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*Review Article*

## **Bibliometric Analysis of Peer Reviewed Literature on Sustainable Agriculture Research – Challenges and Prospects**

Rashmi Sharma<sup>1</sup> and Rama Sisodia<sup>2\*</sup>

<sup>1</sup> Acharya Narendra Dev College, University of Delhi, New Delhi, 110019

<sup>2</sup> Maitreyi College, University of Delhi, New Delhi, 110021

\*Correspondence: [rsisodia@maitreyi.du.ac.in](mailto:rsisodia@maitreyi.du.ac.in)

### **ABSTRACT**

With the need to fulfil the rising food demands of the increasing population, the agriculture sector faces a huge challenge. The issue is compounded by climatic change, severe shortage of water, increasing salinity, habitat vulnerability and pollution amongst others. Considerable emphasis worldwide is focused on research aimed to sustain as well increase agricultural productivity. The present study focuses on systematically mapping the thrust areas of research related to sustainable agriculture based on search results from SCOPUS database. The retrieved data was analysed using VOS viewer application program to create network maps based on term co-occurrence analysis. The analysis further provides insight into the most active authors, countries, institutions as well as citations. A total of 12,261 documents were retrieved. A significant increase in the number of publications was seen in the last decade. The retrieved documents were contributed by authors belonging to 156 countries and had an average of 6.24 citations per document with an *h*-index of 40. Cluster analysis highlighted three focus areas of research- (1) sustainable agriculture (2) factors affecting crop yield and (3) basic research into plant growth, metabolism, development and aging. The underlying principle of all the research programs pertain to the use of innovative technologies and judicious use of resources for maximal production with due importance to environmental, economic and social aspects.

**Keywords:** Sustainable agriculture, Bibliometric analysis, Research themes, SCOPUS

## 1. INTRODUCTION

Climate change, increasing population, and the need for providing food security have been matters of concern, driving research worldwide to develop crops and adopting tools and technologies ensuring crop productivity (Fróna et al., 2019; Peter et al., 2020; Tian et al., 2021). However, the need to produce food sustainably is important so as to meet the challenge of rising threat to land, water, and biodiversity (Knickel et al., 2017; Mockshell & Kamanda, 2018). There is a need for a comprehensive evaluation of areas of research in the context of sustainable agriculture which can provide an overview of the challenges and thrust areas that require attention. The present study aims to analyze the global research activity in agriculture keeping in view the aspect of sustainability, published in peer-reviewed publications from 1979 to 2021. The analysis is based on bibliometrics- a statistical method that quantitatively analyse the research papers related to a specific topic (Donthu et al., 2021). The approach used in the present study is based on data mining terms from scientific journals listed in the SCOPUS database. The SCOPUS database is one of the largest abstract and citation databases of peer-reviewed literature that also has built-in analysis tools and can also generate representative figures (Baas et al., 2020). The analysis includes the nature of documents, years of publication, source, subject area, major journals, active authors, institutions, countries, keyword frequencies, and citation analysis. A number of bibliometric reviews on various aspects of sustainable agriculture have recently been published. Rocchi et al., (2020) focus on the ecological modernization approach to address sustainability in agricultural systems, while Sweileh (2020) has analyzed literature pertaining to food security in the context of climate change. These studies have stressed the need for harnessing adaptive technologies and innovative solutions. The exact themes and research profiles that are being investigated have not been elucidated in detail. Our study aims to provide a macroscopic view of research areas related to sustainable agriculture that can stimulate future research directions.

