

Review

How Can Sustainable Agriculture Increase Climate Resilience? A Systematic Review

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Abstract: In the last few decades, a great deal has been written on the use of sustainable agriculture to improve the resilience of ecosystem services to climate change. However, no tangible and systematic evidence exists on how this agriculture would participate in alleviating impacts on vulnerable rural communities. This paper provides a narrative systematic review (SR) integrated with a bibliometric analysis and a concept network analysis to determine how, in this changing climate, sustainable agriculture can increase the resilience of agrosystems. Our search ranged from the date of the first relevant article until the end of 2018. The results generated demonstrated the following: (a) Only single practices and methods have been studied to assess the impacts on single ecosystem services; (b) Soil quality and health are considered a key indicator of sustainable agriculture; (c) Although the assessed practices and methods were shown to improve the biodiversity of agrosystems, which makes them more resilient to extreme climate events, we are still far from developing interdisciplinary and multidimensional agriculture that integrates all management aspects and generates a full range of ecosystem services. In conclusion, this study addressed the following recommendations for the scientific community and policymakers to orient future research strategies and efforts: (a) The integration of all agrosystem services into sustainable management using an ecosystem-based approach on a life-cycle basis using the Life Cycle Assessment (LCA) method; (b) Improving the scientific understanding of traditional knowledge to facilitate greater synergy and further integration; (c) The unification of assessment methods and indicators for the quantification of impacts; (d) The creation of a platform to share, monitor, screen, and approve assessments and evaluations of sustainable agriculture by region.

Keywords: systematic review; sustainable agriculture; climate change; resilience; agrosystems

1. Introduction

Human-induced climate change, as defined by the WMO [1], was suspected in the early 19th century, but the scientific community did not form a strong and unified opinion about it until the second half of the century when a global consensus began to take a form [2].

Climate change is already having significant global impacts on weather, especially on the frequency, the intensity, the duration, and the spatial extent of extreme events [3]. While these changes are expected to produce some possible benefits (not well documented) to certain local areas, especially in terms of water availability and agriculture [2,4,5], many scientists argue that their costs may counteract these benefits, endangering various aspects of life on Earth (i.e., social, ecological, and physical systems) [6,7]. Consequently, the sustainability of life on Earth is jeopardized by a) the worsening of the economic

dimension and increased poverty, b) a compromised social dimension due to food insecurity, migration, and human health risks, and c) the deteriorating natural environment and ecosystems.

According to the International Panel for Climate Change (IPCC) [3], the effects of climate change will vary in intensity and time, depending on the region and the type of events. For certain extremes (e.g., floods and droughts), regional projections are more reliable and indicate larger changes than global projections. On the other hand, the risks of climate effects also have spatial and temporal patterns of exposure and vulnerability. Thus, understanding and effectively managing climate-related risks for adaptation largely depends on the potential of regional and local communities to mitigate and adapt, which is disproportionate to the lack of advantages among rural communities [8,9]. In 2014, the latter represented 46% of the world's population [10], with a high urbanisation rate in the Americas and Europe, while Africa (60% rural population) and Asia (52% rural population) are mostly highly vulnerable rural communities [11] that depend for their livelihoods on a 'climate-related risky' type of agriculture, which is expected to be severely affected by climate change [2].

To avoid the risks related to climate change, which could be devastating for vulnerable rural communities, and to meet the food demands of an increasing world population that is expected to reach 10 billion by 2050 [10], the International Panel for Climate Change (IPCC) has repeatedly expressed the importance of using sustainable agriculture to adapt to climate adversity and build the resilience of ecosystems so that they can continue to generate services for our societies [2,12–14]. Other authors have also illustrated the close alignment between sustainable agriculture, ecosystem services, and climate adaptation (e.g., [15,16]).

This correlation began to emerge within the scientific community after the WCED (World Commission on Environment and Development) report, known as the Brundtland Report, was released in 1987, parallel to the notion of sustainable development. Yet, this concept has created much ambiguity as to the sustainable development concept [17–19]. Additionally, the resilience concept, which incorporates both general and specific factors and which was originally used in psychology and material sciences, has been increasingly accepted in other disciplines to describe complex socio-ecological systems undergoing continuous mutation [20].

In this research, agrosystem resilience is inspired by Folke et al. [21] and refers to the capacity of agricultural systems to respond to social, economic, and environmental changes via structural reorganization, to offset the impacts of future changes, and to engage in new opportunities, to guarantee continuity for agrosystems. For sustainable agriculture, we adopt the definition given by the Organization for Economic Co-operation and Development (OECD) based on the Brundtland report [22], which states that "sustainable agriculture is agricultural production that is economically viable and does not degrade the environment over the long run" [23]. This type of agriculture has environmental, social, and economic dimensions that must be considered together. According to Ikerd [24], sustainable agriculture must "use farming systems that conserve resources, protect the environment, produce efficiently, compete commercially and enhance the quality of life for farmers and society overall". This mainly requires the implementation of sustainable practices, (the exact definitions of agroecological agriculture, conservation agriculture, and other sustainable practices are reported in the Results section), such as agroecological processes and principles and conservation agriculture, which position agricultural systems at the interface of natural and social systems [25].

Even though the number of recommendations on the use of sustainable agriculture to improve ecosystem services for better resilience to climate change is increasing, no tangible and systematic evidence exists on how this process would participate in alleviating the impacts on vulnerable rural communities. Hence, to remove any scientific ambiguity, based on the definition stated previously, this research will review the efforts made and the results achieved from the date of the first relevant publication (no lower boundary) until the end of 2018, to define an agricultural model that finds a holistic balance between the environment economy and society to understand how, in this changing climate, sustainable agriculture can build the resilience of natural and physical systems. The recommendations highlight the areas where evidence is lacking to address strategic research needs.

