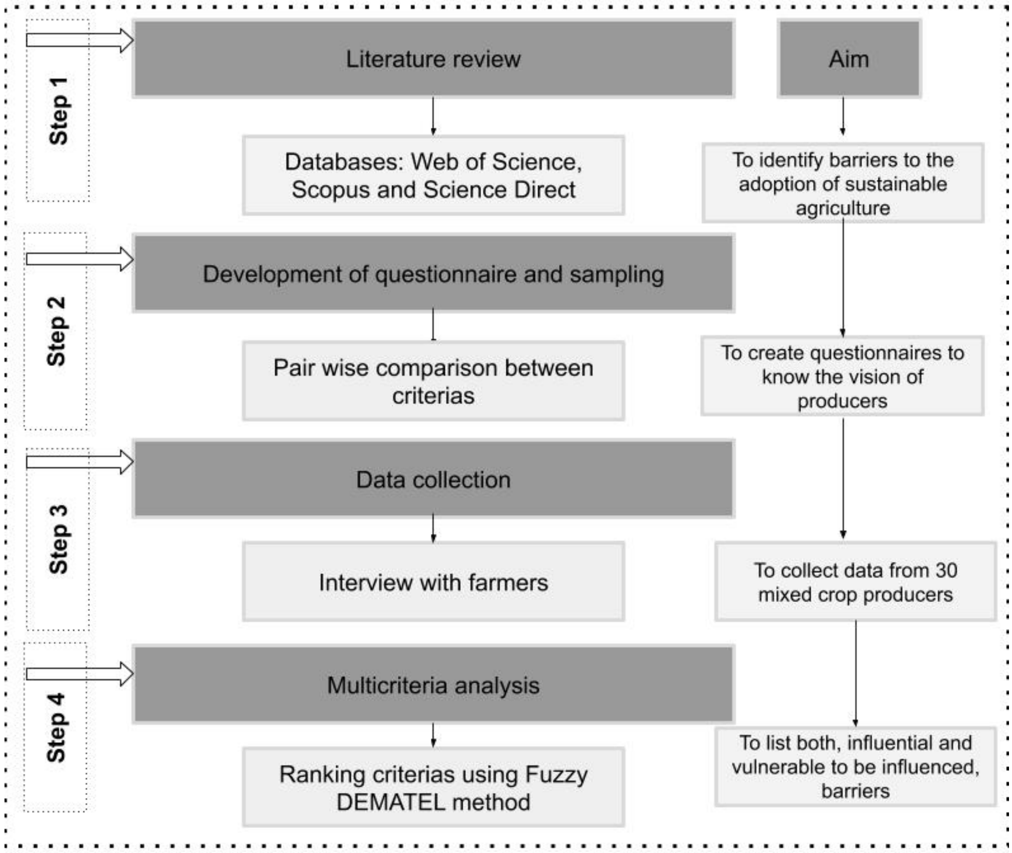

Figure 1. Methodological steps.

3.1. Literature Review

Searches in the Scopus, Web-of-Science, and Science Direct databases were conducted, to retrieve articles from 2007 to 2017. The keywords used were “barrier*”, “sustainable agriculture”, “multi criteria”, “sustainable agriculture practices”, and “implementation barrier*”. Figure 2 describes the procedure for literature selection.

After the database search, 210 articles were screened. After excluding duplicates and filtering by title, abstract, and keywords, 86 articles were excluded. The remaining 124 articles were selected using the Methodi Ordinatio, a systematic review method developed by Pagani et al. [53]. Thus, the final portfolio was formed of 38 articles.

3.2. Questionnaire Development

By reading the final portfolio, 11 barriers were identified, to form the questionnaire for the producers (farmers). Table 4 shows the barriers found in the literature for each sustainability dimension.