## 2. MATERIAL AND METHODS

The study was conducted using the SCOPUS database which is one of the most comprehensive database that offers wide coverage in keyword searching and citation

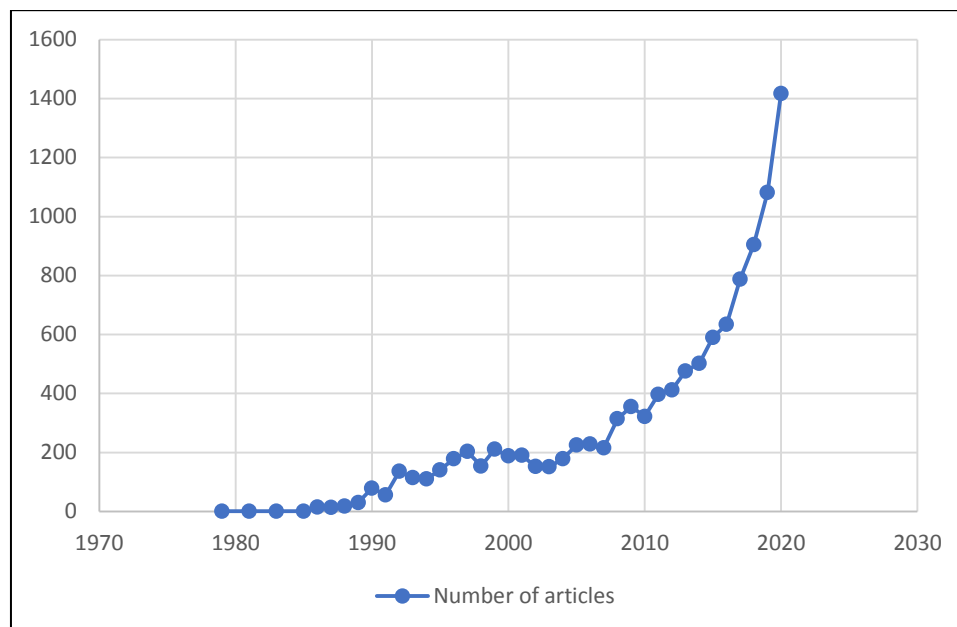
analysis and has been frequently used in bibliometric studies (Lv et al., 2021; Pan et al., 2021). The data between 1979 to 2021 was downloaded from SCOPUS for analysis using the search query “Sustainable Agriculture”. The date of retrieval was 21<sup>st</sup> July 2021. The downloaded search results contained full literature data such as document type, year of publication, title, author, keywords, abstract, references, funding agency, citations. The search was restricted to articles and journals related to the subject area- agriculture and biological sciences. The details of search query: (TITLE-ABS-KEY ("Sustainable agriculture") AND ( LIMIT-TO ( PUBYEAR,2021) OR LIMIT-TO ( PUBYEAR,2020) OR LIMIT-TO ( PUBYEAR,2019) OR LIMIT-TO ( PUBYEAR,2018) OR LIMIT-TO ( PUBYEAR,2017) ) AND ( LIMIT-TO ( DOCTYPE,"ar" ) ) AND ( LIMIT-TO ( SUBJAREA,"AGRI" ) ) AND ( LIMIT-TO ( SRCTYPE,"j" ) ) ). 12,261 articles were retrieved and analyzed. For finding out the current thrust areas of research the search was further restricted to the period of the last five years i.e. between 2017 to 2021 retrieving 1812 articles. The information was downloaded as .csv file and imported into VOSviewer 1.6.16 application software (The Center for Science and Technology Studies, Netherlands; van Eck & Waltman 2010) for creating two-dimensional co-occurrence maps based on keywords. The normalization method was based on association strength. The node size of each keyword represented the frequency of occurrence of the keyword in the retrieved documents. A higher frequency of occurrence was indicated by a larger node size. The impact of publications was measured using the Hirsch -index (*h*-index) which is based on citations of publications.

### **3. RESULTS AND DISCUSSION**

#### **3.1. Publication Trend Overview**

The number of publications showed an increasing trend from 1989 (Figure 1) onwards and the highest number of documents were published in 2020 (1413). The realization that sustainable food production would entail environmental protection was made early on, during the 1980s. The excessive use of synthetic fertilizers and pesticides was contaminating the groundwater and the exposure of humans through drinking water was a matter of concern (Hallberg, 1987). Application of principles of sustainable agriculture, adopting integrated systems of agriculture production that required lesser

input of fertilizers and pesticides and instead of increasing the usage of plant, animal organic water matter for manuring and other conservative agricultural practices was found to be successful (Edwards, 1987). The early eighties also witnessed the beginning of research into biotechnology, aiming to produce herbicide resistance plants (Bunders, 1988). Till about 1991 the number of publications remained below 100 documents per year. A considerable increase in publications was seen after 2010 with the highest growth rate of 30 percent observed from 2019 to 2020.

