Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 February 2020 doi:10.20944/preprints202002.0405.v1

Peer-reviewed version available at *Sustainability* **2020**, *12*, 3119; doi:10.3390/su12083119

How could sustainable agriculture increase climate resilience? A systematic review

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Abstract

In the last few decades, a lot has been written on the use of sustainable agriculture to improve ecosystem services for resilience to climate change. However, no tangible and systematic evidence exists on how this 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 understand how, in a changing climate, sustainable agriculture builds the resilience of agro-systems. The search was set from the date of the first relevant article until the end of 2018. Results generated have demonstrated that:

a. Only single practices and methods have been studied to assess impacts on single ecosystem services.
b. Soil quality and health are considered a key indicator of sustainable agriculture.
c. Albeit the assessed practices and methods have shown to improve the biodiversity of agro-systems, which makes them more resilient to extreme climate events, we are still far from reaching interdisciplinary and multi-dimensional agriculture which integrates all management aspects and generates a full range of ecosystem services.

In conclusion, the study addressed the following recommendations for the scientific community and for decision-makers to orient future research strategies and efforts:

a. Integration of all agro-systems services into sustainable management using an ecosystem-based approach on a life-cycle basis using Life Cycle Assessment (LCA) method;
b. Improving the scientific understanding of traditional knowledge for higher synergies and for further integration;

c. Unification of assessment methods and indicators for the quantification of impacts;
d. 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; Agro-Systems

1. Introduction

Human-induced climate change, as defined by WMO [1], has been suspected in the early 19th century, but the scientific community did not favour 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 and climate extremes especially on the frequency, the intensity, the duration and the spatial extent of such events [3]. While these changes are expected to bring some possible benefits (not well documented) to certain local places especially in terms of water availability and agriculture [2, 4, 5], many scientists argue that 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 jeopardised with: *i)* a worsening of the economic dimension and increased poverty, *ii)* a compromised social dimension due to food insecurity, migration and human health at risk, and *iii)* a deteriorating natural environment and ecosystems.

According to the IPCC [3], the effect of climate change will vary by the intensity and by time depending on the regions and according to the type of events: for certain extremes (e.g. floods, droughts) regional projections are more reliable and indicate larger changes than the global projections. On the other side, the risks of climate effects have also 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 disadvantage of rural communities [8, 9]. In 2014, the latter represented 46% of the world population [10], with a high urbanisation rate in the Americas and Europe, while Africa (60% of rural population) and Asia (52% of rural population) are mostly highly vulnerable rural communities [11], which depend for livelihood on a ‘climate-related risky’ agriculture, expected to be severely affected by climate change [2].

To averse the risks related to climate change which could be devastating for vulnerable rural communities, and to meet food demand of an increasing world population expected to reach 10 billion by 2050 [10], the International Panel for Climate Change (IPCC) has repeatedly expressed the importance of sustainable agriculture to adapt to climate adversities and build resilience of ecosystems so they continue to generate services for our societies [2, 12, 13]. Other authors have also illustrated the close alignment between sustainable agriculture, ecosystem services and climate adaptation [e.g. 14, 15].

This correlation began to emerge within the scientific community after the WCED report known as Brundtland Report in 1987 in parallel to the notion of sustainable development, yet the concept has created as much ambiguity as to the sustainable development concept [16, 17, 18]. Additionally, the resilience concept, which incorporates both general and specific aspects, and which originally has been used in psychology and material sciences, has been increasingly accepted in other disciplines, to describe complex socio-ecological systems in continuous mutation [19]. However, literature has shown that resilience thinking incorporates both specific and general aspects which might generate vagueness if not properly defined.

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In this research, agro-system resilience is inspired by Folke et al. [20] and is the capacity of agricultural systems to respond to social, economic and environmental changes by structural reorganisation, for future changes' prevention and to take the new opportunities. This will guarantee continuity for agro-systems to produce ecosystem services for sustainable agriculture. From another side, for sustainable agriculture, we adopt the definition given by the Organisation for Economic Co-operation and Development (OECD) and based on Brundtland report [21], which stated that "Sustainable agriculture is agricultural production that is economically viable and does not degrade the environment over the long run" [22]. Such agriculture has environmental, social and economic dimensions to be considered together. According to Ikerd [23], it 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[1] such as agro-ecological processes and principles, conservation agriculture, which position agricultural systems at the interface of natural and social systems [24].

Even though recommendations are increasing about the use of sustainable agriculture to improve ecosystem services for resilience to climate change, no tangible and systematic evidence exists on how this would participate in alleviating impacts on vulnerable rural communities. Hence, to remove any scientific ambiguity, and based on the definition stated previously, the 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 the agricultural model which finds a holistic balance between environment economy and society to understand how, in a changing climate, sustainable agriculture builds resilience of the natural and physical systems. The recommendations would highlight the areas where evidence is lacking to address strategic research needs.

2. Material & Methods

Sustainable agriculture is supposed to build up natural and physical systems' resilience, to keep generating services even in front of extreme climate events. 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 paragraphs:

2.1. Bibliometric Analysis

The Systematic Review (SR) protocol which will be described in the next section (2.3) has been adopted for this analysis. The retrieved literature has been exported into Mendeley (reference manager software). All the duplicate and spurious results were eliminated, and before the relevance assessment, the bibliography was analysed, according to a list of indicators including the source and type of documents, the year of

[1] The exact definitions of agro-ecological agriculture, conservation agriculture and other sustainable practices are reported in the results section.

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publication and subject area. Bibliometric methods are now inherent to many scientific research methodologies [25] for the value they add in the data interpretation.

2.2. Concept Network Analysis

The research also integrated a network analysis [26, 27], 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, and graphically represents network relationships between different keywords, using qualitative and quantitative metrics [28].

