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MAPPING GLOBAL RESEARCH ON SUSTAINABLE COTTON PRODUCTION: A BIBLIOMETRIC ANALYSIS OF ORGANIC FARMING, YIELD AND QUALITY, NATURAL FARMING, AND ECOSYSTEM SERVICES

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Abstract:
Cotton (*Gossypium* spp.) is an important fibre crop, and its production increasingly faces challenges associated with climate variability, resource depletion, soil degradation, and environmental impacts of intensive input use. So, sustainable production requires integration of productivity, fibre quality, resource-use efficiency and ecosystem functions. This study mapped research on sustainable cotton production, with emphasis on organic farming, natural farming, yield and fibre quality, and ecosystem services, using bibliometric and science-mapping approaches. Bibliographic records were retrieved from Scopus for 2010-2026 using four thematic searches and analysed using *Biblioshiny* and *Bibliometrix* in R. After screening and integration, 989 publications from 302 sources, involving 3,575 authors and 45,915 references, were analysed. Scientific production showed an increasing trend, with a marked increase after 2020 and a peak of 102 publications in 2025. China and the United States were the leading contributors and collaboration hubs. Life-cycle analysis indicated that the field remains in an expansion phase, with a projected peak of approximately 136 publications in 2042.6. Keyword and co-occurrence analyses showed that cotton yield, fibre quality, soil organic matter, organic carbon, irrigation, water-use efficiency, nutrient management, and soil quality were major research themes. Thematic evolution revealed a shift from conventional field management and yield improvement toward integrated resource management, soil health, quality-oriented production, and climate-responsive practices. The results concluded that sustainable cotton research is becoming multidisciplinary and systems oriented. The future research should integrate organic and natural farming with precision water and nutrient management, biodiversity, ecosystem services, climate resilience, digital technologies, and advanced breeding approaches to develop productive, resource-efficient, and environmentally responsible cotton production systems.

Keywords: Sustainable cotton; Organic farming; Natural farming; Fibre quality; Ecosystem services

1. Introduction

Cotton (*Gossypium* spp.) is a globally important fibre crop that contributes substantially to agricultural economies, rural livelihoods and the textile industry. In addition to fibre, cotton provides edible oil, protein-rich seed products, animal feed and industrial raw materials. Growing demand for natural fibres, coupled with concerns over environmental degradation, resource depletion, and climate variability, has increased the need for sustainable cotton production systems that maintain productivity while reducing environmental impacts (Vitale et al., 2025). Consequently, research has expanded beyond yield to include alternative farming practices, fibre quality, soil health, biodiversity, and ecosystem functioning (Yosung *et al.,* 2020).

Conventional cotton production often depends heavily on synthetic fertilizers, pesticides, irrigation and other external inputs. Poorly managed input use can contribute to soil degradation, water contamination, biodiversity loss and disruption of beneficial agroecosystem processes. Cotton production is also increasingly affected by water scarcity, climatic variability, declining soil fertility and pest pressure (Honfoga, 2018). These challenges have stimulated research on production approaches that improve resource-use efficiency and ecological sustainability. Organic and natural farming have therefore received increasing attention as alternatives for reducing synthetic inputs while promoting soil biological activity, nutrient cycling, biodiversity, and ecosystem health.

Organic cotton production emphasizes organic nutrient sources, biological inputs, ecological pest management, and reduced dependence on synthetic chemicals. Research has evaluated its effects on crop growth, yield, fibre quality, soil fertility, microbial activity, carbon dynamics, input use and profitability (Venugopalan et al., 2010). Natural farming represents another emerging approach based on ecological processes, locally available biological

resources, reduced external inputs, and improved soil-plant-microbial interactions. Although both approaches share sustainability-oriented principles, their management practices and scientific foundations differ (Saha and Biswas, 2026). Assessing their effects on cotton productivity, resource use, and environmental performance is therefore essential for developing context-specific sustainable production strategies.

Yield and fibre quality remain key indicators of cotton production performance and economic viability. Cotton yield is influenced by genotype, nutrient and water availability, pest and disease pressure, environmental conditions, and crop management. Fibre properties, including length, strength, micronaire, and uniformity, determine processing suitability and market value (Scarpin et al., 2025). Sustainable production must therefore balance environmental benefits with agronomic and economic performance. Increasing research has consequently investigated whether alternative systems can reduce external inputs while maintaining or improving yield, fibre quality, profitability, and long-term soil productivity.

The ecosystem-service perspective has further broadened sustainability assessment beyond yield and economic returns. Cotton agroecosystems contribute to nutrient cycling, carbon sequestration, soil organic matter maintenance, biological pest regulation, pollination, water regulation, and soil biodiversity (Power, 2010). Farming practices can influence these services by modifying soil biological communities, habitat diversity, resource availability, and crop-organism interactions. Integrating productivity, quality, farming practices, and ecosystem services therefore provides a comprehensive framework for assessing cotton sustainability and resilience.

Despite growing interest, sustainable cotton research remains dispersed across agronomy, soil science, ecology, crop physiology, agricultural economics, and environmental science. Organic cotton studies often focus on soil fertility and input management, whereas natural farming research emphasizes ecological processes and biological inputs (Cassman and Grassini, 2020). Other studies concentrate on yield and fibre quality, while ecosystem-service research addresses biodiversity, soil functions, carbon dynamics, and resource conservation. Although these themes are interconnected, their collective development and relationships within the global research landscape remain insufficiently characterized.

Bibliometric analysis provides a quantitative approach for systematically evaluating large scientific literature. Publication and citation analysis, collaboration networks, keyword co-occurrence, bibliographic coupling, thematic mapping, and science visualization can identify influential authors, institutions, countries, journals, publications, research themes, and emerging research priorities (Brumă et al., 2023). However, comprehensive bibliometric research integrating organic farming, natural farming, cotton yield and fibre quality, and ecosystem services within a unified sustainable cotton framework remains limited.