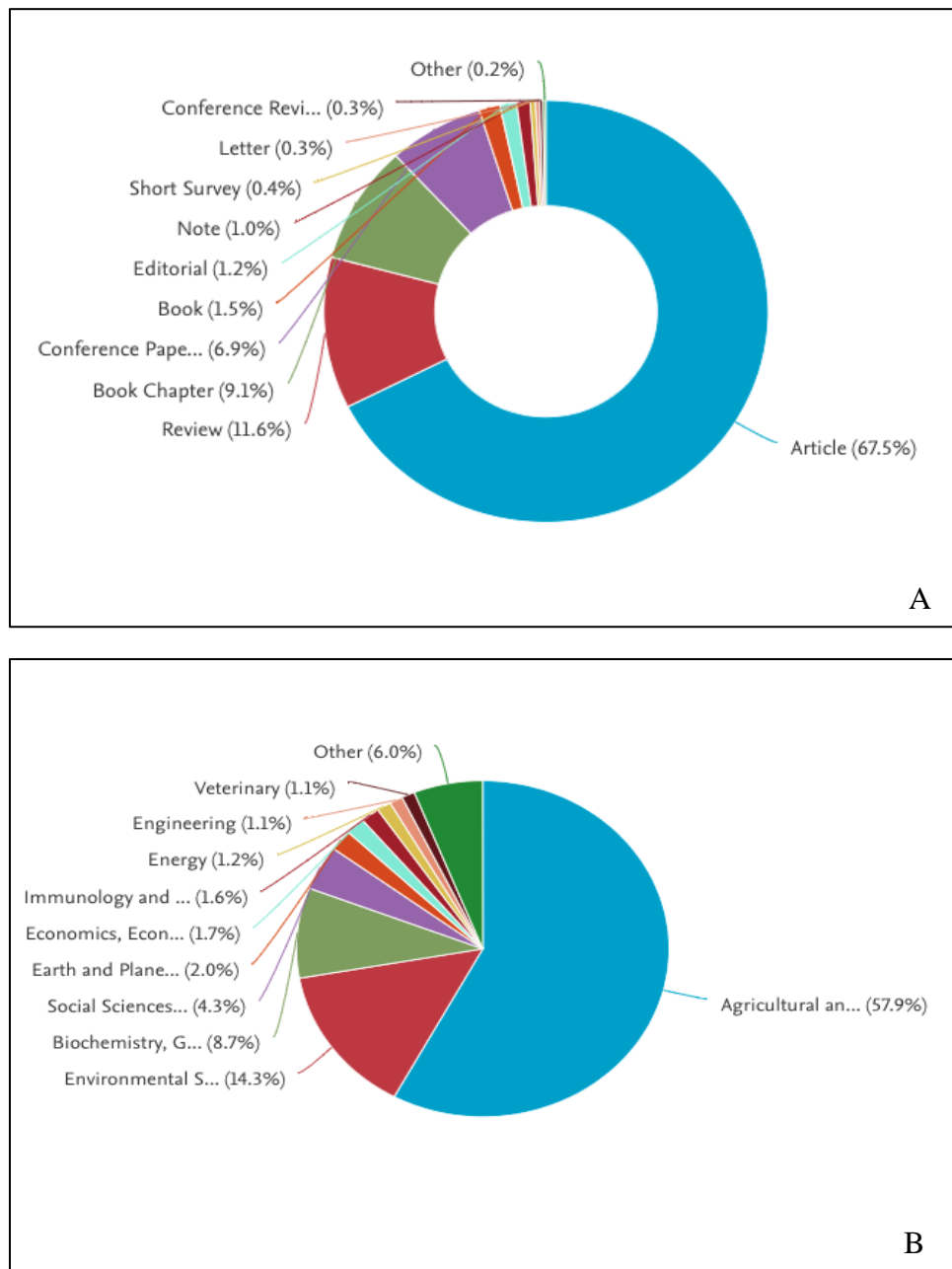


**Figure 1:** Annual growth of publications in focus area of sustainable agriculture (1979-2020). The year 2021 was excluded since it was ongoing year during the preparation of the manuscript.