2. Material and Methods

Sustainable agriculture is intended to increase the resilience of agrosystems to allow them to keep generating services even during extreme climate events [26,27]. To address this argument, this research has integrated multiple methods employing the ecosystem services framework adopted by the Millennium Ecosystem Assessment (MA), as described in the following sections.

2.1. Bibliometric Analysis

The Systematic Review (SR) protocol, which will be described in the next section (Section 2.3), has been adopted for this analysis. The retrieved literature was exported into Mendeley (reference manager software). All the duplicate and spurious results were eliminated, and, before the relevance assessment, the bibliography was analyzed according to a list of indicators, including the source and type of documents, the year of publication, and the subject area. Bibliometric methods are now available in many scientific research methodologies [28] because of the value they add in data interpretation.

2.2. Concept Network Analysis

This research also integrated a network analysis [29,30], which has proven to be effective in text analysis. This method is based on a probabilistic assessment of word co-occurrence with relative word position, considering the structural properties of the text itself. This method graphically represents the network relationships between different keywords using qualitative and quantitative metrics [31].

The analysis was developed through different steps [31], beginning with the submission of the text to InfraNodus (<https://infranodus.com/>), a Web-based analytical engine. First, the text was prepared by removing frequent words to bind it together. The Krovetz Stemmer algorithm then stems the remaining words to reduce their redundancy and complexity [32,33] and further normalizes the text before encoding. InfraNodus converts the submitted text into a network by performing a two-pass analysis. The graphical network can be used to represent the data visually using various software, such as Gephi for visualization and exploration [34].

2.3. Systematic Review Protocol

The Systematic Review (SR) methodology is described in the systematic review guidelines developed by the Collaboration for Environmental Evidence as a way to inform practice and policy in environmental management [35]. The formulation of the primary question is the most important aspect in an SR, which (according to Pullin et al. [36]) requires a compromise between different approaches: a holistic approach and a reductionist one. Therefore, the primary research question that covers all the aspects of sustainable agriculture and its role in building resilience to climate change is the following:

“How can Sustainable Agriculture Increase Resilience to Climate Change?”

Following the systematic review conventions, this research question is broken down, as required by the Collaboration for Environmental Evidence (CEE) guidelines, into definable elements known as the PICO/PECO: (a) the population (sustainable agriculture from the date of the first relevant publication onwards; however, this concept began to emerge in the 80s [37], so no location restrictions will be set because this concept could be applied to any agricultural system); (b) interventions (interventions in the expansion of sustainable agriculture have been done since the 1980s, facilitating changes in natural and physical systems); (c) comparators (sustainable agriculture versus conventional agriculture (Conventional agricultural systems are intensive mono-systems based on high input use.)); and (d) outcomes (resiliency parameters to climate change defined as the quantitative/qualitative changes in ecosystem services). The search terms used for this review were used to formulate different search keywords. A trial was undertaken on 18 September 2018 to refine the search terms using the Scopus database. One keyword was adopted for the systematic review after a discussion of the trial results with the co-authors and experts (Table 1). This keyword was used to search the different scientific database sources, as well as the grey literature, which included only English publications.

All literature retrieved in the first step was screened for relevance according to the previously established inclusion criteria, which included (a) relevant subjects (any country, any spatial scale); (b) the type of intervention (sustainable management); (c) comparators (which compare the benefits and/or impacts on natural and physical systems); (d) methods (modeling, experiments, and surveys); (e) outcomes (studies that consider the benefits/impacts on terrestrial and aquatic ecosystems, hydrology and water resource management, the natural environment, food and fiber production and security, immigration, poverty, human health, human infrastructure, and economic loss).

Table 1. Summary of the search terms used for the question formulation and search keyword structuring.

Population	Intervention	Comparator	Outcomes
Sustainable Agriculture	Production	Impacts	Quantitative/qualitative changes in terrestrial and aquatic ecosystems
	Expansion	Benefits	Hydrology and water resource management natural environment Food and fiber production and security Immigration Poverty Human health Human infrastructure Economic loss
Keyword	"sustainable agriculture" AND "resilience" AND "climate change" AND (agroecol OR ecosystem OR conservation OR integrat OR rotation OR diversification OR organic OR water OR environment OR food OR fiber OR immigration OR poverty OR health OR infrastructure OR income)		
Number of Hits on Topic	2172		

3. Results

The 3563 records gathered from the scientific databases, and the grey literature, were retrieved using the Mendeley software (Table 2). After cleaning and removing duplicates, a total of 2671 documents remained, and a bibliographic analysis was carried out, followed by first filtering based on the title of the literature, followed by using the Network analysis method to map the titles and keywords of all documents that passed the filtering process. This systematic review approach consisted of reviewing the full-text of the filtered documents based on the inclusion criteria and the 'outcome' search terms. This process was carefully and transparently documented and has been schematically summarized for simplification according to the following diagram (Figure 1).

Table 2. Sources of the literature retrieved by the database and the corresponding number of records.

Database	Number of Records	Notes
Scopus	2351	All records were retrieved
Science Direct	854	All records were retrieved
ISI Web of Science	203	All records were retrieved
DOAJ	13	All records were retrieved
Grey Literature * (Google, Websites, etc.)	142	The first 50 records were retrieved
Total	3563	

* The first 50 records were retrieved because the following were assessed and agreed to be repetitive or irrelevant.