Therefore, this study aimed to map the global research landscape of sustainable cotton production using bibliometric and science-mapping approaches, with emphasis on organic farming, natural farming, yield and fibre quality, and ecosystem services. Specifically, the study aimed to: (i) evaluate publication growth and research productivity; (ii) identify leading countries, authors and influential publications; (iii) examine collaboration networks and intellectual structures (iv) identify major research themes and their interrelationships (v) analyse emerging keywords and thematic evolution (vi) identify knowledge gaps and future research directions. By integrating bibliometric performance analysis with science mapping, this study provides a comprehensive overview of the evolution, structure, and emerging priorities of sustainable cotton research, supporting future development of productive, resource-efficient, environmentally responsible, and climate-resilient cotton production systems.

2. Materials and methods:

2.1. Conceptual framework

The conceptual framework integrates four major dimensions of sustainable cotton production: organic farming, natural farming, yield and fibre quality, and ecosystem services. It also incorporates bibliometric analysis to examine the global evolution of research and identify emerging research directions (Figure 1). Organic and natural farming represent alternative approaches for reducing external inputs and improving ecological sustainability, while yield and fibre quality indicate agronomic and economic performance. Ecosystem services broaden sustainability assessment by considering soil health, nutrient cycling, carbon sequestration, biodiversity, and biological regulation (Saharan et al., 2022).

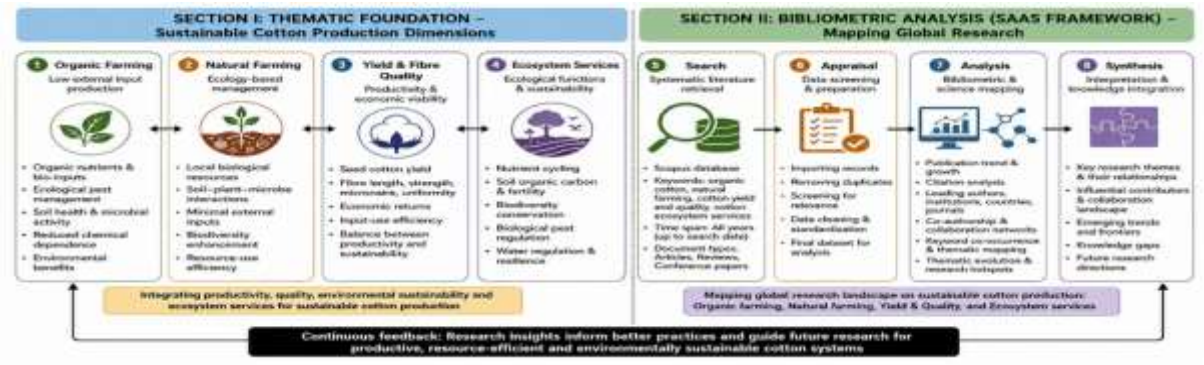


Figure 1. Conceptual framework for mapping global research on sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services, and the SAAS-based bibliometric analysis workflow.

The framework links these components to emphasize that farming practices can influence cotton productivity, fibre quality, resource use, and ecosystem functions. Thus, sustainable cotton production is positioned at the intersection of productivity, quality, environmental sustainability, and ecosystem functioning. Bibliometric analysis maps the development of scientific knowledge across these interconnected themes using the SAAS (Search-Appraisal-Analysis-Synthesis) workflow (Cuccurullo et al., 2013). The Search stage retrieves relevant Scopus publications using predefined terms related to organic cotton, cotton yield and quality, natural farming, and ecosystem services. The Appraisal stage involves screening, data cleaning, duplicate removal, and standardization to ensure dataset quality. The Analysis stage evaluates publication trends, citations, leading contributors, collaboration networks, keyword co-occurrence, bibliographic relationships, and thematic patterns to identify major research themes and emerging topics (Aria and Cuccurullo, 2017; R core team, 2025).
Emphasis is placed on the relationships among organic farming, natural farming, yield and quality, and ecosystem services within sustainable cotton research. Synthesis stage integrates the findings to identify influential research areas, emerging hotspots, knowledge gaps, and future priorities. The framework provides a roadmap for understanding the evolution and interconnections of sustainable cotton research and for identifying opportunities to develop productive, resource-efficient, and ecologically resilient cotton production systems.

2.2. Data collection

The bibliographic data used in this study were retrieved exclusively from the Scopus database, one of the largest and most comprehensive multidisciplinary scientific databases widely used for bibliometric research because of its extensive coverage, standardized indexing, and reliable citation information. Scopus provides high-quality bibliographic records that facilitate science mapping, citation analysis, and visualization of research trends across diverse disciplines (Misra et al., 2021). The methodology of data collection and analysis is illustrated in Figure 2.