### 3.2. Types of documents retrieved

12,261 documents were retrieved using the search query “Sustainable Agriculture”. Figures 2 A and B show the types of articles retrieved and the subject areas under which they were indexed. The majority of articles retrieved were research articles (8327; 67.5%) followed by review articles (1447; 11.7%), book chapters (1106; 9.0%), conference papers (851; 6.9 %), books(191; 1.5%), editorials (148; 1.2%), notes (121; 1%), short surveys (46; 0.4%), letters (36; 0.3%), conference reviews (32; 0.3%). All the articles retrieved were in the English language. Most of the documents were indexed under the subject area of agricultural and biological sciences (6780; 29.7%) followed by

environmental sciences (4513; 19.8%), social sciences (2069; 9.1%), biochemistry, genetics, and molecular biology (1595; 7%).



**Figure 2:** A. Pie-chart depicting the type of document and B. subject areas of research of the documents retrieved in the study

### 3.3. Citation analysis

It is understood that highly cited articles have a significant impact on the concerned subject worldwide. The citation analysis of retrieved documents showed 11334 citations

with an average of 6.24 citations per document. Table 1 shows the top ten highly cited articles. The retrieved documents had a *h*-index of 40 with a range of citations from 0 to 264. The most cited (264 times) article was published in 2017 titled “Research priorities for harnessing plant microbiomes in sustainable agriculture” in the journal *PLOS ONE*. The review article promotes research on developing plant microbiome systems to enhance productivity. Five of the most cited articles were research articles and the other five were reviews. These articles discussed the aspects of precision agriculture, conservation biological control, organic farming, use of plant biostimulants, botanical insecticides, and biological control as measures for ensuring resilient and sustainable agriculture

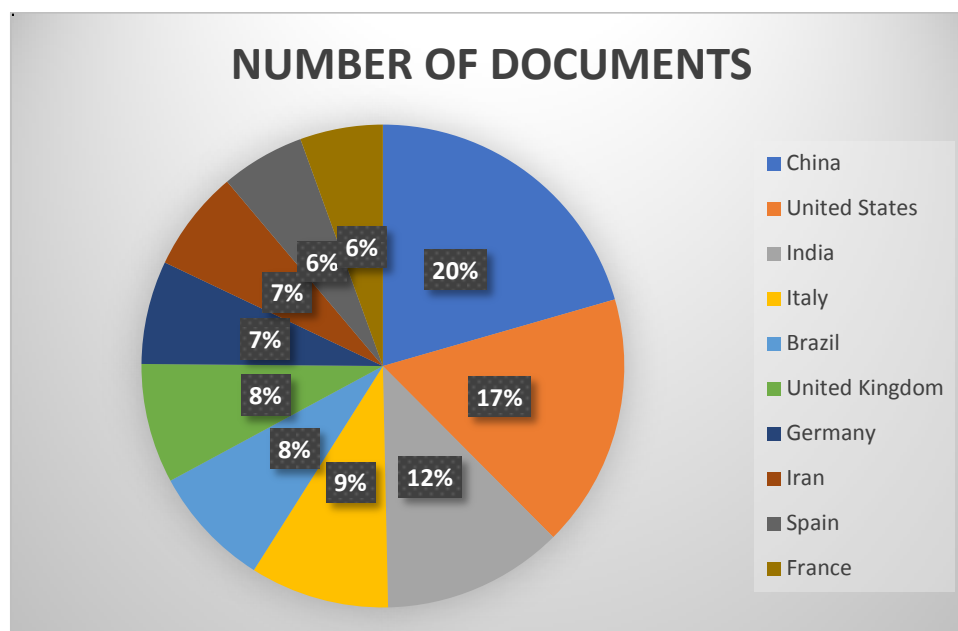
**Table 1:** Top ten most cited articles under the theme of sustainable agriculture.