The analysis is carried on different steps [28], beginning with the submission of the text to InfraNodus (https://infranodus.com/), a web-based analytical engine. Firstly, the text is prepared to remove frequent words binding it together, the Krovetz Stemmer algorithm then stems the remaining words to reduce redundancy and complexity [29, 30] and further normalising the text before encoding. InfraNodus converts submitted text into a network by performing a two-pass analysis. The graphical network could be used to represent data visually using various software i.e. Gephi for visualisation and exploration [31].

2.3. Systematic Review Protocol

The Systematic Review (SR) methodology, which has been described in the systematic review guidelines developed by the Collaboration for Environmental Evidence to inform practice and policy in environmental management [32].

The formulation of the primary question is the most important aspect in an SR, which requires according to Pullin et al. [33], a compromise between different approaches: a holistic approach and a reductionist one. Therefore, the primary research question that would cover all the aspects of sustainable agriculture and its role in building resilience to climate change would be:

"How could sustainable agriculture increase resilience to climate change?"

Following the systematic review convention, the research question is broken down as required by the Collaboration for Environmental Evidence (CEE) guidelines into definable elements known as the PICO/PECO: *i)* the population (Sustainable agriculture from the date of the first relevant publication onwards, however, this concept began to emerge in the 80s [34], no location restrictions will be set because this concept could be applied on any agricultural system); *ii)* interventions (The intervention is the expansion of sustainable agriculture since the eighties of the last century leading changes in the natural and physical

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systems); *iii)* comparators (Sustainable agriculture versus conventional agriculture[2]); *iv)* outcomes (Resiliency parameters to climate change defined as quantitative/qualitative changes in ecosystem services).

Scientific database sources, as well as grey literature, were used in this review, which included only English bibliography.

All literature retrieved in the first step have been screened for relevance according to the previously established inclusion criteria, which included *i)* relevant subjects (Any country, any spatial scale); *ii)* type of intervention (Sustainable management); *iii)* comparator (Compares benefits and/or impacts on natural and physical systems); *iv)* Methods (modelling, experiments and surveys); *v)* outcomes (Studies that consider benefits/impacts on terrestrial and aquatic ecosystems, hydrology and water resources management, natural environment, food and fibre production and security, immigration, poverty, human health, human infrastructure, and economic loss).

3. Results

The total number of 3,563 records gathered from the scientific databases and grey literature were retrieved using Mendeley software (**Table 1**). After cleaning and removing duplicates a total of 2,671 documents remained, the bibliographic analysis was carried out, this was followed by the first filtering based on the title of the literature, followed by the Network analysis method which mapped all the titles and keywords of all documents which passed the filtering process. The systematic review approach consisted of reviewing the full text of the filtered documents, based on the inclusion criteria and the 'outcome' search terms. All the process has been carefully documented transparently and has been schematically summarised for simplification according to the PRISMA flow diagramme (**Figure 1**).

3.1. Bibliometric Analysis

The date of the first relevant publication capturing the question subject to this research has been in mid-nineties, even though sustainability as a concept has been first discussed in the eighties. The analysis has shown that most of the documents are with restricted access, with a slight increase in the open-access publications from 2010 onward (**Figure 2**). The United States is the major country of publication, with Australia, China and many European countries in the top 10 countries that published 56.5% of the relevant research in the study's time frame (**Figure 3**). Three major subject areas have been identified, under which 68.9% of the documents retrieved are classified i.e. 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 are

[2] Conventional agricultural systems are intensive mono-systems based on high input use.

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research articles and 14.8% review papers, while books, book chapters and conference papers are less in numbers (**Figure 5**).

3.2. Concept Network Analysis

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

The analysis has identified the 'most influential words' and the main topics of the text assessed (titles and keywords) and has suggested a correlation between them, on a form of 'a question to ask', which highlights this relation (**Table 2**). Mapping the text (**Figure 6**) emphasises the results summarised in the table and leads us to make the following observations:

- While the network has several perspectives, the combined structure is focused. The analysis identified a possible connection between the topics "agriculture-conservation-climate" and "crop-system-production" in the combined network (**Figure 6**).
- Very high consistency in the results of the combined contexts (91% similarity of most influential elements), which validates the filtering process performed.
- The influential words highlight the importance of crop systems and soils, which means that most literature focused only on soil quality and health among all other ecosystem services. This can be justified according to Doran [35] by the fact that soil quality and health is the primary indicator of sustainable management and it is vital to global ecosystems functioning.

3.3. Systematic Review Protocol

According to the literature assessed, sustainable agriculture is a group of multi- or transdisciplinary agricultural practices which apply ecological principles to agricultural systems [e.g. 36-38], to harness ecosystem services and to contribute to agriculture resilience to extreme climatic events [14]. These practices are numerous and could be location-specific and could be associated with local farming conditions [15, 39]. For instance, Harvey [40] identified 3.8 ecosystem-based practices[3] by farm in six central American landscapes and could be location-specific and could be associated with local farming conditions [15, 39]. Therefore, different practices generate different trade-offs.

The list of sustainable agricultural practices could go on as much as different ecosystems are managed by different communities, in way of simplification of the systematic review results, we classified the assessed practices into eight different categories: Integrated Management, Soil management, crop management,

[3] Ecosystem-based agriculture is a group of practices which according to Altieri and Koohafkan [42], could improve all ecosystem services (provisioning, regulating, habitat, cultural), and therefore contribute to human well-being.

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landscape management, water management, genetic management, biodiversity management and knowledge management (**Table 3**). Further, the review has been based on a narrative synthesis, more suited to this study with abroad subject content and a disparate range of outcomes.