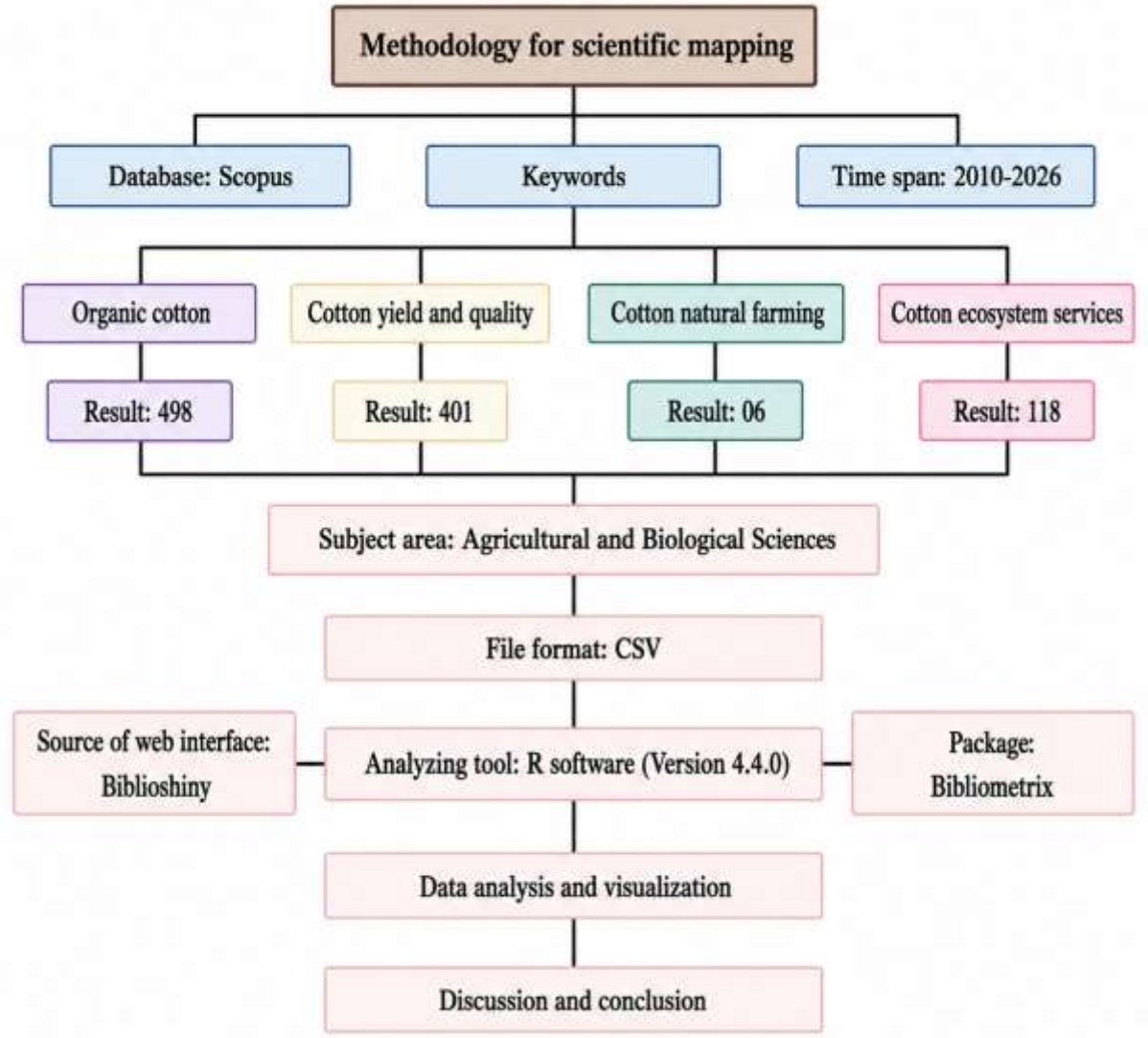


Figure 2. Methodology adopted for scientific mapping of research on organic and natural cotton farming and cotton ecosystem services.

The literature search was conducted using four thematic keyword combinations to capture the major dimensions of sustainable cotton production, namely organic farming, yield and fibre quality, natural farming, and ecosystem services. All searches were restricted to the publication period 2010-2026 and limited to the subject area *Agricultural and Biological Sciences* to improve the relevance and consistency of the retrieved literature. The first

search used the keyword '*organic cotton'*, which retrieved 498 publications. The second search used '*cotton yield and quality'*, resulting in 401 publications. The third search used '*cotton natural farming'*, which retrieved 6 publications, reflecting the relatively limited development of research specifically addressing natural farming in cotton. The fourth search used '*cotton ecosystem services*', yielding 118 publications. These four thematic searches were designed to capture the principal research dimensions examined in the present study.

The records retrieved from the four searches were exported from Scopus for subsequent bibliometric analysis. Prior to analysis, the datasets were examined for consistency, and bibliographic information was standardized where necessary. The records from the four thematic searches were subsequently integrated to develop a comprehensive dataset representing global research on sustainable cotton production. The combined dataset was then imported into Biblioshiny, the web interface of the Bibliometrix package in R, for bibliometric performance analysis and science mapping.

The four searches collectively identified 1,023 records before integration and screening. The resulting dataset formed the basis for evaluating publication growth, research productivity, citation patterns, collaboration networks, influential authors and publications, thematic structures, keyword relationships, thematic evolution, and emerging research trends. By integrating these four thematic dimensions, the analysis provides a comprehensive assessment of the global research landscape surrounding sustainable cotton production, with particular emphasis on organic farming, yield and fibre quality, natural farming, and ecosystem services. The documents and metrics overview mentioned in Figure 3.



Figure 3. The overview of the main information

2.3. Data analysis and visualization

The retrieved bibliographic records were analysed using Biblioshiny, the web interface of the Bibliometrix package in R, together with Microsoft Excel for data organization, verification, and graphical presentation. Bibliometrix is a widely recognized open-source bibliometric package that provides comprehensive tools for quantitative analysis, science mapping, and visualization of scientific literature. The Biblioshiny interface enables interactive analysis of publication performance, citation patterns, collaboration networks, keyword relationships, thematic structures, and research evolution (Aria et al., 2021).

The cleaned and integrated Scopus dataset representing the four major dimensions of sustainable cotton production, namely organic farming, yield and fibre quality, natural farming, and ecosystem services, was imported into Biblioshiny for bibliometric analysis. Various descriptive and science-mapping techniques were employed to characterize the global research landscape of sustainable cotton production. These included annual scientific production, source analysis, authorship patterns, country and institutional productivity, citation analysis, collaboration networks, keyword co-occurrence, thematic mapping, thematic evolution, trend topic analysis, and conceptual structure analysis. These analyses provided insights into the development, intellectual structure, research hotspots, collaboration patterns, and emerging themes within sustainable cotton research. Microsoft Excel was used to organize the bibliographic data, verify descriptive statistics, and prepare tables and graphical presentations. Key bibliometric indicators, including the number of publications, sources, authors, author keywords, references, annual growth rate, average citations per document, international co-authorship, and co-authors per document, were summarized to describe the overall characteristics of the dataset (Table 1).