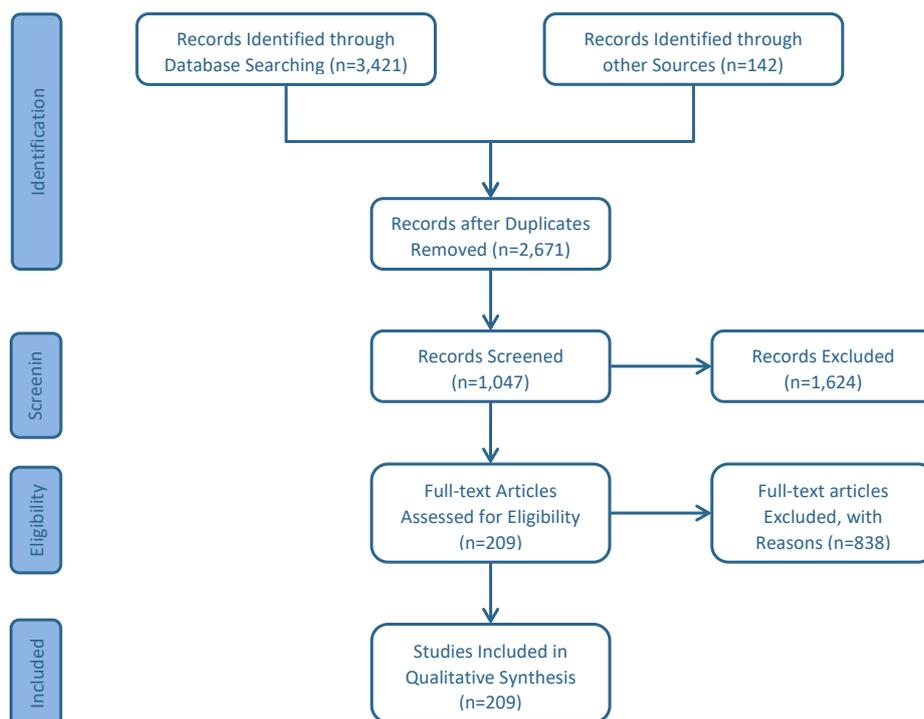


Figure 1. Flow Diagram of the research process (after Moher [38]).

3.1. Bibliometric Analysis

The date of the first relevant publication capturing the question subject to this research was the mid-nineties, even though sustainability as a concept was first discussed in the eighties. This analysis shows that most of the documents feature restricted access, with a slight increase in open-access publications from 2010 onward (Figure 2). The United States offers the most publications, with Australia, China, and many European countries among the top 10 countries that published 56.5% of the relevant research during our study’s timeframe (Figure 3). Three major subject areas were identified, for which 68.9% of the documents retrieved are classified, including environmental science, agricultural and biological sciences, and social sciences. Minor subject areas, according to the analysis, include Earth and planetary science, engineering, chemistry, and others (Figure 4). Finally, 61.8% of the documents retrieved were research articles, and 14.8% were review papers, while books, book chapters, and conference papers were fewer in number (Figure 5).

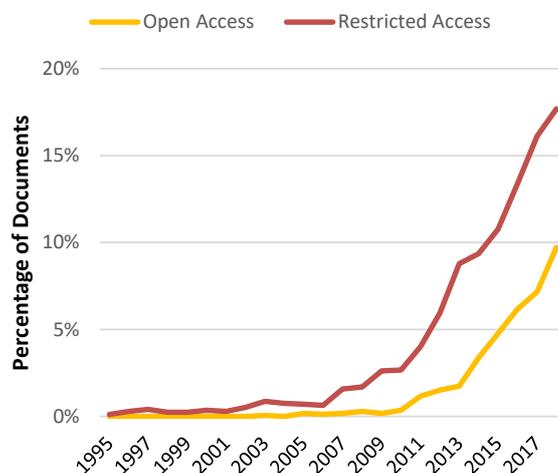


Figure 2. Percentage of documents retrieved by year and access type.

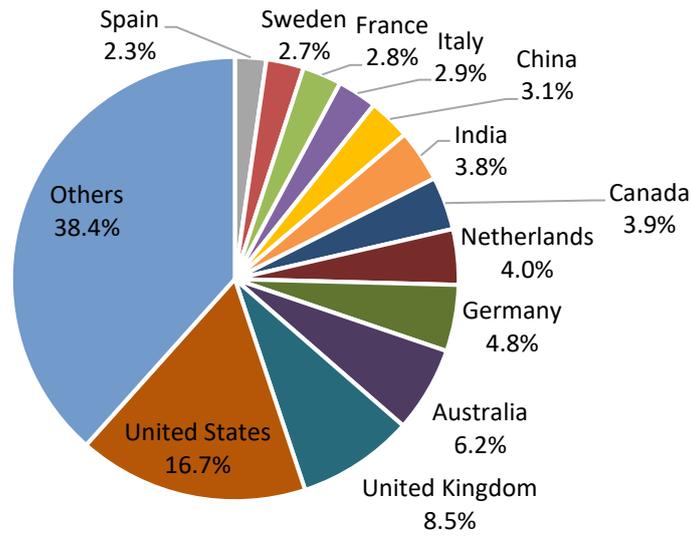


Figure 3. Percentage of documents retrieved by country of publication.

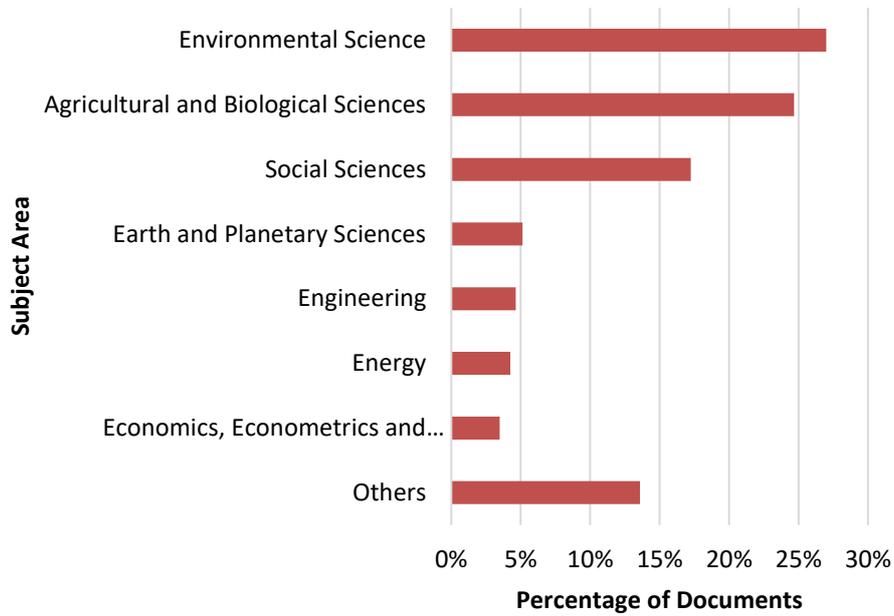


Figure 4. Percentage of documents retrieved by subject area.