3.3.1. Integrated Management

So many integrated farm management methods exist in the literature, but not all of them have emerged using the research question adopted in this review. Thus, the big number of papers included in this category is mainly due to two facts: *1)* a big part of the studies included in this management category is the integration of two or more practices belonging to different categories and have been added under this category to prevent replication in the analysis. Given the diversity of the approaches implemented to assess these studies, it was not easy, in most cases, to isolate the impacts of the single practices and to evaluate them. However, the overall impacts were positive (**Appendix I**). *2)* The other part of the documents reviewed are recognised methods mentioned in the literature with recognised principles and respected rules (i.e. Conservation Agriculture (CA), Sustainable Intensification (SI), Integrated Agricultural Systems (IAS), Organic Agriculture (OA)).

Conservation Agriculture is a method which involves three main principles [41]: *a)* soil management to reduce soil physical disturbance and reduce its degradation; *b)* crop management such as residue management to protect the soil top layers; and *c)* genetic management to increase agricultural systems' biodiversity and in consequences their resilience. In general, the documents reviewed showed the importance of Conservation Agriculture (**Appendix I**), especially under extreme climate conditions [e.g. 43, 44]. Sommer [45] was the only exception, demonstrating that CA could just slow down the loss of soil organic carbon over time.

Sustainable Intensification (SI) includes the System of Crop Intensification (SCI) method and is another method which uses sustainable practices to safeguard natural resources and meet the growing demand for agricultural production, considering the three sustainability dimensions to build resilience [46, 47]. To reach this objective, the concept of Sustainable Intensification is established on four fields of action [48]: *1)* Agronomic Development, *2)* Resource Use Efficiency, *3)* Land Use Allocation, *4)* Regional Integration. In practice, this study has detected a few documents which relate Sustainable Intensification to resilience and climate change, they used different assessment criteria and diverse indicators (e.g. change in yields, gas emissions, etc.) have generated positive externalities (**Appendix I**), which could be according to Ares [49], comparable to externalities generated by Conservation Agriculture.

The low diversity of conventional systems has led to degradation and have reduced the ecosystem services traditionally supplied by agriculture [50]. Integrated Agricultural Systems is a method promoted internationally for its relevance (as well as related concepts), in increasing farm diversity and in lowering reliance on external inputs, enhancing nutrient cycling and increasing natural resource use efficiency [51-52]. This study has screened several documents which assessed the impacts of IAS in terms of economic

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benefits, environmental efficiency and social aspects studied singularly (**Appendix I**), all of them confirmed the positive impacts of this concept. Even the studies who evaluated the three sustainability dimensions combined [using qualitative methods] generated positive impacts [53, 54].

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 [55]. The literature assessed has acknowledged the importance of Organic Agriculture in improving the ecology and biodiversity of agriculture systems and in reducing social, economic and environmental risks (**Appendix I**). However, there is an evident disagreement within the scientific community on the potential of this practice to guarantee high levels of food security. From one side, a part of the literature studied reports a considerable reduction in yields observed in organic agricultural systems [56-60]; and from another side, other literature retains, based on trials, that achieved yields could comparable to the conventional systems [61-64]. This divergence in output could be explained by Seufert [65] who reviewed the performance of Organic Agriculture in the literature and have shown that it could have in some cases higher yields compared to conventional agriculture, while in other cases yields are lower significantly lower or insignificantly lower (statistically). The authors pointed out that variability in yield results highly depend on the crop variety and socio-economic conditions in the case study, and Organic Agriculture could [65]. Finally, if convergence in results is observed in average climate years it is to be noticed that Organic Agriculture overweighed conventional agriculture in extreme weather years [63, 66], 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 synergies between agricultural adaptation and mitigation to climate change [67, 68], and it is currently lively debated in this regard. Except the material that the Food and Agriculture Organisation of the United Nations is directly or indirectly publishing [e.g. 39, 69, 70], which all showed encouraging results; two recent documents have been screened in this review which assessed the impacts Climate-Smart Agriculture on resilience of agriculture and have shown positive results in terms of yields, concentration of inputs and resource use efficiency [71, 72].

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

3.3.2. Soil Management

Soil quality and health are considered a key indicator of sustainable management because 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 is expressed in the total amount of reviewed publications (69 out of 209) which analysed the impacts of sustainable agriculture on soil quality and health, without including the number of documents assessing the relation between soil management and sustainable agriculture which have been classified under 'Integrated Management' category (**Table 3**), given that they were combined with other practices e.g. tillage practices with different irrigation regimes; crop diversity with improved seeds and tillage practices (**Appendix I**).

The methods and practices for soil management vary from soil amendments (biochar, litter, compost, 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, the review showed inconsistency in the methodologies adopted and the indicators selected for the assessments. The focus was diversified between biological, physical and chemical characteristics; and within each characteristic, indicators were very different. For instance, **Appendix I** included so many soil quality indexes different from a 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. [72-77]; the biological activity could be evaluated through the nematode communities in soils [e.g. 79], or through bacterial and fungal diversity [e.g. 80] or even through enzymatic activity [e.g. 81]; physical indicators included soil porosity, soil compaction, soil erosion index, hydraulic conductivity, holding capacity, etc. [e.g. 82-86].

Albeit the difference in methodologies and indicators, the practices assessed (i.e. tillage practices, mulching techniques, and soil amendments) showed positive impacts in terms of soil quality and health improvements, which are more eminent under extreme weather conditions [87-90]. However, the reference system in comparison is to be carefully selected [91]; for instance, comparing the impacts of organic amendments on yield increase when the control is a high input system would not be in favour of the organic amendments.

Very few studies (**Table 3**, impact sign (±)), have stressed out the dependence of the outcomes on crop type, soil type, climate and weather conditions [e.g. 82]. Some studies have raised awareness about the no-till practice which is confirmed to increase top-soil organic carbon, saying that this increase in not always translated into improved crop growth given that the larger concentration near the surface [92, 93]. To be noted that none of the documents included under the 'soil management' category has adopted an ecosystem-based approach, defined as an adaptation strategy to the adverse effects of climate change [94-96], neither 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. It includes several practices to manage the crop in the field such as crop rotation, cover crop, intercropping, residue management, and different techniques to stimulate crop resistance and growth like plant bioregulators and plant growth-promoting microbes. The latter is recently having a lot of scientific attention to validate their promoting and bio-stimulation properties on plants.