S.No	Publication year	Document Title	Authors	Journal Title	Total No. of citations
1.	2017	Research priorities for harnessing plant microbiomes in sustainable agriculture	Busby P.E., Soman C., Wagner M.R., Friesen M.L., Kremer J., Bennett A., Morsy M., Eisen J.A., Leach J.E., Dangl J.L.	PLoS Biology	264
2.	2018	Synergistic biostimulatory action: Designing the next generation of plant biostimulants for sustainable agriculture	Rouphael Y., Colla G.	Frontiers in Plant Science	115
3.	2017	Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies	Lindblom J., Lundstrom C., Ljung M., Jonsson A.	Precision Agriculture	109
4.	2017	Drought stress had a predominant effect over heat stress on three tomato cultivars subjected to combined stress	Zhou R., Yu X., Ottosen C.-O., Rosenqvist E., Zhao L., Wang Y., Yu W., Zhao T., Wu Z.	BMC Plant Biology	108

S.No	Publication year	Document Title	Authors	Journal Title	Total No. of citations
5.	2018	Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions	Pigford A.-A.E., Hickey G.M., Klerkx L.	Agricultural Systems	93
6.	2017	Tomato facultative parthenocarp results from SIAGAMOUS-LIKE 6 loss of function	Klap C., Yeshayahou E., Bolger A.M., Arazi T., Gupta S.K., Shabtai S., Usadel B., Salts Y., Barg R.	Plant Biotechnology Journal	90
7.	2017	A functional overview of conservation biological control	Begg G.S., Cook S.M., Dye R., Ferrante M., Franck P., Lavigne C., Lovei G.L., Mansion-Vaquie A., Pell J.K., Petit S., Quesada N., Ricci B., Wratten S.D., Birch A.N.E.	Crop Protection	83
8.	2018	Hydrological and erosional impact and farmer's perception on catch crops and weeds in citrus organic farming in Canyoles river watershed, Eastern Spain	Cerda A., Rodrigo-Comino J., Gimenez-Morera A., Keesstra S.D.	Agriculture, Ecosystems and Environment	80
9.	2018	Titanium dioxide nanoparticles improve growth and enhance tolerance of broad bean plants under saline soil conditions	Abdel Latef A.A.H., Srivastava A.K., El-sadek M.S.A., Kordrostami M., Tran L.-S.P.	Land Degradation and Development	76
10.	2019	Use of botanical insecticides for sustainable agriculture: Future perspectives	Campos E.V.R., Proenca P.L.F., Oliveira J.L., Bakshi M., Abhilash P.C., Fraceto L.F.	Ecological Indicators	74

### 3.4. Geographical distribution of retrieved documents

Geographical distribution analysis was based on country of affiliation of the authors. Publications from authors belonging to 156 countries were retrieved (Figure 3). China, The United States of America, India, Italy, and Brazil were among the top five countries publishing highest number of articles in the period 2017-2021. China, with 285 documents, was the country with highest number of publications.



**Figure 3:** Top ten countries according to author affiliation

### 3.5. Active authors, institutions, and organizations

The identification of the most frequent authors helps to identify potential mentors and reviewers. A total of 160 authors were involved in publications retrieved during the defined period. Seven articles by Youssef Roupael, the most active author in this field were cited 142 times. Five of the top ten authors (Table 2) belonged to Università degli Studi di Napoli Federico II, Naples, Italy. Data analyzed for most active institution/organization showed that the Università degli Studi di Napoli Federico II, Naples, Italy had the highest number of documents (Table 3). Top funding agencies sponsoring research focusing on sustainable agriculture include National Natural Science Foundation, China, and European Commission in the period 2017 (Table 4). The maximum number of articles were published in the journal Agronomy followed by



Frontiers in Plant Science (Table 5). The most cited article in the journal Agronomy was by Gao et al., (2020) and their study recommended the combined usage of bio and organic fertilizers for enhancing growth and reducing the usage of chemical fertilizers.