Based on the objectives of the study, the bibliometric indicators evaluated included: (i) annual publication trends and scientific growth (ii) the most productive journals, authors, institutions, and countries (iii) citation performance of publications, authors, and sources; (iv) international collaboration networks (v) author keyword frequency, co-occurrence, and emerging trends (vi) thematic mapping and thematic evolution (vii) the conceptual structure and intellectual development of sustainable cotton research. These analyses enabled a comprehensive assessment of the global development of research on organic farming, yield and fibre quality, natural farming, and ecosystem services in cotton, while facilitating the identification of influential contributors, major research themes, emerging research hotspots, and potential future research directions.

Table 1. The overall information on bibliometric data

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2010:2026
Sources (Journals, Books, etc)	302
Documents	989
Annual Growth Rate %	2.36

Document Average Age	6.6
Average citations per doc	19.52
References	45915
DOCUMENT CONTENTS	
Keywords Plus (ID)	5746
Author's Keywords (DE)	3119
AUTHORS	
Authors	3575
Authors of single-authored docs	22
AUTHORS COLLABORATION	
Single-authored docs	23
Co-Authors per Doc	5.92
International co-authorships %	19.21
DOCUMENT TYPES	
article	937
book chapter	23
conference paper	11
review	13

3. Results

3.1. Descriptive statistics of the study data, annual trend, and countries' contributions

A total of 989 publications related to sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services were published between 2010 and 2026, with annual scientific production showing an overall increasing trend. Publication output remained relatively stable during the early period (2010-2019), generally ranging between 34 and 53 articles per year, followed by a noticeable increase from 2020 onwards. Scientific production reached 75 publications in 2020 and continued to rise, attaining its highest level of 102 publications in 2025, indicating growing global research interest in understanding abiotic stress responses, stress tolerance mechanisms, and climate-resilient cotton production. Although the number of publications declined to 61 in 2026, this comparatively lower output is likely attributable to the incomplete indexing of publications at the time of data retrieval. Citation impact also varied across the study period, with the highest mean total citations per article (40.59) recorded in 2015, while the highest mean total citations per year (3.52) was observed in 2022 (Figure 4).

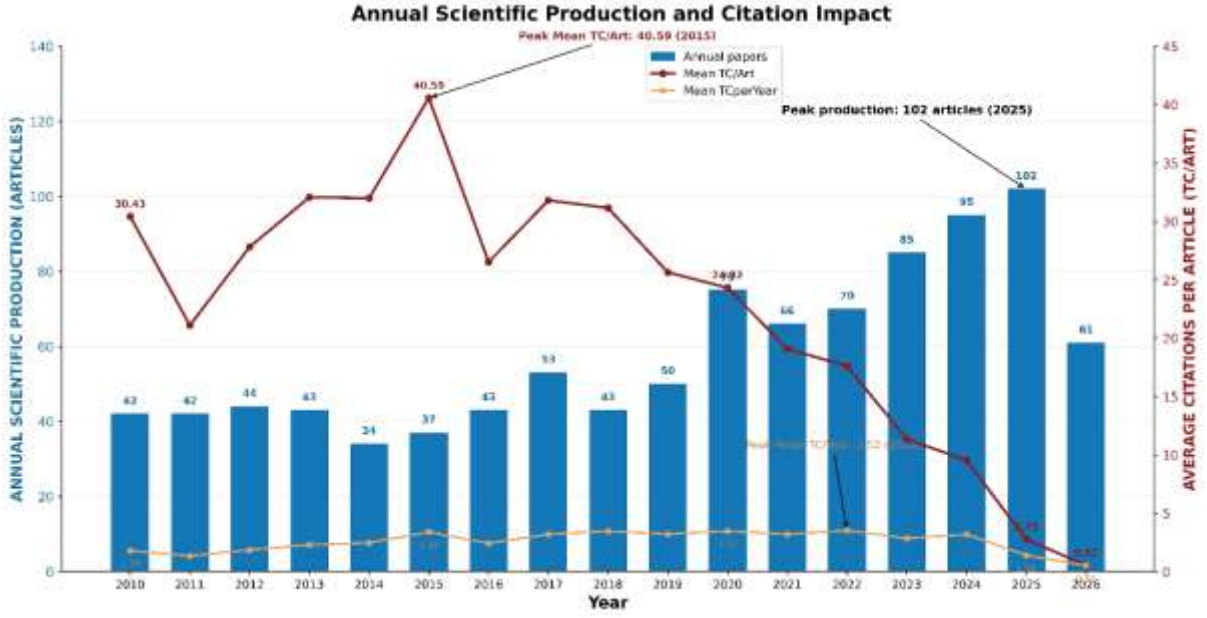


Figure 4. Evolution of annual scientific production and average citation impact (2010-2026).

This comprehensive view combines annual publication output with citation impact indicators, including Mean TC/Art (total citations per article) and Mean TC/Year (total citations per year), highlighting the increasing research productivity and variation in citation impact over the study period. The figure shows the peak scientific production in 2025 and the highest Mean TC/Art in 2015, while the primary and secondary Y-axes are used to represent the divergent scales of publication output and citation impact.