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The practices and techniques filtered in this review have been studied with different methodologies and different outputs, and all had positive results, which confirms the importance of crop management to improve agricultural systems' sustainability. Acknowledging the benefits that these techniques and practices generate, Roberts and Mattoo [97] have doubted that crop management would produce yields like the current production patters. Other studies, however, have pointed out the importance of these techniques especially in extreme weather conditions [98-102], which is evidence that crop management could in the future under climate conditions, outweigh the current production systems and thus increase resilience.

Nevertheless, the inability to assess crop management considering the three dimensions of sustainability [environmental, economic and social] indicates that research in this field has not yet reached an interdisciplinary level, able to reflect the sustainability of the whole agricultural system. Only two recent review studies have assessed available literature (**Appendix I**) – one for intercropping practices and one for plant growth-promoting microbes – on a three-dimensional structure to demonstrate that appropriate implementation of these practices and techniques could create a balance between productivity, resilience and environmental health [103, 104].

3.3.4. Landscape Management

Landscape management of production systems recognised by FAO [105] as an integrated and multidisciplinary approach to generate ecosystem services, has recently emerged in the literature with different principles and practices such as Agroforestry, trees plantation and traditional systems which are considered to contribute to increasing sustainability of agricultural systems and their resilience to climate change. A good number of documents have analysed the effects of some landscape practices on the sustainability of production systems (**Appendix I**), most of them have shown positive impacts that could be higher in extreme climate conditions [106]. Two scientific papers have adopted an ecosystem-based approach to assess the sustainability of traditional systems (**Appendix I**): one research paper has studied irrigation systems in New Mexico [107], and one review paper which qualitatively considered the impacts of traditional terracing on ecosystem services [108].

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 it transmits the absence of an ecosystem-based approach to assess water management and to elicit the impacts on different services of agro-systems. Besides, 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 were not easy to separate from the overall impacts of the integrated management practices (**Appendix I**).

Therefore, the literature assessed methods like water harvesting, water-saving techniques, unconventional water sources, and irrigation regimes, mostly on one or two aspects of the sustainability dimensions. The

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three sustainability pillars (economic, social and environmental) were not considered except for two review studies that evaluated the literature published on rainwater harvesting and results reported positive impacts of this practice on different ecosystem services [109, 110]. Excluding one research carried by Martin-Gorriz [111] which concluded that the use of alternative water resources such as water desalination, reduces the resilience of agricultural systems because this consumes more energy and participates in GHG emissions; results of the documents assessed showed generally positive impacts (**Appendix I**).

3.3.6. Genetic Management

In this category, we have excluded the genetically modified organism for their direct and indirect environmental implications and impacts on human health, despite their enhanced yield potential [112, 113].

Even though breeding is a method supposed to confer higher resilience to agro-ecosystems, Lammerts van Bueren [114] have reviewed current finding in plant breeding and have concluded that all plant breeding orientations adopted up to date (i.e. corporate-, community-, ecosystem- and trait-based breeding), do not create a sustainable agriculture and they suggested a systems-based breeding approach to participate in developing a resilient sustainable agriculture.

Under this category, two practices have been found in the literature: crop diversity and cultivar diversity. Both practices have generated positive results in terms resilience of agro-ecosystems and household food security [due to diet diversification], soil quality and other environmental aspects (i.e. disease control, predator abundance). However, there is disagreement in the literature about the impacts of genetic management on yield increment. While some authors support that crop and cultivar diversity is positively and significantly related to production [115-117], others sustain that productivity increase is observed only in normal years, not in extreme weather events and epidemics [118].

To be noted that most of the research documenting the benefits of diversification have evaluated a single ecosystem service [119].

3.3.7. Biodiversity Management

Methods like agro-ecology, agro-biodiversity, and ecological intensification which apply ecological principles to agriculture have been investigated for the last few decades to promote synergies between biodiversity and social aspects of agro-systems. The papers assessed in this review have shown positive results (**Appendix I**), however, the assessments focused on environmental aspects. Yet, Calderón [120] have indicated that agro-ecology-based farmers in Guatemala had higher levels of food availability than semi-conventional ones during extreme weather seasons.

3.3.8. Knowledge Management

Knowledge management is according to Newman and Conrad [121] “an integration of numerous endeavours and fields of study”, which makes it complicated to define. Thus, based on the latter study and on the efforts made by Boom [122] to define knowledge management, we adopt in this research the following definition:

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"A process to improve performances of individuals, organisations, and systems; and to generate value from intellectual and knowledge-based assets". This includes both tacit and explicit knowledge, the former being based on experiences (e.g. indigenous, local and traditional knowledge), while the latter is recorded in the literature [123]. Both types of knowledge have been recognised 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 move knowledge from tacit to explicit forms [124].

Knowledge management for agricultural systems' resilience is recent in the literature, which explains the limited number of documented studies. The major research topics were the indigenous and traditional knowledge systems with only two studies on meteorological information and knowledge sharing, and all confirmed the importance of these practices for agro-systems resilience (**Appendix I**). These results are a step forward to achieved knowledge transfer and sharing for climate resilience as suggested previously, as they transform indigenous and traditional knowledge from tacit to explicit knowledge. However, to enhance resilience and for sustainable agriculture, more effort should be done to improve the understanding of traditional knowledge for building synergies with scientific knowledge [125, 126].

4. Discussions and Recommendations

Several observations have emerged from the results of this systematic review, we will discuss them, and we will make some recommendations for the scientific community and decision-making in sustainable agriculture related-issues.