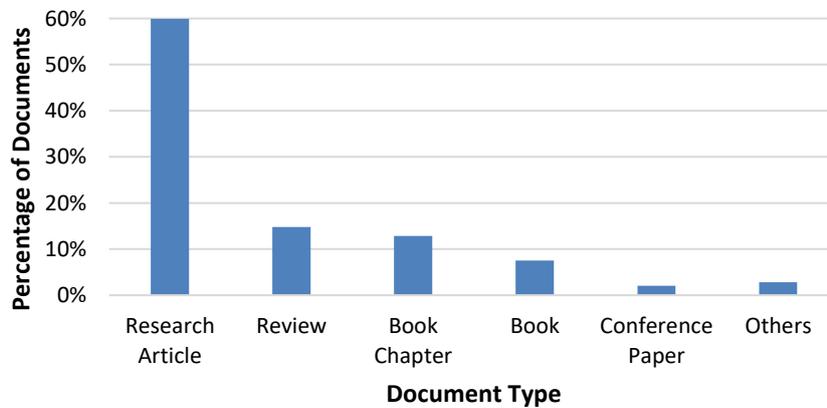


Figure 5. Percentage of documents retrieved by type.

3.2. Concept Network Analysis

As already anticipated, by the end of the second filtering process, the Infranodus Web-based analytic engine had analyzed and mapped the titles and keywords (combined in one graph) of the publications selected for the final review in this research.

This analysis identified the ‘most influential words’ and the main topics of the assessed texts (titles and keywords) and suggested a correlation between them in the form of ‘a question to ask’, which highlighted this relationship (Table 3). Mapping the text (Figure 6) emphasized the results summarized in the table, which allows us to make the following observations:

- While the network has several perspectives, its combined structure is focused. This analysis identified a possible connection between the topics “agriculture–conservation–climate” and “crop–system–production” in the combined network (Figure 6).
- There was a very high consistency between the results of the combined contexts (91% similarity for the most influential elements), which validates the filtering process.
- The influential words highlight the importance of crop systems and soils, which means that most of the literature focuses only on soil quality and health while neglecting other ecosystem services. This can be justified, according to Doran [39], by the fact that soil quality and health is the primary indicator for sustainable management and is vital to the functioning of the global ecosystem.