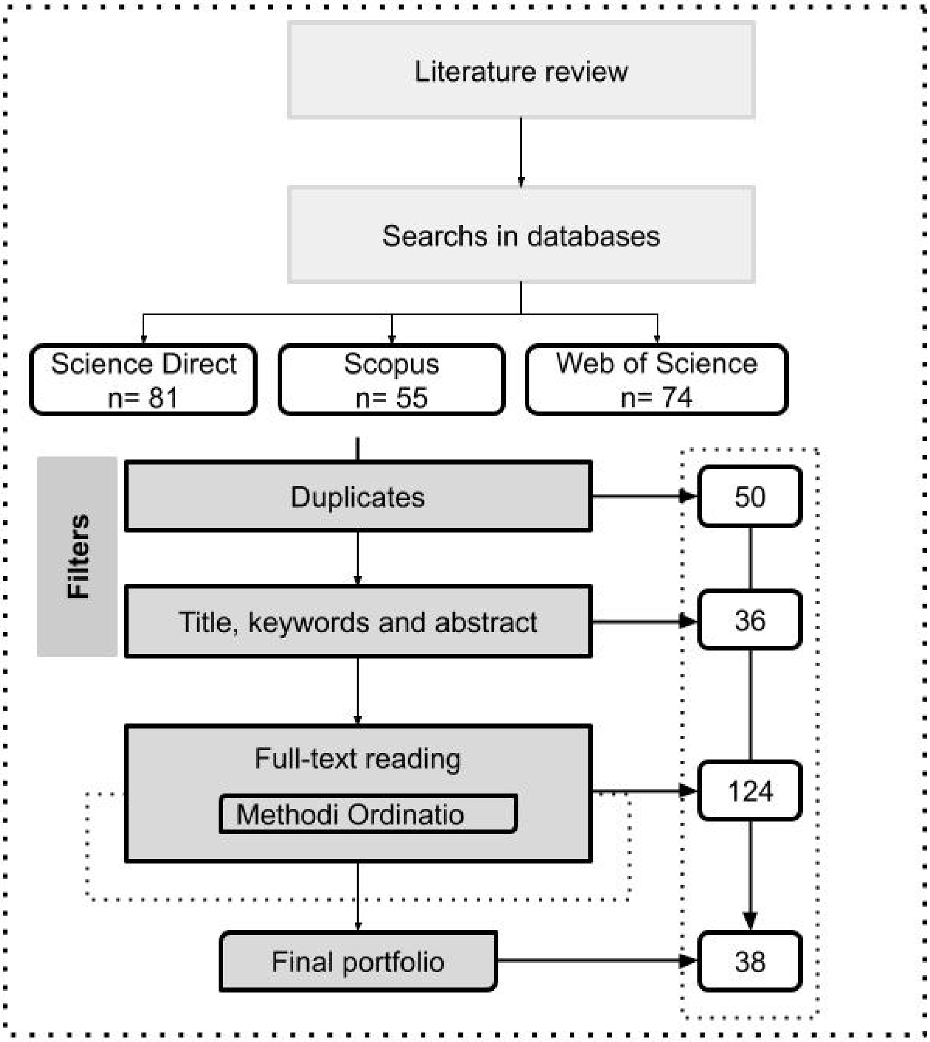

Figure 2. Literature selection.

Table 4. Barriers found in the literature.

Social	Environmental	Economic
• Culture (beliefs, attitudes, moral values, fear of change). • Workforce/techniques for adopting sustainable agriculture. • Cooperation (networking). • Incentives (policy, advertising, inspection). • Norms and laws to regulate and enforce the implementation of sustainable agriculture.	• Use of agrochemicals (insecticides, herbicides, pesticides). • Pest control (weeds). • Climate change/Soil control/Production management.	• Low financial return/Cost benefit/Maintenance of cash flow. • Financial incentives • Lack of capital to invest in sustainable agriculture/Financial viability.

Each barrier was compared on a peer-to-peer basis, to construct the questionnaire. As 11 barriers were identified in the literature, a total of 121 questions were asked to farmers. For each question, an issue was proposed (for example, "what is the influence between your culture and the low financial return to adopt sustainable agriculture?"). The verbal scale used is specified in Table 5. Triangular fuzzy numbers were used to provide a range of variation, because interviewee responses are not precise, creating a divergence. These numbers are a variation of the three numbers of the points described in Table 5.

Table 5. Linguistic scale.

Linguistic Terms	Influence Score	Triangular Fuzzy Numbers
No Influence (NO)	0	(0, 0, 0.3)
Low Influence (LI)	1	(0.3, 0.5, 0.6)
Moderate Influence (MI)	2	(0.6, 0.7, 0.8)
Very High Influence (VH)	3	(0.8, 0.9, 1.0)

3.3. Data Collection

To test the proposed method, an intentional sample of 75 farmers who were not practitioners of sustainable agriculture were selected. Nonetheless, only 30 farmers completed the research questionnaire, so they formed the final sample for analysis. This study was conducted in the Campos Gerais area, which is located in southeastern Paraná, Brazil. Thus, farmers from the following cities were interviewed: Antônio Olinto (n = 2), Carambeí (n = 2), Castro (n = 3), Contenda (n = 2), Congonhinhas (n = 2), Lapa (n = 2), Reserva (n = 2), São Mateus do Sul (n = 6), Palmeira (n = 2), and Porto Amazonas (n = 7). All the farmers produce mixed crops (more than one type of product), as such, maintaining a homogeneous sample.