Sustainability is a three-dimensional model that requires a change in practices to contravene disciplinary boundaries, thus, reaching transdiciplinarity [127], which is a step forward for interdisciplinarity towards full integration. This is far from being achieved according to Brandt [128], and this review has further demonstrated that, in agriculture, we have not reached a level of interdisciplinarity in which knowledge and methods from different disciplines are integrated into a synthesis approach.

Results have confirmed that different management aspects are studied separately, which in other terms means that the literature has not studied sustainable agriculture, but some practices and technologies which would participate towards sustainable agriculture mainly through the improvement of systems' biodiversity and ecosystem services. To cope with the challenges of sustainable agriculture, changes in management strategies must be based on the integration of all management categories (**Table 3**) to have unique management of agro-systems which accounts for soils, water, crops, genetics, landscape, biodiversity and knowledge with unified quantitative methods for evaluation and assessment.

The ecosystem-based approach described earlier in the paper is the most effective tool to reach this integration for sustainable management of agro-systems under climate change, because it is based on the management of all ecosystem processes or services, improving the ability of crops to maintain yields [94-96]. This is to be done on a life cycle basis as it has been successfully used in the literature in the agro-food

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systems [e.g. 129, 130] because it considers interactions between resources use and potential impacts on biodiversity [131, 132]. Finally, climate change impacts and resilience of agro-systems are highly dependent on local conditions (environment, socio-economic and management), which complicates the process of quantification of sustainable agriculture [133]. Therefore, our recommendations are as follows:

- Integration of all agro-systems services into sustainable management using an ecosystem-based approach on a life-cycle basis using Life Cycle Assessment (LCA[4]) method;
- Improving the scientific understanding of traditional knowledge for higher synergies and further integration;
- Unification of assessment methods and indicators for the quantification of impacts;
- Creation of a platform to share, monitor, screen, and approve assessments and evaluations of sustainable agriculture by region;

5. Conclusion

The number of papers including "sustainable agriculture" found on the scientific databases is very impressive. It constituted almost 10% of the total "agriculture" papers on 'Scopus' (28,509 out of 283,593 papers on 13 February 2019). This systematic review has set the primary question and has researched sustainable agriculture and its impacts on agro-systems' resilience under climate change. Results generated have demonstrated that only single practices and methods have been studied to assess impacts on single ecosystem services. Albeit the assessed practices and methods have shown to improve agro-systems (mainly environmental aspects) and make them more resilient to extreme climate events; we are still far from reaching 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 orient future research strategies and efforts for sustainable agriculture under climate change conditions and for decision-makers who design and finance strategies.

6. Conflict of Interest Statement

The authors certify the absence of any kind of financial or intellectual conflicting interests in this manuscript.

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[4] 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 cradle to grave [134].

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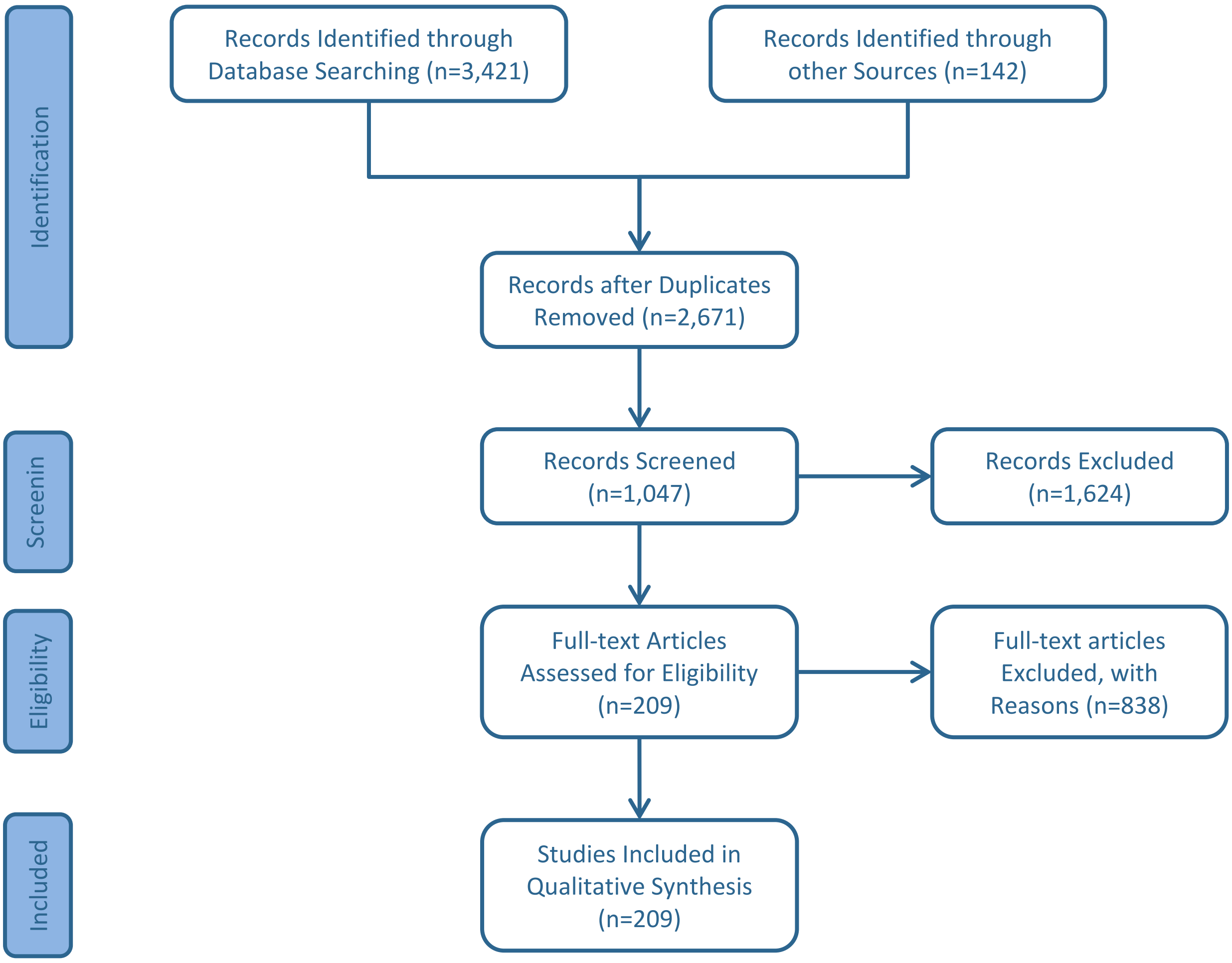