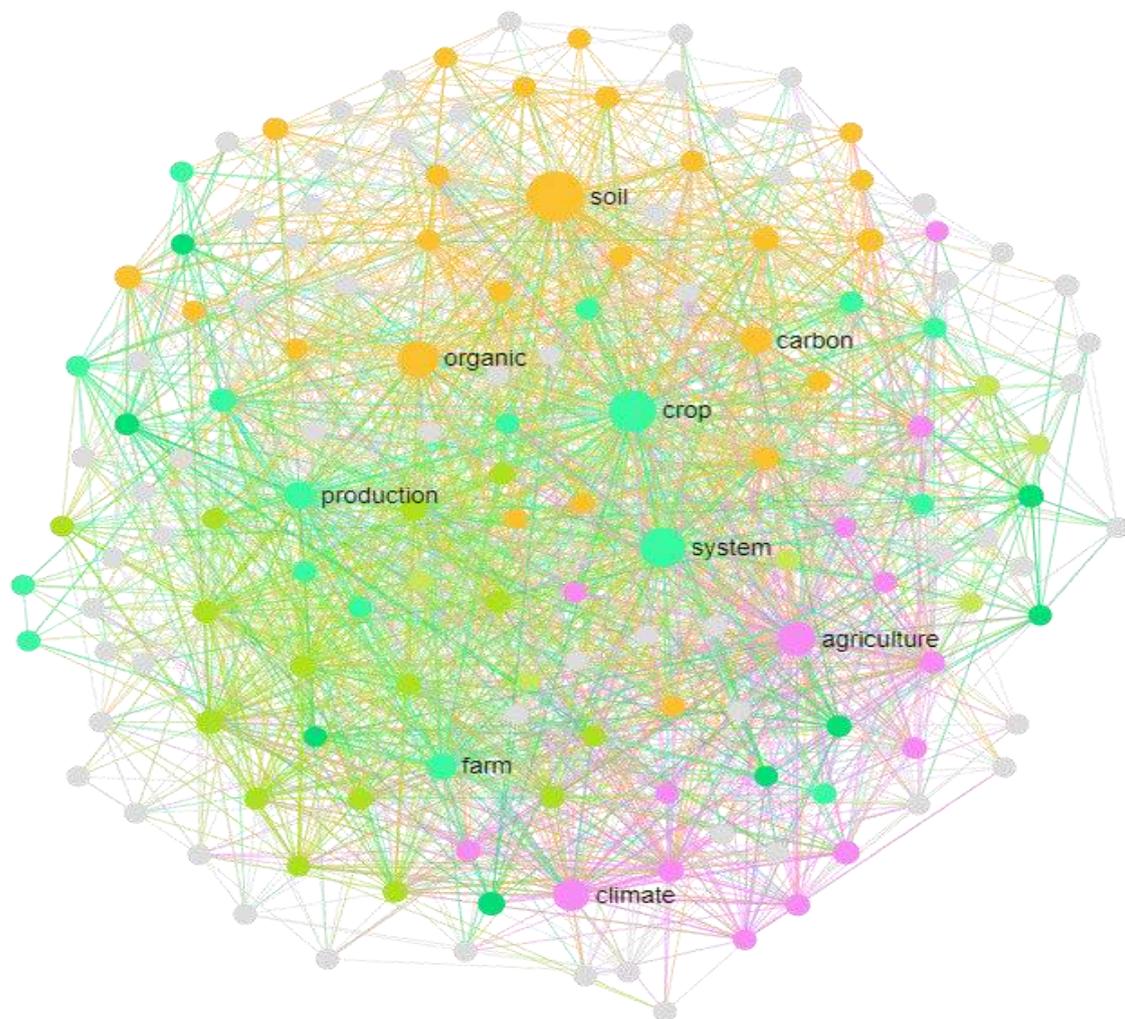


Figure 6. Combined concept network map for the titles screened for the final review and the corresponding keywords.

Table 3. Synthetic report of the network analysis generated by combining titles and keywords using the Infranodus software.

Context	Influential Words	Main Topics	Question to Ask
Combined (Titles + Keywords)	crop, soil, system, organic (highest between titles and keywords)	1. soil, organic, water	What is the relationship between "agriculture–conservation–climate" and "crop–system–farm"?
		2. resilience, food, sustainable	
3. crop, system, farm			
4. agriculture, conservation, climate			
Network structure: A total of 150 nodes, 0.3 modularity, 32% of words in the top topic (a total of 6 topics), 100% in the main connected component (1 in total), influence dispersal 50%.			
Network diversity level: focused			

3.3. Systematic Review Protocol

According to the literature, sustainable agriculture is a group of multi- or transdisciplinary agricultural practices that apply ecological principles to agricultural systems e.g., [40–42] to harness ecosystem services and to contribute to agriculture’s resilience to extreme climatic events [15]. These practices are numerous and can be location-specific and associated with local farming conditions [16,43]. For instance, Harvey [44] identified 3.8 ecosystem-based practices (Ecosystem-based agriculture is a group of practices, which, according to Altieri and Koohafkan [45], could improve all ecosystem services (provisioning, regulating, habitat, and cultural), and thereby, contribute to human well-being) per farm in six central American landscapes that could be location-specific and associated with local farming conditions [16,43]. Therefore, different practices generate different trade-offs.

The list of sustainable agricultural practices could continue, as many different ecosystems are managed by different communities. To simplify the systematic review results, we classified the assessed practices into eight different categories: integrated management, soil management, crop management, landscape management, water management, genetic management, biodiversity management, and knowledge management (Table 4). Further, this review was based on a narrative synthesis, which is more suited to studies with broad subject content and a disparate range of outcomes.

Table 4. Categorized practices for sustainable agriculture .

Category	Agricultural Practices [†]	N ^o of Reviewed Documents	Impact [*]	Sustainability Dimensions ^{‡, §, ¶}
	Soil Management	49	Mostly Positive	
	Amendments (Biochar use, manure, etc.)	27	+ (24); ± (3)	
	Tillage Practices	20	+ (17); ± (3)	1D (24); 2D (25)
	Mulching Techniques	5	+ (4); ± (1)	
	Crop Management	29	Mostly Positive	
	Crop Rotation	15	+ (13); ± (2)	
	Intercropping	9	+ (8); ± (1)	
	Cover Crop	3	+ (2); ± (1)	
	Residue Management	2	+ (2)	1D (14); 2D (13); 3D (2)
	Plant bio-regulators (PBRs): e.g., stimulants, elicitors	3	+ (3)	
	Plant Growth-Promoting Microbes (PGPM)	4	+ (4)	
	Landscape Management	17	Mostly Positive	
	Landscape ecology design and management	0		
	Land fragmentation	0		
	Agroforestry	9	+ (8); ± (1)	1D (10); 2D (5); 3D (2)
	Trees Plantation	4	+ (4)	
	Traditional Systems	4	+ (3); ± (1)	
	Water Management	8	Mostly Positive	
	Irrigation Regimes	0		
	Water Harvesting	4	+ (3); ± (1)	
	Water-Saving	3	+ (2); ± (1)	1D (3); 2D (3); 3D (2)
	Water Reuse	0		
	Unconventional Water	2	± (1); - (1)	
	Genetic Management	9	Mostly Positive	
	High-quality seeds and planting materials	0		
	Adapted and native varieties	0		
	Crop/Cultivar Diversity	11	+ (9); ± (2)	1D (8); 2D (3)
	Breeding and genetic technologies	0		
	Microbiome science	0		
	Biodiversity Management	5	All Positive	
	Agro-ecology	3	+ (3)	
	Ecosystem-based approaches			
	Pollination management			1D (5)
	Community biodiversity management (CBM)	1	+ (1)	
	Functional Agrobiodiversity	1	+ (1)	
	Ecological Intensification			
	Knowledge Management	6	All Positive	
	Meteorological Forecast	1	+ (1)	
	Indigenous/Traditional Knowledge Systems (IKS)	4	+ (4)	1D (4); 2D (2)
	Knowledge Sharing	1	+ (1)	

Table 4. Cont.