The questionnaires were completed face-to-face by the farmers, to clarify any possible doubts related to the questions. In this regard, the research was carried out between December 2019 and February 2020, due to the numerous questions in the questionnaire. Since the model used is based on multi-criteria, i.e., the Fuzzy DEMATEL method, it was unnecessary to use an expressive sample.

3.4. Multi-Criteria Analysis

Barriers impeding sustainable agriculture adoption were described, considering their theoretical background. They were used in this study as criteria for the multi-criteria analysis, to prioritize each barrier, so that they can become facilitators for sustainable agriculture. The Fuzzy DEMATEL method was used to assess the criteria together, as a whole (e.g., peer-to-peer). This method allows the inclusion of a linguistic assessment, facilitating the analysis of farmers' responses.

3.4.1. DEMATEL Method

The DEMATEL method, developed by Fontela and Gabus [54], comprises digraphs representing the connection between criteria. Digraphs are graphs that represent the relations of each criterion of the model in a pairwise comparison [55]. These digraph representations function through numerical judgments made using a scale of importance [54,56].

There are four steps to achieve the goal of the DEMATEL method:

1. To build the cross-relationship matrix A = [aij]: A pairwise comparison between the defined criteria is specified in this matrix. The numbers i and j in the matrix aij represent the values of the rows and columns, respectively. Then, a numerical value is attributed to the judgment of the comparisons.
2. To build the direct relationship matrix D: The matrix D represents the relationship between the elements i and j of the matrix A by multiplying matrix S and matrix A.
3. To obtain the total relationship matrix F = D (I − D) − 1: matrix F is the result of multiplying matrix D, with subtraction of the inverse identity matrix (I) and the matrix D.
4. To obtain the normalized values of the total relationship: The last step of the process consists of normalizing the values obtained in matrix D. There are several ways to normalize a matrix, so this is at the researcher's discretion.

The DEMATEL method is helpful in assessing problems and finding the relationship between criteria, when there are clear and accurate values for the judgments. However, as explained previously, judgments are uncertain and not very accurate. Thus, the fuzzy theory linked to DEMATEL is applied to solve this problem [56].

3.4.2. Fuzzy DEMATEL method

Linguistic values are assigned and can be transformed into fuzzy numbers, mostly triangular ones; this is one of the assumptions of the Fuzzy DEMATEL method [55].

- First definition: comparison between pairs of criteria considering the numbers "0, 1, 2, and 3" as "without influence", "low influence", "high influence", and "very high influence", respectively.
- Second definition: The direct matrix Z, of magnitude nxn is calculated, using the previously defined values. This matrix is represented as:

$$Z = \left[Z_{ij}\right]_{nxn}, \tag{1}$$

where i and j are the lines of the matrix, z is the judgment of the decision-makers, and n is the magnitude of the matrix.

- Third definition: normalization of matrix Z. This transforms the numbers from 0 to 3 on a scale from 0 to 1. There are several normalization techniques, but Wu and Lee [55] suggest the multiplication of matrices.

$$X = s\ x\ Z, \tag{2}$$

where X is the normalized matrix and,

$$s = \frac{1}{max_{1 \le x \le n}\ \sum_{j=1}^{n} z_{ij}}, \tag{3}$$

- Fourth definition: a total ratio matrix is calculated (T)

$$T = X\ (1 - Z)^{-1}, \tag{4}$$

where I is an identity matrix.

- Fifth definition: the sum of the rows (D) and the sum of the columns (R) after calculating the matrix T.

$$T = t_{ij}, i, j = 1, 2, 3, \ldots, n,$$

$$D = \sum_{j=1}^{n} t_{ij} \tag{5}$$

$$R = \sum_{i=1}^{n} t_{ij} \tag{6}$$

5. Sixth definition: a causal diagram is obtained by adding and subtracting the matrices D and R.

$$(D + R,\ D - R), \tag{7}$$

In short, the authors used triangular Fuzzy numbers in the model, due to their versatility and convenience for research [55]. This research used fuzzy logic to elucidate the farmers' judgments.