Figure 1: PRISMA flow Diagramme of the research process (After Moher [135])

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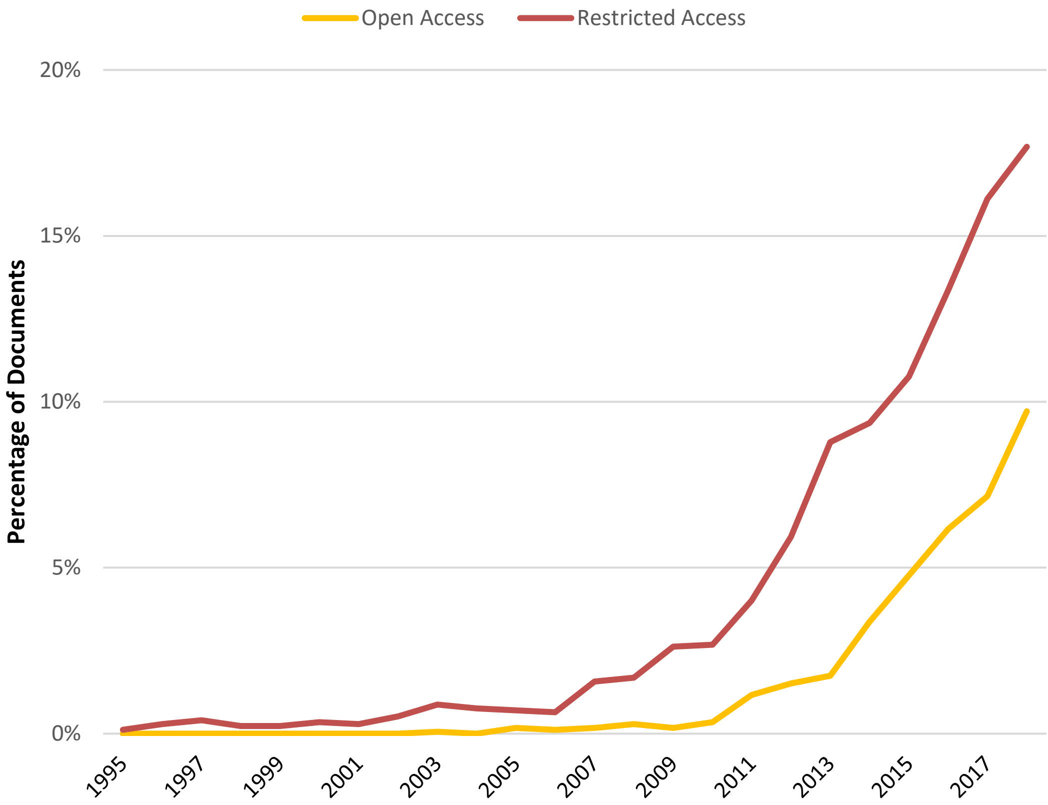

Figure 2: Percentage of documents retrieved by year and access type.

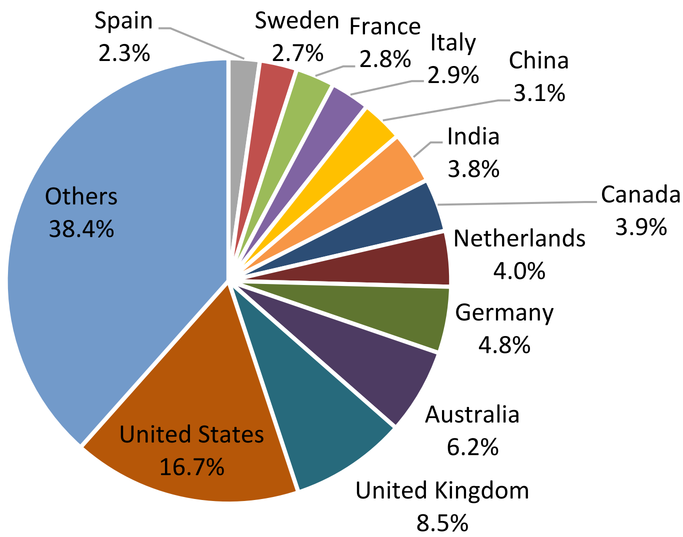

Figure 3: Percentage of documents retrieved by country of publication.