Category	Agricultural Practices †	N° of Reviewed Documents	Impact *	Sustainability Dimensions ‡,§,¶
	Integrated Management	86	Mostly Positive	
	Conservation agriculture (CA)			
	Integrated Agricultural Systems (IAS)	17	+ (14); ± (2); - (1)	
	Organic agriculture (OA)	20	+ (18); ± (1); - (1)	
	System of Crop Intensification (SCI)	19	+ (9); ± (7); - (3)	
	Climate-smart agriculture (CSA)	10	+ (8); ± (1); - (1)	
	Extensive Systems (ES)	2	+ (2)	1D (35); 2D (42); 3D (9)
	Other integrated practices‡	2	+ (2)	
	Integrated Natural Resources Management (INRM)	28	+ (24); ± (3); - (1)	
	Nature-Based Solutions (NBSs)			
	Natural System Agriculture (NSA)			
	Diversified Farming Systems (DFS)			

The number of documents per category might differ from the sum of the reviewed papers per agricultural practice because some documents might have assessed more than one agricultural practice in the same category. * A positive impact is any improvement in the indicators assessed in each study belonging to any sustainability dimension. † This refers to the sustainability dimensions that have been assessed in each study (economic, environmental and social), e.g., if a study assessed soil biological activity, it is considered one dimensional (1D), if it assessed both soil biological activity and yield, it is considered two dimensional (2D). ‡ Agricultural practices with 0 reviewed papers mean the a) such practices were mentioned in the literature as sustainable practices but were not caught by the primary question or b) these practices have been studied in combination with other practices, and their count is included under 'other integrated practices'. ‡ 'Other integrated practices include combined practices from different categories.

3.3.1. Integrated Management

Many integrated farm management methods exist in the literature, but not all of them emerged using the research question adopted in this review. Thus, the large number of papers included in this category is mainly due to two facts: (a) A significant portion of the studies included in this management category features the integration of two or more practices belonging to different categories and were added under this category to prevent replication in the analysis. Given the diversity of the approaches implemented to assess these studies, it was challenging, in most cases, to isolate the impacts of these single practices and evaluate them. However, the overall impacts were positive (Supplementary Materials). (b) The other portion of the documents reviewed features the consolidated methods mentioned in the literature with recognized principles and respected rules (i.e., Conservation Agriculture (CA), Sustainable Intensification (SI), Integrated Agricultural Systems (IAS), and Organic Agriculture (OA)).

Conservation Agriculture is a method that involves three main principles [46]: (a) soil management to reduce the soil's physical disturbance and its degradation; (b) crop management, such as residue management, to protect the soil's top layers; and (c) genetic management to increase the agricultural systems' biodiversity and thus, their resilience. In general, the documents reviewed showcase the importance of Conservation Agriculture (Supplementary Materials), especially under extreme climate conditions (e.g., [47,48]). Sommer [49] was the only exception, demonstrating instead that CA can merely slow the loss of soil organic carbon over time.

Sustainable Intensification (SI) includes the System of Crop Intensification (SCI) method and is another method that uses sustainable practices to safeguard natural resources and meet the growing demand for agricultural production, considering the three sustainability dimensions to build resilience [50,51]. To reach this objective, the concept of Sustainable Intensification is established in four fields of action [52]: (1) agronomic development, (2) resource use efficiency, (3) land use allocation, and (4) regional integration. In practice, this study detected a few documents that relate Sustainable Intensification to resilience and climate change. These works used different assessment criteria and diverse indicators (e.g., change in yields, gas emissions, etc.) to generate positive externalities (Supplementary Materials), which could be (according to Ares [53]) comparable to the externalities generated by Conservation Agriculture.

The low diversity of conventional systems has led to degradation and has reduced the ecosystem services traditionally supplied by agriculture [54]. The Integrated Agricultural System is a model promoted internationally for its relevance (as well as related concepts) in increasing farm diversity and lowering reliance on external inputs, enhancing nutrient cycling, and increasing natural resource use efficiency [55,56]. This study screened several documents that assessed the impacts of IAS in terms of economic benefits, environmental efficiency, and social aspects studied individually (Supplementary Materials); all factors confirmed the positive impacts of this concept. The studies that evaluated the three sustainability dimensions combined (using qualitative methods) also generated positive impacts [57,58].

Organic Agriculture (OA) is another integrated production method, which, according to IFOAM-Organics International, sustains soil health, ecosystems, and people based on four principles: health, ecology, fairness, and care [59]. The assessed literature acknowledges the importance of Organic Agriculture in improving the ecology and biodiversity of agriculture systems and reducing social, economic, and environmental risks (Supplementary Materials). However, there is evident disagreement within the scientific community on the potential of this practice to guarantee high levels of food security. From one perspective, a portion of the literature reports a considerable reduction in yields observed in organic agricultural systems [60–64]; however, other literature maintains, based on trials, that the achieved yields are comparable to those of conventional systems [65–68]. This divergence in output is explained by Seufert [69], who reviewed the performance of Organic Agriculture in the literature and showed that it could have, in some cases, higher yields compared to conventional agriculture; however, in other cases, the yields are significantly lower or insignificantly lower (statistically). The authors

pointed out that variability in yields highly depends on the crop variety and socio-economic conditions in the case study [69]. Finally, when convergence in results was observed in average climate years, Organic Agriculture outweighed conventional agriculture in extreme weather years [67,70], which makes this integrated method very efficient for agricultural resilience.

The concept of Climate-Smart Agriculture (CSA) emerged in 2009 as a potential approach to capture the synergy between agricultural adaptation and mitigating climate change [71,72]. CSA is currently lively debated in this regard. Apart from the studies that the Food and Agriculture Organization of the United Nations directly or indirectly publishes (e.g., [43,73–75]), which all show encouraging results, two recent documents screened in this review both assessed the impacts of Climate-Smart Agriculture on the resilience of agriculture and have shown positive results in terms of yields, the concentration of inputs, and resource use efficiency [76,77].

Other methods have been mentioned in the literature (e.g., Natural System Agriculture (NSA), Integrated natural resource management (INRM), etc.), but had not been studied or assessed in relation to resilience and climate change sufficiently to be retrieved for this review.