4. Results and Findings

The application of the Fuzzy DEMATEL method followed the steps described in Section 3.4.2.

1. Identifying barriers: the barriers identified in the literature review are described in Section 2. Therefore, the barriers are "Culture" (C1), "Technical knowledge" (C2), "Co-operation" (C3), "Laws and standards" (C4), "Incentive" (C5), "Agrochemicals use" (C6), "Pests control" (C7), "Climate change and management" (C8), "Low financial return" (C9), "Lack of capital" (C10), and "Financial incentive" (C11).
2. Judgment of experts (farmers' opinion) on the relationship between barriers: In this step, an evaluation matrix using pair-wise comparison (Table 6) was obtained.

Table 6. Linguistic judgment (average).

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	NO	VH	VH	VH	LI	VH	VH	VH	VH	VH	VH
C2	VH	NO	LI	LI	VH	VH	VH	VH	LI	LI	VH
C3	VH	VH	NO	LI	LI	LI	VH	VH	VH	LI	VH
C4	LI	VH	VH	NO	LI	LI	VH	VH	VH	LI	VH
C5	VH	VH	VH	VH	NO	VH	VH	VH	VH	VH	VH
C6	LI	VH	VH	VH	VH	NO	VH	VH	VH	LI	VH
C7	VH	VH	VH	LI	LI	LI	NO	VH	LI	VH	LI
C8	VH	VH	VH	VH	VH	VH	VH	NO	LI	LI	VH
C9	VH	VH	LI	LI	LI	VH	VH	LI	NO	LI	VH
C10	LI	VH	VH	LI	LI	VH	VH	LI	LI	NO	VH
C11	LI	LI	LI	LI	LI	VH	VH	LI	LI	VH	NO

3. Calculating the direct relation matrix: It was necessary to standardize the initial matrix using the Formulas (1)–(3) (Table 7). First, the linguistic judgments (Table 6) were ordered on a number scale. The fuzzy triangular numbers were not utilized in the matrix, but the influence score (Table 5) and the fuzzy numbers, as previously mentioned, were used to facilitate evaluation of the farmers' judgments.

Table 7. Normalized matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	0.000	0.105	0.089	0.089	0.071	0.089	0.129	0.123	0.094	0.094	0.089
C2	0.100	0.000	0.076	0.073	0.084	0.087	0.118	0.105	0.092	0.068	0.087
C3	0.089	0.097	0.000	0.066	0.068	0.076	0.115	0.105	0.081	0.076	0.084
C4	0.073	0.089	0.094	0.000	0.071	0.076	0.081	0.089	0.081	0.071	0.081
C5	0.092	0.100	0.097	0.081	0.000	0.079	0.105	0.102	0.089	0.081	0.087
C6	0.081	0.089	0.079	0.081	0.087	0.000	0.108	0.102	0.084	0.076	0.081
C7	0.076	0.094	0.079	0.076	0.076	0.071	0.000	0.087	0.073	0.081	0.076
C8	0.079	0.097	0.081	0.084	0.092	0.079	0.097	0.000	0.071	0.076	0.079
C9	0.084	0.094	0.073	0.073	0.071	0.076	0.084	0.068	0.000	0.076	0.089
C10	0.071	0.097	0.084	0.073	0.076	0.073	0.084	0.068	0.100	0.000	0.094
C11	0.066	0.073	0.068	0.071	0.079	0.060	0.079	0.066	0.087	0.079	0.000

4. Calculating the total ratio matrix: The total DEMATEL relation matrix (Table 8) was obtained using Formula (4). This is the final matrix and in helped calculating the next step.

The average in Table 8 is 0.485, which was used as a parameter to assess the connections between barriers. If the value of a barrier is bigger than this reference value, it means that the barrier influences one of the others. Thus, in Table 8, barrier C1 is connected to all other barriers, except itself, and belongs to the cause group, which means that producers' culture is the barrier having the greatest influence on all others, because there is no other barrier that influences all the others. Hence, a change in culture is imperative for a transition from traditional to sustainable production systems.