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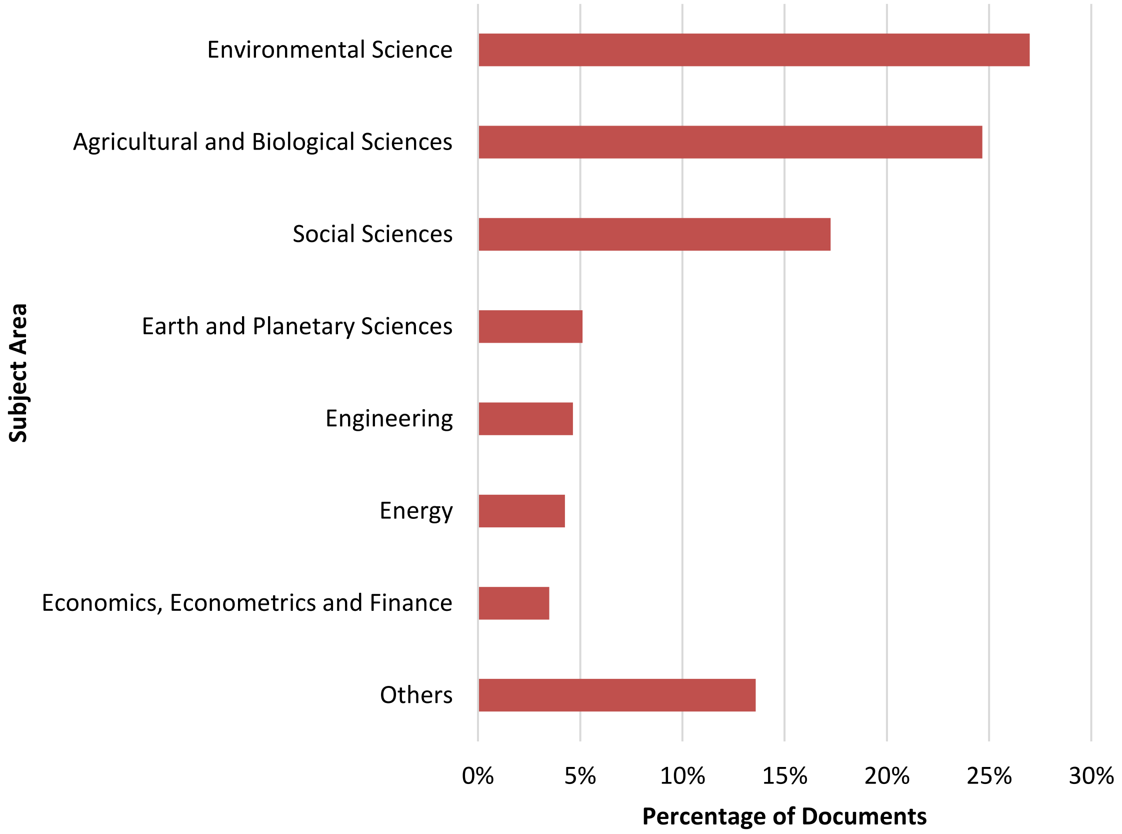

Figure 4: Percentage of documents retrieved by subject area.

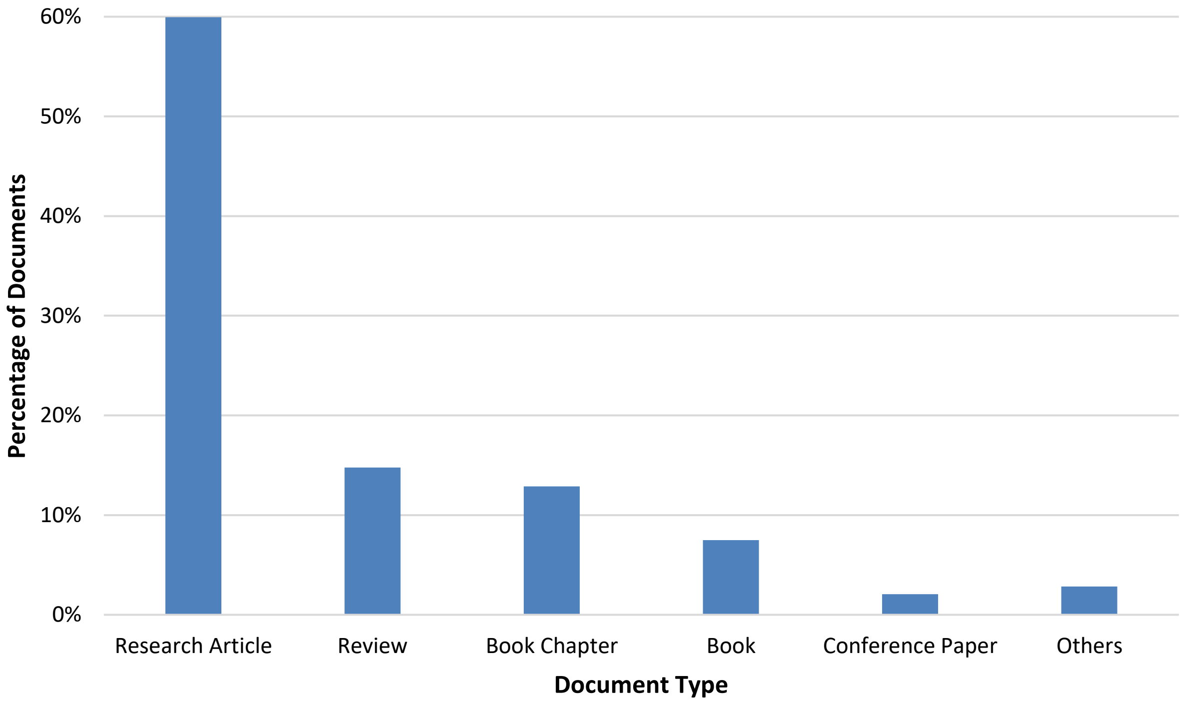

Figure 5: Percentage of documents retrieved by type.