3.3.2. Soil Management

Soil quality and health are considered a key indicator of sustainable management because the assessment criteria integrate ecosystem processes, climate variables, and physical, chemical, and biological properties. This explains the growing interest in soil management for more sustainable agriculture. This focus is expressed in the total amount of reviewed publications (69 out of 209) that analyzed the impacts of sustainable agriculture on soil quality and health, without including the number of documents assessing the relationship between soil management and sustainable agriculture that were classified under the 'Integrated Management' category (Table 3) because they were combined with other practices, such as tillage practices with different irrigation regimes and crop diversity with improved seeds (Supplementary Materials).

The methods and practices for soil management vary from soil amendments (biochar, litter, compost, and manure) to tillage practices (zero tillage, minimum tillage, etc.) and mulching techniques. Even though soil management is one of the most intensively studied and best-documented categories, this review showed inconsistency in the methodologies adopted and the indicators selected for the relevant assessments. The research focus was divided between biological, physical, and chemical characteristics; within each characteristic, the indicators were very different. For instance, Supplementary Materials includes many soil quality indexes that differed from one study to another, such as cation exchange capacity (CEC), sodium adsorption ratio (SAR), electric conductivity (EC), available and/or total phosphorus and nitrogen, microbial biomass carbon (MBC), total organic carbon (TOC), soil organic carbon (SOC), soil organic matter (SOM), etc. [78–83]. Biological activity can be evaluated via the nematode communities in soils (e.g., [84]), through bacterial and fungal diversity (e.g., [85]), or even through enzymatic activity (e.g., [86]). Physical indicators included soil porosity, soil compaction, soil erosion index, hydraulic conductivity, holding capacity, etc. (e.g., [87–91]).

Despite the differences in methodologies and indicators, the practices assessed (i.e., tillage practices, mulching techniques, and soil amendments) showed positive impacts on soil quality and health. These impacts were more pronounced under extreme weather conditions [92–95]. However, the reference system, in comparison, must be carefully selected [96]. For instance, comparing the impacts of organic amendments on yield increases when the control is a high input system would not favor of organic amendments.

Very few studies (Table 4), impact sign (\pm) have emphasized the dependence of outcomes for crop type, soil type, climate, and weather conditions (e.g., [87]). Some studies have raised awareness about the no-till practice, which is confirmed to increase top-soil organic carbon, noting that this increase in not always translated into improved crop growth due to the larger concentrations near the surface [97,98]. Notably, none of the documents included under the 'soil management' category adopted an ecosystem-based approach, which is defined as an adaptation strategy to the adverse

effects of climate change [99–101]. Likewise, no studies assessed all three dimensions of sustainability (environmental, social, and economic pillars).

3.3.3. Crop Management

This category is the second after soil management in terms of the number of documents studied and screened for the review. This category includes several practices to manage crops in the field, such as crop rotation, cover crop, intercropping, residue management, and different techniques to stimulate crop resistance and growth, such as plant bioregulators and plant growth-promoting microbes. The latter has recently received considerable scientific attention to validate their bio-stimulation and growth properties in plants.

The practices and techniques in this review were studied via different methodologies with different outputs, but all had positive results, which confirms the importance of crop management for improving agricultural system sustainability. Acknowledging the benefits that these techniques and practices generate, Roberts and Mattoo [26] doubted whether crop management could produce yields like current production patterns. Other studies, however, have noted the importance of these techniques, especially in extreme weather conditions [102–106], which suggests that crop management could, under future climate conditions, outweigh the current production systems and thus increase resilience.

Nevertheless, the inability to assess crop management via the three dimensions of sustainability (environmental, economic, and social) indicates that research in this field has not yet reached an interdisciplinary level that can reflect the sustainability of the whole agricultural system. Only two recent review studies assessed the available literature (Supplementary Materials)—one on intercropping practices and one on plant growth-promoting microbes on a three-dimensional structure—to demonstrate that the appropriate implementation of these practices and techniques could facilitate a balance between productivity, resilience, and environmental health [107,108].

3.3.4. Landscape Management

The landscape management of production systems, which was recognized by FAO (The Food and Agriculture Organization of the United Nations) [109] as an integrated and multidisciplinary approach to generate ecosystem services, has recently emerged in the literature under different principles and practices, such as agroforestry [110], tree plantations, and traditional systems that are used to contribute to increasing the sustainability of agricultural systems and their resilience to climate change. Several documents have analyzed the effects of some landscape practices on the sustainability of production systems (Supplementary Materials); most of them show the positive impacts that could be greater under extreme climate conditions [111]. Two scientific papers adopted an ecosystem-based approach to assess the sustainability of traditional systems (Supplementary Materials): One research paper studied irrigation systems in New Mexico [112], and one review paper qualitatively considered the impacts of traditional terracing on ecosystem services [113].

3.3.5. Water Management

The limited number of papers dealing with water management screened do not reflect the total number of water management papers in the databases, but this limitation does highlight the absence of an ecosystem-based approach to assess water management and determine the impacts on the different services in agrosystems. Moreover, some water management methods have been assessed in combination with other management methods and different agricultural practices. Even though the impacts of these combined methods were positive, the single impacts of water management are not easily separated from the overall impacts of the integrated management practices (Supplementary Materials).

Therefore, the available literature primarily assesses methods, such as water harvesting, water-saving techniques, unconventional water sources, and irrigation regimes, based on one or two aspects of the sustainability dimensions. The three sustainability pillars (economic, social,

and environmental) were not considered, except for two review studies that evaluated the literature published on rainwater harvesting, which reported the positive impacts of this practice on different ecosystem services [114,115]. Excluding one study by Martin-Gorriz [116], which concluded that the use of alternative water-based techniques, such as water desalination, reduces the resilience of agricultural systems by consuming more energy and participating in GHG emissions, the results of the assessed documents generally show positive impacts (Supplementary Materials).

3.3.6. Genetic Management

In this category, we excluded genetically modified organisms due to their direct and indirect environmental implications and alleged impacts on human health, despite their enhanced yield potential [117,118].