**Table 2:** Top ten active authors working in the field of sustainable agriculture

Rank	Name	Number of articles	Affiliations
1	Rouphael, Y.	7	Università degli Studi di Napoli Federico II, Naples, Italy
2	Mori, M.	6	Università degli Studi di Napoli Federico II, Naples, Italy
3	Abhilash, P.C.	5	Banaras Hindu University, India
4	Babalola, O.O.	5	North-West University, Potchefstroom, South Africa
5	Colla, G.	5	Università degli Studi di Napoli Federico II, Naples, Italy
6	Di Mola, I.	5	Università degli Studi di Napoli Federico II, Naples, Italy
7	El-Nakhel, C.	5	Università degli Studi di Napoli Federico II, Naples, Italy
8	Fraceto, L.F.	5	UNESP-Universidade Estadual Paulista, Sao Paulo, Brazil
9	Lee, I.J.	5	Kyungpook National University, Daegu, South Korea
10	Li, L.	5	Gansu Agricultural University, Lanzhou, China

**Table 3:** Top ten active institutions involved in research in the field of sustainable agriculture

Institution/Organization	Number of documents
Chinese Academy of Sciences	47
Wageningen University & Research	39
Chinese Academy of Agricultural Sciences	33
Ministry of Agriculture of the People's Republic of China	33
China Agricultural University	32
Ministry of Education China	26
Empresa Brasileira de Pesquisa Agropecuária - Embrapa	26
University of Chinese Academy of Sciences	25
INRAE	24
Università degli Studi di Napoli Federico II	22

**Table 4:** Details of top ten funding agencies sponsoring research in the theme of sustainable agriculture.

<b>Top ten funding agencies</b>	<b>No. of articles</b>
National Natural Science Foundation of China	153
National Key Research and Development Program of China	64
Conselho Nacional de Desenvolvimento Científico e Tecnológico	60
European Commission	59
Ministry of Science and Technology of the People's Republic of China	42
U.S. Department of Agriculture	33
Biotechnology and Biological Sciences Research Council	32
Coordenação de Aperfeiçoamento de Pessoal de Nível Superior	32
Ministério da Ciência, Tecnologia e Inovação	29
European Regional Development Fund	25

**Table 5:** Top ten journals publishing the most number of articles on sustainable agriculture

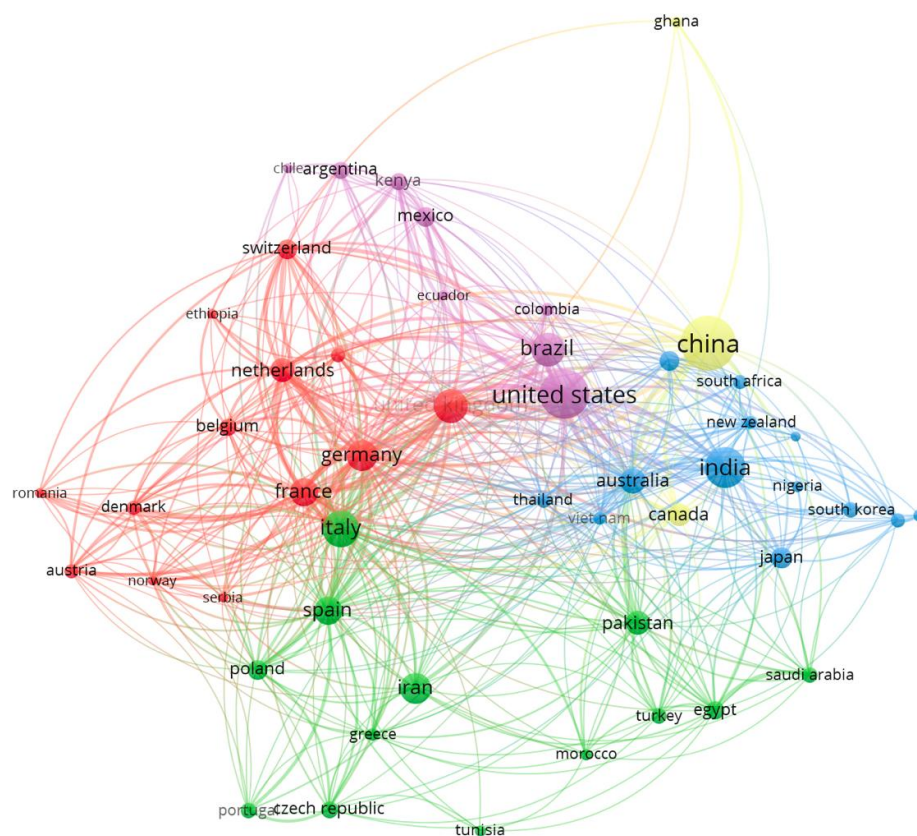
<b>Name of journal</b>	<b>Number of articles</b>
Agronomy	84
Frontiers In Plant Science	59
Agriculture Switzerland	45
Agriculture Ecosystems And Environment	36
Land Use Policy	31
Plants	30
International Journal of Agricultural Sustainability	29
Applied Soil Ecology	26
Frontiers In Sustainable Food Systems	26
Agricultural Systems	23