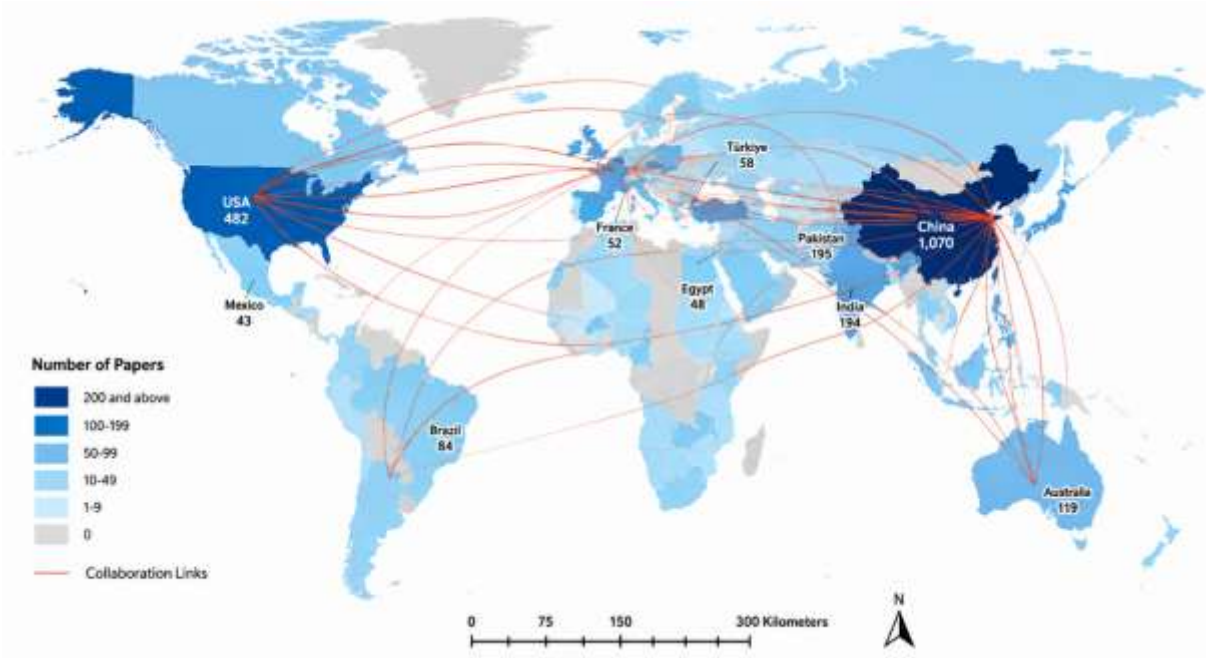


Figure 5. Global scientific collaboration network and country-level collaboration structure in sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services (2010-2026). World collaboration map illustrating the geographical distribution of publications and international research collaborations, where country color intensity represents publication output and connecting lines indicate collaborative links between countries

Country-wise scientific production revealed that China was the leading contributor, accounting for 1,070 publications, followed by the United States (482), Pakistan (195), and India (194). Other notable contributors included Australia (119), Brazil (84), Türkiye (58), France (52), Egypt (48), and Mexico (43). The geographical distribution of publications indicates that research on sustainable cotton production is concentrated mainly in major cotton-producing and research-intensive countries. These studies broadly focus on organic farming, natural farming, yield and fibre quality, and ecosystem services, reflecting growing scientific interest in developing sustainable and resource-efficient cotton production systems. The dominance of China and the United States highlights their substantial contributions to research on sustainable cotton production, particularly in improving production efficiency, enhancing yield and fibre quality, promoting environmentally friendly farming practices, and strengthening ecosystem services.

The country collaboration network demonstrated extensive international research linkages among major contributing countries (Figure 5). The strongest collaboration was observed between China and the United States, with a collaboration frequency of 29, followed by China-Pakistan (17), China-Australia (11), China-Canada (8), and United States-Canada (7). Additional collaborative connections were observed between China and France, China and Switzerland, Pakistan and Saudi Arabia, United States and Mexico, and Mexico and Switzerland. These linkages demonstrate the increasingly international nature of sustainable cotton production research, involving countries across Asia, North America, Europe, Oceania, and South America. The strong position of China as both a major producer of scientific publications and a central collaboration hub indicates its important role in coordinating international research activities. Such collaborative networks facilitate knowledge exchange, sharing of research expertise and resources, and integration of organic farming, natural farming, yield and fibre quality improvement, and ecosystem services approaches. These collaborations contribute to the development of more sustainable, resource-efficient, and environmentally responsible cotton production systems. The overall pattern is consistent with the broader bibliometric dataset, which recorded an international co-authorship rate of 18.31%, demonstrating that international collaboration constitutes an important component of global research on sustainable cotton production.

3.2. Life cycle of scientific production

The life cycle analysis revealed a rapidly expanding research trend on sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services over the study period (Figure 6). During the initial phase, annual publication output remained relatively low, indicating the emerging nature of the research domain. A progressive increase in publications was observed in subsequent years, with a noticeable acceleration during the recent period, reflecting growing scientific interest in advancing sustainable cotton production through organic farming, natural farming, yield and fibre quality improvement, and ecosystem services. The logistic growth model showed a good fit to the observed publication data ($R^2 = 0.688$) and predicted a peak scientific productivity of approximately 136 publications in 2042.6, indicating that the research field is expected to continue expanding before reaching its maximum growth phase.