Even though breeding is expected to confer higher resilience to agroecosystems, Lammerts van Bueren [119] reviewed the current findings on plant breeding and concluded that all plant breeding orientations adopted to date (i.e., corporate-, community-, ecosystem-, and trait-based-breeding) do not facilitate sustainable agriculture. These authors suggested using a systems-based breeding approach to participate in developing resilient, sustainable agriculture.

Under this category, two practices were found in the literature: crop diversity and cultivar diversity. Both practices generated positive results in terms of the resilience of agroecosystems and household food security (due to diet diversification), soil quality, and other environmental aspects (i.e., disease control and predator abundance). However, there is disagreement in the literature about the impacts of genetic management on yield increases. While some authors argue that crop and cultivar diversity is positively and significantly related to production [120–122], others maintain that a productivity increase is observable only in normal years, not during extreme weather events or epidemics [123]. Notably, most of the research documenting the benefits of diversification evaluated a single ecosystem service [124].

3.3.7. Biodiversity Management

Methods, such as agroecology, agrobiodiversity, and ecological intensification, which apply ecological principles to agriculture, have been investigated for the last few decades to promote synergy between biodiversity and the social aspects of agrosystems. The papers assessed in this review show positive results (Supplementary Materials). However, these assessments focused on environmental aspects. Calderón [125], on the other hand, indicated that agroecology-based farmers in Guatemala have higher levels of food availability than semi-conventional farmers during extreme weather seasons.

3.3.8. Knowledge Management

Knowledge management is, according to Newman and Conrad [126], “an integration of numerous endeavors and fields of study”, which makes it complicated to define. Based on the latter study and the efforts made by Boom [127] to define knowledge management, we adopt in this research the following definition: “A process to improve the performances of individuals, organizations, and systems, and to generate value from intellectual and knowledge-based assets”. This definition includes both tacit and explicit knowledge, the former being based on experiences (e.g., indigenous, local, and traditional knowledge) and the latter being recorded in the literature [128]. Both types of knowledge have been recognized as fundamental to build resilience to climate change and contribute to sustainable development [13]. However, to share knowledge and achieve adaptation, a transfer strategy is essential to transfer knowledge from a tacit to an explicit form [129].

Knowledge management for agricultural system resilience is a recent development in the literature, which explains the limited number of relevant studies. The major research topics include indigenous and traditional knowledge systems, with only two studies on meteorological information and knowledge sharing; all relevant studies confirmed the importance of these practices for agrosystem resilience (Supplementary Materials). These results are a step forward to achieve knowledge transfer and sharing

for climate resilience, as suggested previously, as these results transform the nature of indigenous and traditional knowledge from tacit to explicit. However, to enhance resilience and facilitate sustainable agriculture, more efforts should be made to improve our understanding of traditional knowledge for building synergy using scientific knowledge [130,131].

4. Discussions and Recommendations

Several observations have emerged from the results of this systematic review. Next, we discuss the observations and make some recommendations for the scientific community and policymakers in sustainable agriculture-related areas.

Sustainability is a three-dimensional model that requires a change in practice to contravene disciplinary boundaries, thereby realizing transdisciplinarity [132], which represents a step forward for interdisciplinarity towards full integration. This goal is far from being achieved, according to Brandt [133], and this review has further demonstrated that, in agriculture, we have not yet reached a level of interdisciplinarity where the knowledge and methods from different disciplines are unified into a synthetic approach.

The results confirm that different management aspects are commonly studied separately, which means that the literature has not studied sustainable agriculture as a whole but merely some practices and technologies that participate in sustainable agriculture, mainly through the improvement of system biodiversity and ecosystem services [14]. To cope with the challenges of sustainable agriculture, changes in management strategies must be based on the integration of all management categories (Table 4) to produce a unique management method for agrosystems that accounts for soils, water, crops, genetics, the landscape, biodiversity, and knowledge and uses unified quantitative methods for evaluation and assessment.

The ecosystem-based approach described earlier in the paper is the most effective tool to achieve integration for the sustainable management of agrosystems under climate change because it is based on the management of all ecosystem processes and services, thereby improving the ability of crops to maintain their yields [99–101]. This is to be done on a life cycle basis and has been successfully applied in the literature to agro-food systems (e.g., [134,135]) because it considers the interactions between resource use and potential impacts on biodiversity [136,137]. Finally, climate change impacts and resilience of agrosystems are highly dependent on local conditions (environmental, socio-economic, and management), which complicates the process of quantifying sustainable agriculture [138]. Therefore, our recommendations are as follows:

- The integration of all agrosystems services into sustainable management using an ecosystem-based approach on a life-cycle basis via the Life Cycle Assessment (LCA(Life-cycle assessment, or LCA, is an environmental accounting and management approach that considers all the aspects of resource use and environmental releases associated with an industrial system from the cradle to the grave [139].)) method;
- Improving the scientific understanding of traditional knowledge for greater synergy and further integration;
- The unification of assessment methods and indicators for the quantification of impacts;
- The creation of a platform to share, monitor, screen, and approve the assessments and evaluations of sustainable agriculture by region.

5. Conclusions

The number of papers in scientific databases that include “sustainable agriculture” is very impressive, constituting almost 10% of the total “agriculture” papers on ‘Scopus’ (28,509 out of 283,593 papers on 13 February 2019). This systematic review analyzed sustainable agriculture and its impacts on agrosystem resilience under climate change. The results demonstrate that only single practices and methods have been studied to assess the impacts on single ecosystem services. Although the

assessed practices and methods have shown to improve agrosystems (mainly their environmental aspects) and make them more resilient to extreme climate events, we are still far from interdisciplinary and multi-dimensional agriculture that integrates all management aspects and generates a full range of ecosystem services.

The recommendations of this study are addressed to the scientific community to help orient their future research strategies and efforts to produce sustainable agriculture under climate change conditions and to policymakers who design and finance such strategies.

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