### 3.6. Bibliometric analysis of keywords

Keywords from the 1674 publications were analyzed using VOSviewer. Keywords that occurred in the title and abstract fields, more than 50 times, were identified. Out of the 12248 keywords, 62 met the threshold. Frequent terms in the abstracts were mapped into



had the highest number of documents; 2274 citations with a total link strength of 149. The main collaborating partners of China were Canada and Ghana. The United States of America, with 237 documents and having 1982 citations, was in second place. The link strength for the US was 245, which was higher than China indicating higher collaborative nature of the projects. The main collaborators of the US were the South American nations of Brazil, Chile, Colombia, Argentina and Mexico. India was at third place with 164 documents, having 997 citations and 73 total link strength. Of the 5090 organizations that were involved in research, collaborations was seen between 21 (with minimum threshold of three documents and three citations).



**Figure 5:** The network map of co-authorship based on affiliation of authors belonging to different countries

### 3.8. Research themes

To understand the main research approaches being pursued worldwide for achieving sustainable agriculture a keyword co-occurrence analysis was performed. Three

closely related research themes were observed in the retrieved documents. Of particular interest was the research theme with a focus on sustainable agriculture. An interplay of issues such as climate change, food security, and food supply and linkage with sustainable development is highlighted in the analysis and these are the driving forces highlighted in research profiles. Soaring population and the interlinked need for ensuring food security has resulted in imposing heavy environmental pressure and changing land and water use (Bufebo & Elias, 2021). Climate change, increasing water shortage, salinization of arable lands has driven researchers to explore the identification of alternative sustainable crops that are able to sustain growth amidst these stresses (Lin et al., 2021; Meco et al., 2019). Greenhouse gases are typical by-products of agriculture and known contributors to climate change. Case studies on carbon footprint assessment based on spatiotemporal pattern of carbon emission and carbon sequestration have been conducted to provide the base for adopting measures to improve carbon sink function and promote sustainable agriculture (Li & Li, 2021; Qiao et al., 2019; G. Zhang et al., 2018). Climate-smart agriculture envisages a mechanism to ensure reducing dependability on environmental resources without affecting productivity (Rampa et al., 2020). Essential to reducing dependency on irrigation and ensuring judicious use of water resources is the research into water use efficiencies of crops (Brombin et al., 2020), identification of cultivars with lower water requirements (Wakchaure et al., 2021), adoption of technology such as adsorption based atmospheric water harvesting (Wang et al., 2021) and use of moisture adsorbent gels (Zhou et al., 2020). Additionally, microclimate modeling techniques to predict crop suitability and enable food production have been studied (Gardner et al., 2021). The use of agrochemicals to enhance crop yield endangers biodiversity and ecosystems (Malaj et al., 2020). Reduced fertilizer usage by replacing it with biofertilizers (Klaic et al., 2021; Tsachidou et al., 2021), ensuring a sustained release of nutrients using amendments such as biochar (Ullah et al., 2020) and nanoparticles (Avellan et al., 2021), soil organic carbon sequestration (Abera et al., 2021; Brombin et al., 2020; Mancinelli et al., 2020), crop rotation (Hirzel et al., 2021; Shrestha et al., 2020), intercropping (Shah et al., 2021), adoption of agroecological practices (Abbasi Surki et al., 2021; Rakotovao et al., 2021), utilization of crop residues for maintaining soil fertility (Berazneva et al., 2018; P.