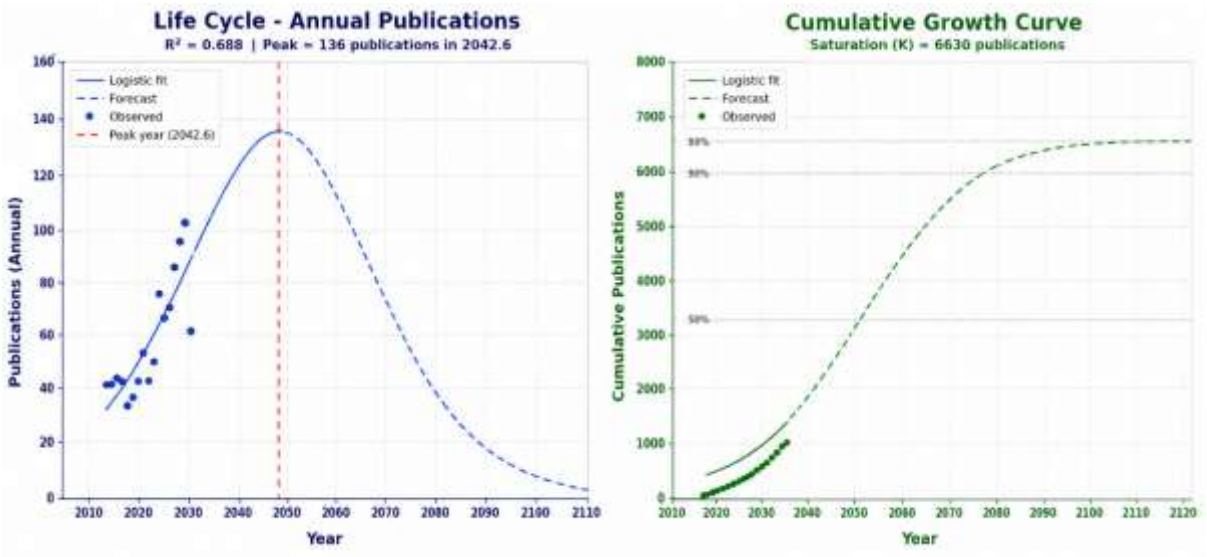


Figure 6. Life Cycle Analysis of Scientific Production and Cumulative Growth in sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services (2010-2026).

The figure presents the observed annual publication trend, logistic growth fit, projected publication trajectory, and estimated peak scientific productivity (136 publications in 2042.6; $R^2 = 0.688$), together with the cumulative growth curve and projected saturation level (K = 6,630 publications), illustrating the long-term growth and future development potential of the research field.

The cumulative growth curve exhibited a characteristic sigmoidal pattern, with an estimated saturation level or carrying capacity (K = 6,630 publications). The model indicates that cumulative scientific production is expected to increase substantially in the coming decades before gradually approaching the estimated saturation level. This relatively high carrying capacity suggests considerable scope for further research and expansion within the field. Future research is likely to increasingly focus on functional genomics, transcriptomics, genome editing, molecular breeding, phenomics, and advanced stress-screening approaches to improve cotton resilience under changing climatic conditions. Overall, the life cycle analysis indicates that abiotic stress tolerance research in cotton remains an actively developing field with substantial future growth potential, rather than having already reached complete maturity.

3.3. Keywords, thematic clustering, and co-occurrence network analysis

The word cloud analysis highlighted the most frequently occurring terms in the literature on sustainable cotton production, providing an overview of the dominant research themes within the field (Figure 7A). As expected, *cotton* and *Gossypium hirsutum* were the most prominent terms, reflecting their central role in the research domain. Other frequently occurring terms, including *fiber quality, crop yield, cotton yield, yield, seed cotton yield,* and *crop production*, indicate a strong research emphasis on improving cotton productivity and fibre characteristics. The prominence of terms such as *soil organic matter, organic carbon, soil quality, soils, nitrogen, fertilizer application,* and *cultivation* demonstrates increasing attention to soil fertility management, nutrient cycling, and soil health as important components of sustainable cotton production. Similarly, the occurrence of *irrigation, cotton drip irrigation,* and *water use efficiency* highlights the importance of efficient water management for improving cotton productivity under resource-constrained conditions. Terms such as *biomass, physiology, nitrogen, varieties,* and *fertilizer application* further indicate the integration of crop growth, nutrient management, and agronomic practices in sustainable cotton production research.

The keyword co-occurrence network further illustrated the conceptual relationships and thematic structure of sustainable cotton production research (Figure 7B). The network was organized into several interconnected clusters, with *cotton* occupying the most central position and showing extensive associations with *crop yield, cotton yield, irrigation, drip irrigation, fiber quality, seed cotton yield,* and *yield*. These interconnected terms indicate that productivity, fibre quality, and efficient resource utilization constitute major research priorities. A prominent cluster surrounding *Gossypium hirsutum* was strongly associated with *soil organic matter, organic carbon, soil quality, soil fertility, crop rotation, cropping practice, crop production, nitrogen,* and *fertilizers*, highlighting the importance of soil and nutrient management in sustainable cotton-based production systems. The presence of *organic carbon, soil carbon,* and *soil quality* within this cluster further demonstrates growing interest in maintaining soil health and enhancing ecosystem functions through improved production practices.

Another interconnected cluster was characterized by *cotton, crop yield, irrigation system, drip irrigation, water use efficiency, seed cotton yield,* and *fiber quality*, emphasizing the relationship between water management, yield formation, and fibre performance. The network also contained a smaller cluster involving *volatile organic compounds, metabolism, chemistry, physiology,* and *animals*, suggesting research extending beyond conventional agronomic production towards plant physiological processes, biochemical interactions, and ecological dimensions. Co-occurrence network demonstrates that research on sustainable cotton production has evolved

beyond a narrow focus on yield to encompass soil health, organic carbon management, nutrient use, water-use efficiency, fibre quality, crop productivity, and ecological processes.