Table 8. Total DEMATEL relation matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	0.457	0.616	0.542	0.516	0.505	0.515	0.669	0.620	0.562	0.526	0.556
C2	0.513	0.481	0.495	0.470	0.482	0.479	0.618	0.566	0.524	0.470	0.517
C3	0.490	0.554	0.410	0.449	0.455	0.457	0.598	0.550	0.500	0.463	0.500
C4	0.454	0.522	0.475	0.366	0.436	0.436	0.543	0.512	0.477	0.437	0.475
C5	0.517	0.584	0.524	0.486	0.414	0.483	0.619	0.576	0.532	0.491	0.528
C6	0.487	0.552	0.488	0.467	0.475	0.391	0.597	0.553	0.507	0.467	0.503
C7	0.449	0.518	0.454	0.430	0.433	0.425	0.458	0.502	0.463	0.439	0.463
C8	0.471	0.543	0.476	0.456	0.466	0.450	0.571	0.445	0.481	0.454	0.486
C9	0.455	0.517	0.449	0.427	0.428	0.429	0.535	0.486	0.394	0.434	0.474
C10	0.457	0.533	0.470	0.439	0.445	0.438	0.550	0.499	0.498	0.375	0.492
C11	0.411	0.466	0.415	0.398	0.407	0.388	0.495	0.451	0.444	0.409	0.363

After barrier C1, the second most influential barrier is C2 ("Technical knowledge"), which influences all the other barriers, except C11 and itself. This result suggests that a lack of technical knowledge impedes sustainable practices from being put into practice by the farmers interviewed. However, C2 is also the most influenced barrier, because the same nine barriers it influences have an influence on it.

Three other barriers influence at least five others, namely: Barrier C3 ("Cooperation") influences the barriers C1, C2, C7, C8, C9, and C11; barrier C6 ("Agrochemical use") influences the barriers C1, C2, C3, C7, C8, C9, and C11; and barrier C10 ("Lack of capital") influences the barriers C2, C7, C8, C9, and C11. These results evidence the importance of cooperating and investing in cooperation among farmers, and show the relevance of knowledge about the management of the agrochemicals available to every farmer, and the lack of capital to invest in sustainable practices, which are significant barriers inhibiting the adoption of sustainable agriculture.

5. Obtaining the sum and subtraction of rows and columns: The sum of rows (D) and columns (R) was calculated using the Formulas (5) and (6), respectively. Table 9 shows the results. Thus, a barrier is a cause when $D - R$ is positive; meanwhile, it is an effect when $D - R$ is negative. The cause criteria (considered as barriers and not criteria in this study) influence the effect criteria. In other words, the causes are the criteria that prevent the effects from being practiced [57].

Table 9. Cause and effect groups.

Barrier	D	R	D + R	D − R	Cause/Effect
C1	6.08	5.15	11.24	0.93	Cause
C2	5.62	5.88	11.50	−0.27	Effect
C3	5.43	5.19	10.62	0.23	Cause
C4	5.13	4.90	10.04	0.23	Cause
C5	5.75	4.94	10.70	0.81	Cause
C6	5.49	4.88	10.38	0.60	Cause
C7	5.03	6.25	11.29	−1.22	Effect
C8	5.30	5.76	11.06	−0.46	Effect
C9	5.03	5.38	10.41	−0.35	Effect
C10	5.20	4.97	10.16	0.23	Cause
C11	4.65	5.36	10.01	−0.71	Effect

To interpret Table 9, when $D - R$ is negative, this means that the barrier is influenced by the others. On the contrary, when D-R is positive, the barrier affects or contributes to the existence of the other barriers. In this sense, barriers C2, C7, C8, C9, and C11 have a negative result; thus, these barriers are influenced by others.

On the other hand, barriers C1, C3, C4, C5, C6, and C10 are cause barriers, which means that they significantly influence the putting into practice of the effect barriers. Therefore, the most effort has to be addressed to resolving the cause barriers because, in this study, they interfere with overcoming the other barriers. Hence, they slow down the transition from conventional to sustainable agriculture.

There are six barriers in the cause group; while in the effect group, there are five. This result demonstrates that more barriers have an influence the adoption of sustainable agriculture than have an effect on the other barriers.

6. Diagramming: As seen in Table 9, a causal and effect diagram was obtained, where the horizontal axis is D + R, and the vertical one is D − R. This step shows the cause and effect barriers found through the judgments (Figure 3).