Zhang et al., 2021) are important for ensuring socio-ecological sustainability. Mathematical modeling to predict the vulnerability of crops to climatic factors enables the utilization of suitable strategies for mitigating effects on crop productivity (Anapalli et al., 2021). Unique strategies such as real-time monitoring of plant growth requirements (Lan et al., 2021), effective nutrient management strategies (Huang et al., 2021) to enhance sustainable use of resources thereby reducing ecological footprints are areas under investigation. Another key research area involved understanding the soil-plant-microbe dynamics, that evolves because of interactions between specific plant phenological stage linked with specific nutrient applied and the particular microbial community that results (Pathan et al., 2020). Enhancement of plant growth using microbial consortia as biostimulants or biofertilizers (Amirnia et al., 2019; Avio et al., 2018; Castiglione et al., 2021; Kandasamy et al., 2021; Rouphael & Colla, 2018) and replacing the use of pesticides with natural pest control agents such as root arbuscular mycorrhizal fungi (Deng et al., 2021), are key to improving productivity without compromising the soil biodiversity, have been investigated in detail. Addressing the concern of soil loss in hilly terrains with the adoption of erosion control measures such as bench terracing for growing crops, highlight the research focus with specific agro-ecological zones in mind (Rutebuka et al., 2021). Increasing awareness amongst farmers, changing their perception towards adoption of sustainable agricultural practices, has also been recognized (Hayran et al., 2018; Nguyen & Drakou, 2021). A number of studies have highlighted the fact that the successful adoption of any strategy and generation of public support will only be useful if it is economically sustainable even for small farm households (Branca et al., 2021; Veluguri et al., 2021). Importantly, the specific strategy adopted would have to be sensitive to regional diversity with specific agro-climatic zones and farmer preferences and behaviors if it is to be successfully implemented (Orduño Torres et al., 2020). Studies have assessed the awareness and attitudes of farmers towards climate change, environmental and human repercussions of the current agricultural practices that need to be modified in order to address sustainable production (Gebaska et al., 2020). The concerns and willingness of farmers to adopt newer strategies and technologies as a means for achieving higher economic gains has been ascertained (Roesch-Mcnally et al., 2020). Small scale projects envisaging the usage of

community-supported farming and interlinking economic viability to such initiatives have shown promise even in regional contexts (Bisht, 2021; Lanker et al., 2020). A holistic approach that addresses economic, social, and environmental concerns will hold the key to developing viable sustainable agricultural systems (Daniel, 2020).

### **3.9. Limitations**

The current study has focused on literature retrieved from the Scopus database. The counting of articles was based on affiliation. This limits the data since a document having several authors is counted only once whereas a document having two authors from different countries is counted once for each country. A bias could also have been created since self-citations were not excluded. Also, the search query was based on the theme of sustainable agriculture which has broad and complex scope making it difficult to ensure complete inclusion of literature on the topic. However, the authors have included suitable restrictions to keep the key area in focus.

## **4. CONCLUSION**

Against the backdrop of climate change and increasing population, the challenge faced by scientists is how to enhance food production without compromising the environment. Currently, the research focus worldwide is on providing innovative solutions to meet these challenges. Sustainable agriculture management advocates measures to promote soil carbon sequestration, increasing soil fertility by modifying the microbiome, nutrient management using life-stage specific delivery, adoption of crops with higher resilience. The case studies offer the possibility for wider geographical adoption with suitable amendments ensuring a balance between productivity and ecosystem values. Future research needs to be collaborative and transdisciplinary and should focus on providing innovative agroecological solutions tailor-made to address the regional issues while balancing economic productivity within sustainability for the present as well as future generations.

## **5. CONFLICT OF INTEREST**

The authors declare that they have no conflict of interest.

## 6. ACKNOWLEDGEMENT

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None

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