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Table 1. Source of literature retrieved by database and the corresponding number of records

Database	Number of Records	Notes
Scopus	2,351	All records have been retrieved
Science Direct	854	All records have been retrieved
ISI Web of Science	203	All records have been retrieved
DOAJ	13	All records have been retrieved
Grey Literature* (Google, Websites, etc.)	142	First 50 records have been retrieved
Total	**3,563**	
* First 50 records have been retrieved because the following have been assessed and agreed to be repetitive or irrelevant		

Table 2. Synthetic report of the network analysis generated combining titles and keywords by 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 2. resilience, food, sustainable 3. crop, system, farm 4. agriculture, conservation, climate	What is the relation between "agriculture - conservation - climate" and "crop - system - farm"?
	Network structure: total 150 nodes, 0.3 modularity, 32% of words in the top topic (total 6 topics), 100% in the main connected component (1 in total), influence dispersal 50%. Network diversity level: focused		

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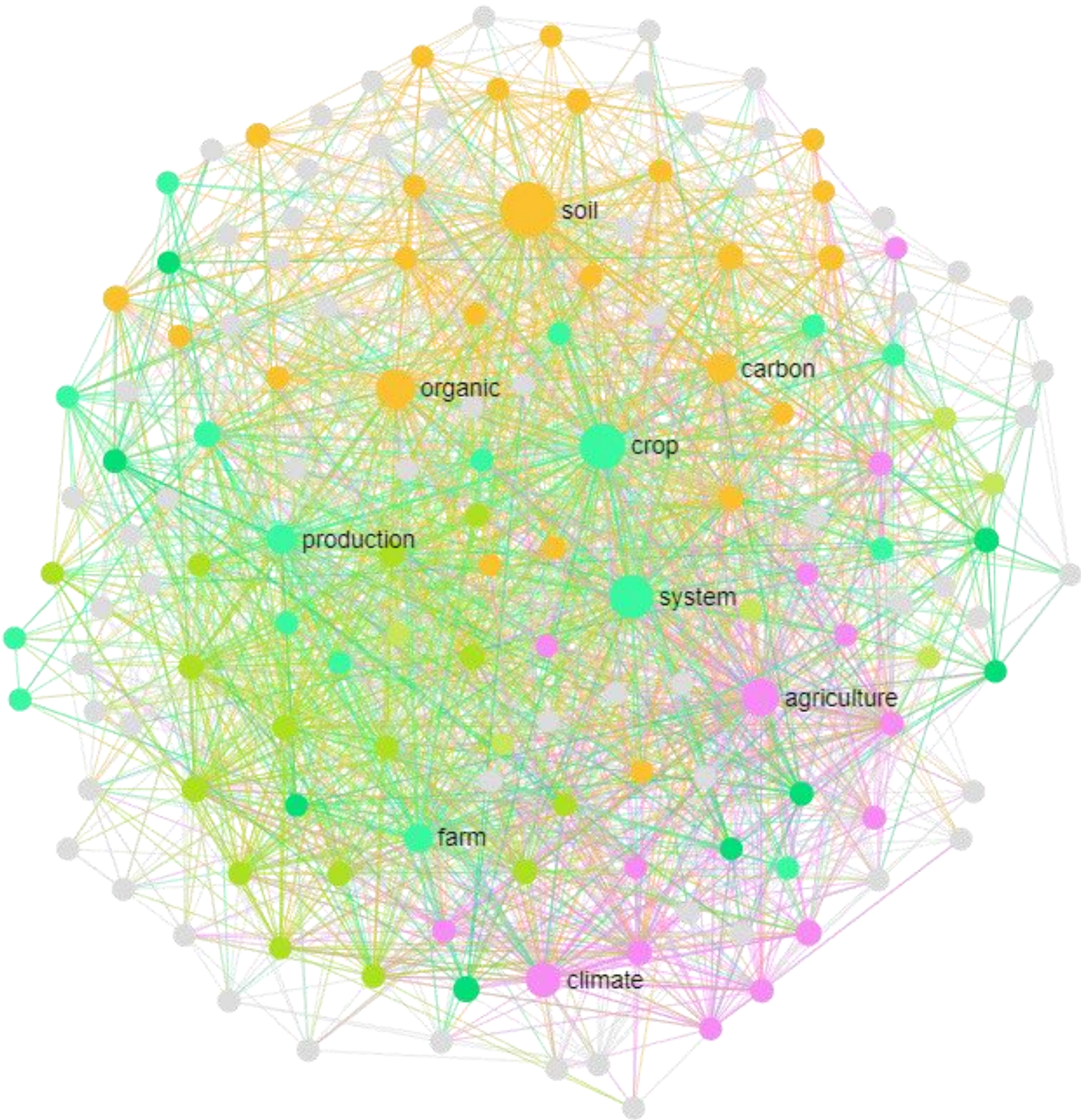

Figure 6: Combined concept network map for titles screened for the final review and the corresponding keywords.

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Table 3. Categorised practices for sustainable agriculture[§]

Category	Agricultural Practices[†]	N° of Reviewed Documents	Impact[*]	Sustainability Dimensions[‡ζƀ]
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 designing 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)	

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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)	
Integrated Management		**86**	**Mostly Positive**	
	Conservation agriculture (CA)	17	+ (14); ± (2); - (1)	
	Integrated Agricultural Systems (IAS)	20	+ (18); ± (1); - (1)	
	Organic agriculture (OA)	19	+ (9); ± (7); - (3)	
	System of Crop Intensification (SCI)	10	+ (8); ± (1); - (1)	
	Climate-smart agriculture (CSA)	2	+ (2)	1D (35); 2D (42); 3D (9)
	Extensive Systems (ES)	2	+ (2)	
	Other integrated practices‡	28	+ (24); ± (3); - (1)	
	Integrated Natural Resources Management (INRM)			
	Nature Based Solutions (NBSs)			

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	Natural System Agriculture (NSA) Diversified Farming Systems (DFS)			

[§] The number of documents per category might differ from the sum of 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.

[ς] 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 dimension (1D) if it assessed soil biological activity and yield it is considered two dimensions (2D).

[†] Agricultural practices with 0 reviewed papers mean: *a)* they were mention mentioned in the literature as sustainable practices but have not been caught by the primary question or b) they 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.