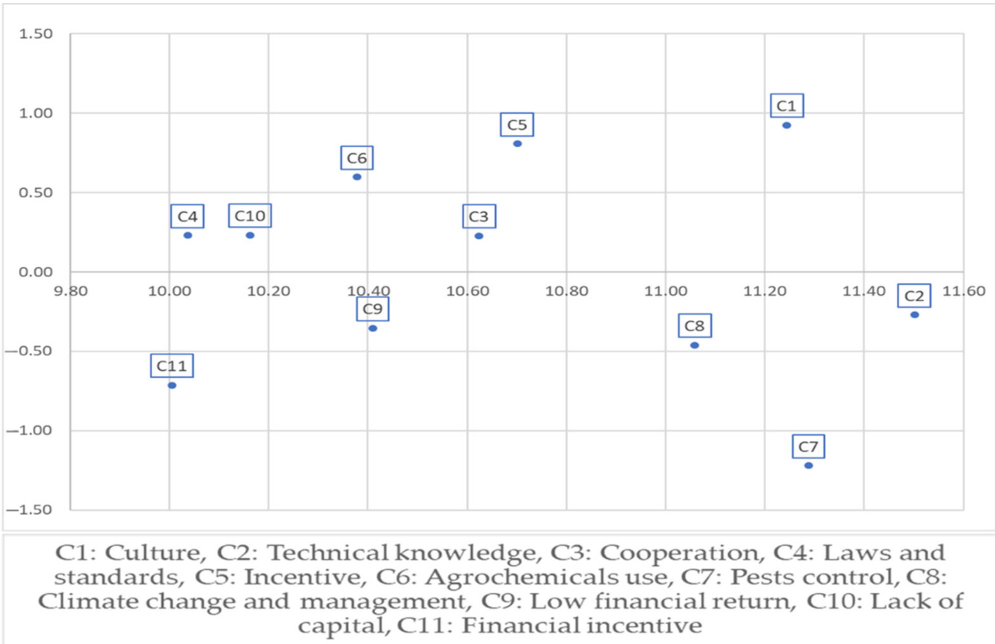

Figure 3. Cause and effect diagram.

The cause and effect diagram (Figure 3) may help public policymakers determine which barriers significantly impact the others. The barriers found to be causes are the ones that most influence the others; on the contrary, the effect barriers are those most affected by the others [58,59]. As an example, barrier C1 ("Culture") is a cause for barrier C2 ("Technical knowledge") not being put into practice, so (the lack of) technical knowledge is an effect of the culture of farmers.

In this study, as a pairwise comparison was conducted between all barriers, every cause barrier influences all the effect barriers. According to Falatoonitoosi et al. [57], it is necessary to invest in the causes, and, consequently, the effect barriers will be enhanced.

In the cause group, there are six barriers: (C4), (C10), (C6), (C3), (C5), and (C1). Meanwhile, for the effect group, there are five barriers: (C11), (C9), (C8), (C7), and (C2). Regarding Figure 1, the most critical barriers belong to the cause group, because they influence the effect group; thus, it is important to give them proper consideration. It is necessary to focus on the cause barrier, in the face of the influences that they have on the effect barrier [54].

The results showed that, of the five social barriers, four are causes (C1, C3, C4, and C5), with only barrier C2 being an effect. In the environmental dimension, of the three barriers, only one is a cause (C6); and in the economic dimension, of the three barriers, only one is a cause (C10). This suggests that social factors are strongly related to the adoption of sustainable practices of the farmers who participated in this survey.

The barrier with the highest causal value (D + R) is C2; thus, it is crucial to give more importance to this barrier in the treatment and direction of improvements for implementing sustainable agriculture. Hence, technical knowledge/qualified workforce is the most influential barrier to the adoption of sustainable agriculture, according to the interviewed farmers.

The lowest value obtained in (D − R) was for pest control (C7), which means it is the most influenced barrier. This barrier can be considered the most vulnerable and the most difficult to put into practice. The barrier of pest control (C7) is the most vulnerable to being influenced, due to farmers' lack of knowledge about implementing sustainable practices. Thus, pests directly affect farmers' productivity, so a lack of knowledge about how to control them is an obstacle to adopting sustainable agriculture.

Moreover, Financial incentives (C11) received the lowest value (D − R), which means that public policies to financially encourage farmers to adopt sustainable agriculture could function as a facilitator. The social barriers of Laws and standards (C4) and Inspection (C5) were placed in the cause group, which directly affects barrier C11 and provides financial incentives to farmers.

5. Discussion

The results demonstrated that training encourages farmers to implement sustainable practices and motivates them to disseminate knowledge to their peers, promoting knowledge transfer and improving relations within society.