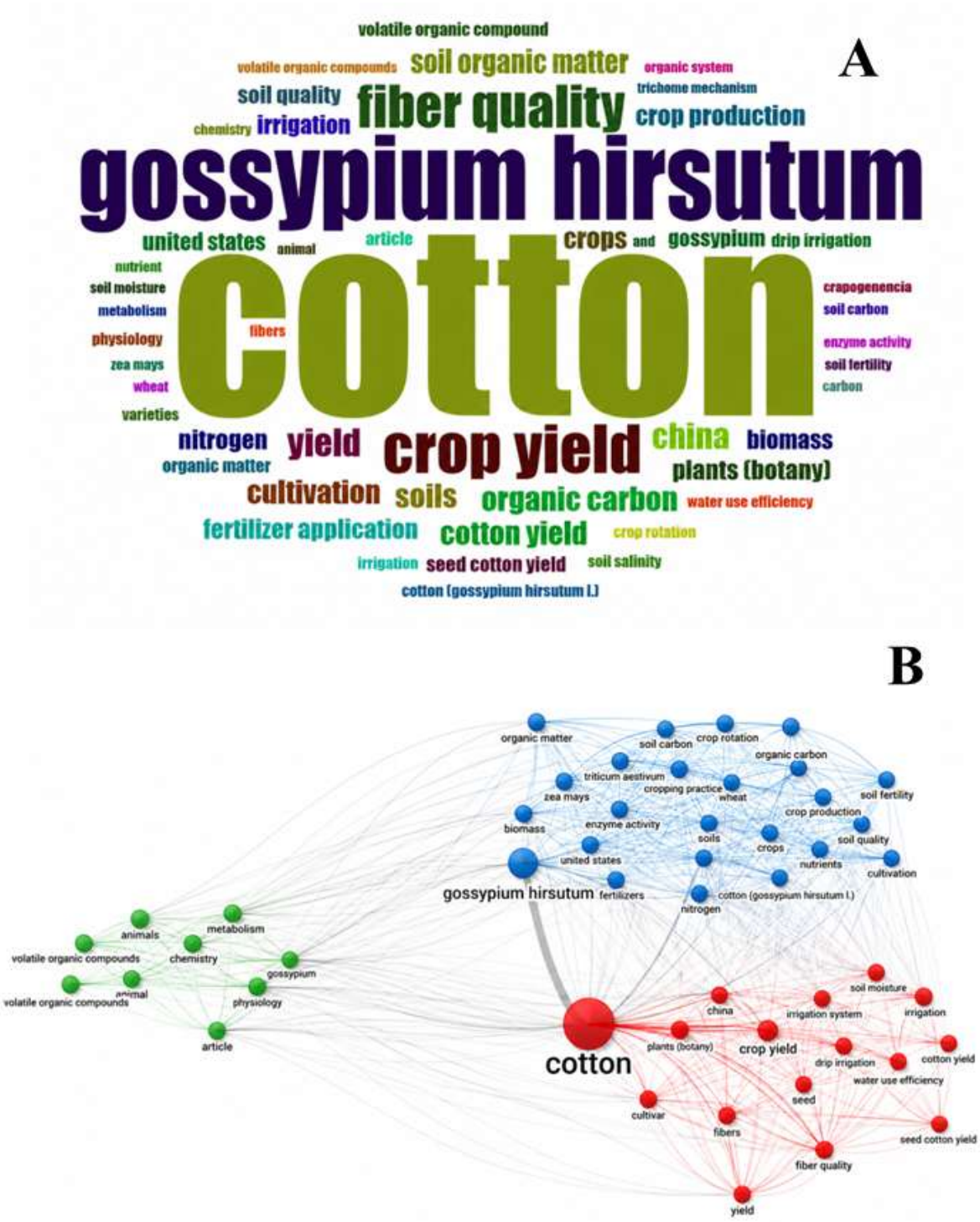


Figure 7. Keyword analysis of global research on sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services (2010-2026).

(A) Word cloud illustrating the most frequently occurring author keywords, where word size is proportional to keyword frequency. (B) Keyword co-occurrence network showing the relationships and clustering of major research themes, with node size representing keyword occurrence, line thickness indicating the strength of co-occurrence, and colors denoting different thematic clusters.

3.4. Three-field thematic plot and topic trend analysis

The three-field thematic plot illustrates the relationships among the most productive authors, their associated cited references, and the dominant keywords in the literature on sustainable cotton production (Figure 8). This visualization provides an integrated overview of the intellectual structure of the field by linking leading researchers with the key publications and research themes associated with their contributions. The analysis highlights authors such as *Wang Z., Zhang J., Li Y., Wang J., Li X., Wang X., Zhang X., Yang Y., Wang Y., Zhang Z., Li H.,* and *Sun J.*, who show extensive connections with the identified research themes. The right-hand keyword

field is dominated by terms such as *cotton, fiber quality, China, crop yield, cotton yield, Gossypium hirsutum, plants (botany), yield, irrigation, soils, soil quality, cultivation,* and *organic carbon*, indicating that research has primarily focused on cotton productivity, fibre characteristics, soil health, and resource-efficient crop management.