According to Siebrecht [60], personal obstacles (which in this study were considered social barriers) focus on the farmers' culture and willingness to change. In contrast, practical obstacles are bureaucratic issues, such as a lack of support, cost, recognition, and uncertainties. In this sense, sustainable systems require farms to have a highly specialized advisor [61].

This specialized advisor may give knowledge to farmers, to make them aware of which incentives are available and which techniques are the most suitable for them in adopting sustainable agriculture. A literature review [62] demonstrated that public and private entities from many countries grant financial incentives for employing sustainable agriculture practices. In this study, the results showed that a lack of incentives (C5) inhibits the adoption of such practices. Possibly, this is closely related to the ignorance of those incentives.

The search for technical knowledge to adopt sustainable practices is a barrier widely discussed in the literature, due to either a lack of financial capital [42] or access to knowledge [16], or even the complexity and time demanded to adopt these practices [63].

The results showed that barrier C2 ("Technical knowledge") is the most influential. In the opinion of Goldberger et al. [34], lack of knowledge and techniques for sustainable agriculture is not limited to producers, but is shared by everyone involved in the process, from suppliers to entities supporting sustainable agriculture. Thus, the transition process from conventional to sustainable agriculture involves various stakeholders, not only farmers. In this sense, sensitizing and raising awareness about the benefits of sustainable agriculture is necessary, in order to adopt the changes demanded for this transition.

Nevertheless, the ignorance about adopting technologies on farms impedes the reduction of costs. These technologies include the use of robots and drones, which reduce workforce costs, help with climatic prevision, and increase competitiveness in agricultural systems [64].

Barrier C7 ("Pest control") is the most influenced by the others. This barrier represents the knowledge of the interviewed farmers on the management of crops to avoid damages due to pests. Thus, accurate knowledge is necessary to adopt more efficient practices and to control pests effectively [27]. This statement implies the necessity of having the appropriate technical knowledge to overcome this barrier, reflecting our results that found barrier C2 ("Technical knowledge") to be the most influential.

To facilitate pest control, Chadwick et al. [41] used organic products to control pests, such as the use of manure in plantations; thus, avoiding unsustainable practices, reducing the use of unsustainable products, and increasing productivity. These authors also pointed out that the use of organic fertilizers did not achieve its full potential, maybe due to the producers' ignorance of the efficiency of these products in combating pests. In this regard, precision agriculture uses tools and technologies to increase resource utilization and maximize production [65]; as such, it may be an ally in reducing the use of pesticides, by reducing their application and preserving the use of water [66].

The change to organic pesticides involves responding to consumer demands [39]. It involves a change in the culture and behavior of the market. This study showed that barrier C6 ("Agrochemical use") significantly influences several other barriers, so farmers must be aware and use alternative (eco-friendly) products to control pests.

Guthman [39] reported that farmers were restricting the use of conventional pesticides, because of the negative consequences that these products entail for the environment; thus, gradually, they were trying to minimize their use. These authors also mentioned that farmers were moving from conventional to organic (sustainable) practices, due to restrictions imposed by the local government. This shows the relation between the knowledge needed to adopt new practices in line with sustainable agriculture, the ease of controlling pests, and the influence of the government in promoting sustainability, with the formulation of policies and their diffusion to farmers.

Public policies are intertwined with the environmental dimension, to economically support and establish the correct use of conventional agrochemicals, which are not allowed in sustainable agriculture [11,39,41], because they pollute the environment and are highly dangerous to human health. As an alternative, Chowdhury et al. [11] proposed using organic pesticides made from plants, which do not harm humans or the environment.

The second most influenced barrier is C11 (Financial incentive), meaning that farmers have no government support or other incentives for adopting sustainable practices. Weiss and Bonvillian [36] argued that the lack of interest from public entities is related to the threat that these entities can suffer when adopting new technologies that benefit producers. According to Brown [28], it is imperative to establish partnerships between sustainable agriculture practitioners and public and private entities, mainly with the government, rural entities, and activist networks.

This study showed that the formulation of public policies is relevant to putting into practice sustainable agriculture. In this regard, De Olde et al. [30] explained the necessity of formulating public policies that support farmers moving to sustainable agriculture. They also pointed out that there must be a consensus between public agencies and producers on the existing rules of the current production system [29], aiming to reduce barriers to implementing sustainable agriculture. Isgren [32] argued that political interest must be in line with sustainable agriculture in order to be effective, offering financial support and benefits for sustainable producers. Other research revealed that access to the Internet, in addition to public policies, promotes the implementation of precision agriculture on farms [67].

A lack of capital (C10) was one of the most influential barriers. It impedes the adoption of sustainable practices in agriculture, as well as the investment in knowledge and the search for new technologies in agriculture. Even if sustainable agriculture is a system that brings benefits to all the actors involved, the high costs of its implementation prevent its adoption [37].

As a result of this study, C1 ("Culture") is an effect barrier; this implies a large influence on the adoption of sustainable agriculture. Hence, to raise awareness among producers about the importance of sustainable agriculture, Chowdhury et al. [11] promoted workshops and courses on disaster management. They held meetings with the population to explain the benefits of clean production for sustainable agriculture.

Promoting the transition from conventional to sustainable agriculture should start with public entities, and connecting small farmers and political powers [4]. As the results of this study indicate, there is a need for public entities to develop policies to encourage the adoption of new practices in sustainable agriculture; this could promote knowledge transfer and relations among farmers. Thus, cooperation is formed, and sustainability is practiced.

In this sense, Isgren [32] reports that political interests must be in place to be effective, as they are adverse and linked to financial aspects. Therefore, together, they can bring benefits to sustainable agricultural producers.

The rational use of water and natural fertilizer is highlighted to preserve the environment [68]. Another way to achieve sustainable agriculture is to invest in no-till crops, because they are not damaging to the soil. Marques et al. [23] reported confusion among farmers about no-till crops and soil erosion; for Witmer et al. [69], no-tillage is a form of sustainable agriculture, so it entails soil conservation, and if it is added to a correct use of water resources, the benefits are more significant.

However, since a definition of sustainable agriculture has not been achieved, it is difficult to put it into practice, which limits the proposition of solutions. For example, there is a need to consider the particularities of each farm and the complex system of socioeconomic and environmental variables that influence its adoption [60]. These results from previous studies are in line with the barriers found in this study, such as the cooperation or networking among farmers and the lack of technical knowledge.

It is necessary to apply regional solutions in order to implement sustainable agriculture globally; these practices focus on reducing food waste and recycling the nutrients used in production [70].

6. Conclusions

After an extensive literature review, 11 barriers to sustainable agriculture were revealed through the application of a multi-criteria model. They impede the adoption of sustainable practices in agricultural farms. Among these barriers, the more influential were the lack of specialized workforce and technical knowledge, due to the ignorance about this topic, caused by a lack of public incentives and a poor engagement of farmers; which is reflected in practice. However, this also represents an opportunity to make efforts to fulfill the demand for the adoption of sustainable practices.

Using the Fuzzy DEMATEL method provided an easy understanding of farmers, to obtain their judgments, and a straightforward treatment of data, to solve the research problem. The results suggest that public agencies and academics must implement norms and perform research, to allow farmers to implement sustainable practices.

The main results focus on promoting technical knowledge to farmers on how to implement sustainable agriculture, the need for public policies to promote agricultural sustainability, cooperation networks that are willing to share practices, and financial incentives from the government. In summary, our research shows that a lack of knowledge is related to all other barriers. The solution lies in creating cooperation networks, allowing public and private bodies to create laws and regulations that help the sharing of information, so that farmers understand the benefits of sustainable agriculture. A lack of knowledge leads farmers to be unaware that there are financial, fiscal, and environmental incentives for promoting sustainable practices.

If the government and farmers invest in training, sustainable agriculture could be implemented quickly, because this barrier seems to influence all the others. Moreover, other practices already discussed in the literature also encourage sustainable agriculture, such as water reuse [71], precision agriculture combined with access to the Internet [67], and the development of public policies to promote sustainable agriculture [72].

Nevertheless, this study has some limitations. First, the barriers were taken from the literature, and although the literature exposes real problems, it may not be consistent with the context analyzed. In this sense, another limitation is the study area, because of the consideration of only one region in Brazil. Another limitation was the number of respondents to the questionnaire and the consideration of only mixed crop producers; thus, the barriers for single crop producers might differ. Moreover, the size of the farms and the quantity of productions could have been factors that influenced the results.

Thus, future research may use the proposed model in different countries and production cultures. Moreover, other multi-criteria models or statistical techniques could also be used to identify barriers. In addition, consideration of the factors that may have intervened in the results is suggested, in future studies.

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