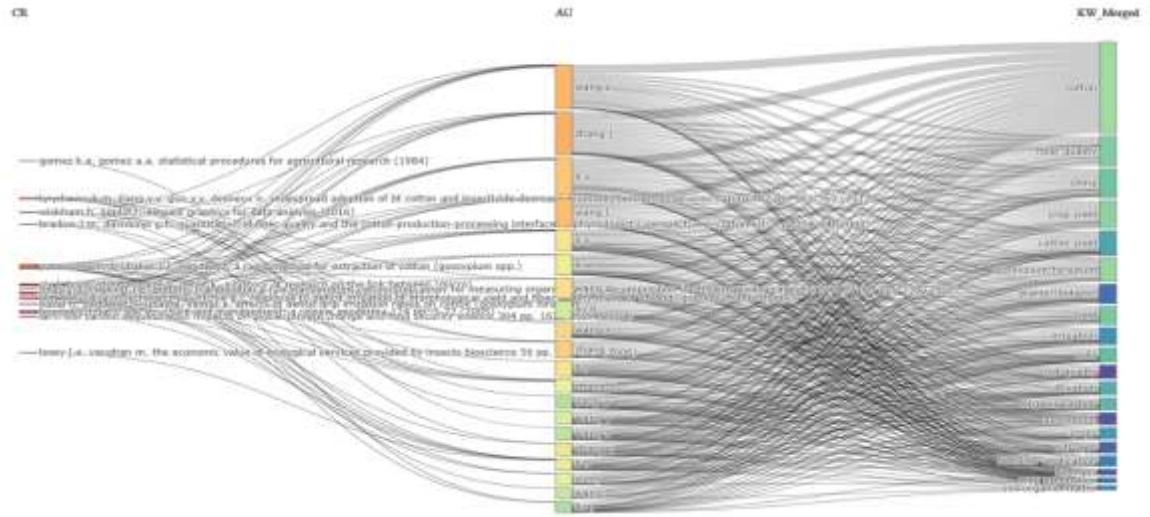


Figure 8A. Three-field thematic plot illustrating the relationships among the most relevant authors, author keywords, and indexed keywords in global research on sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services (2010-2026).

The width of the connecting links represents the strength of the associations, highlighting the major contributors and dominant research themes, including cotton, *Gossypium*, genetics, metabolism, gene expression regulation, plant proteins, and physiological stress.

The strong linkages between authors and keywords further demonstrate the multidisciplinary nature of sustainable cotton research, integrating yield improvement, fibre quality, irrigation management, soil fertility, organic carbon management, nutrient application, crop production, and sustainable cultivation practices. The presence of keywords such as *soil organic matter, soil carbon, nitrogen, fertilizer application, biomass, crop rotation, organic system,* and *water use efficiency* indicates increasing attention to resource conservation and ecosystem-oriented production approaches. The three-field relationships, suggest that contemporary research on sustainable cotton production is moving beyond yield maximization towards an integrated framework combining productivity, fibre quality, soil health, efficient use of water and nutrients, and environmentally sustainable farming practices.

The topic trend analysis demonstrates the temporal evolution of research priorities in sustainable cotton production (Figure 8B). During the early years (2010–2014), research was primarily associated with basic crop and field-management aspects, with topics such as *rainfall, seed yield, field experiment, pH, water supply, growing season,* and *tillage* reflecting an emphasis on crop establishment, soil conditions, and resource management. Between 2015 and 2018, the research focus gradually expanded toward broader agronomic and soil-related themes, including *residue management, biofuels, manure, Gossypium hirsutum, soil organic matter, soil carbon, enzyme activity, fertilizer application,* and *biomass*. This period indicates increasing attention to soil health, nutrient management, organic inputs, and the ecological dimensions of cotton production.

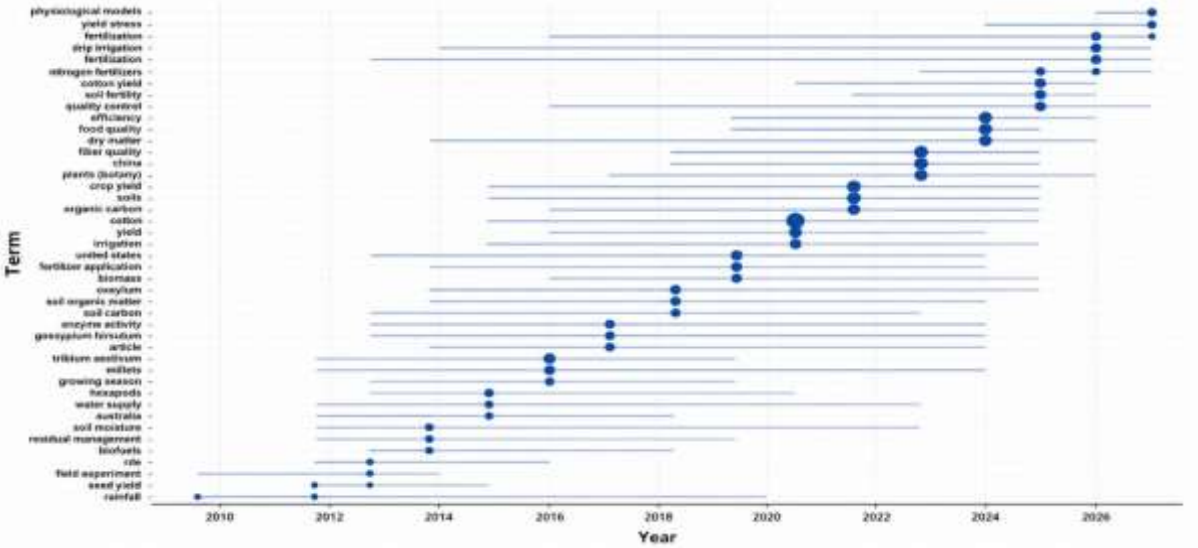


Figure 8B. Temporal evolution of research topics in sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services (2000-2026) based on author keywords.

Bubble size represents keyword frequency, while the horizontal line indicates the duration of each topic's occurrence over the study period.
From 2019 to 2022, research increasingly concentrated on crop productivity and resource-use management, with prominent topics such as *cultivation, irrigation, crop yield, cotton, yield, organic carbon, soils, plants (botany), fiber quality,* and *China*. The emergence and persistence of *organic carbon, soil quality,* and *fiber quality* indicate a growing integration of productivity, soil sustainability, and end-use quality in cotton research. During 2023-2024, the thematic landscape further diversified toward *quality control, efficiency, food quality, dry matter,* and *seed*, suggesting greater emphasis on production efficiency and quality-oriented outcomes. In the most recent period (2025-2026), topics such as *nitrogen fertilizers, cotton yield, fertilization, arid regions, subirrigation, yield stress,* and *physiological models* have become increasingly prominent, highlighting a shift toward optimizing nutrient and water management under resource-limited and environmentally challenging conditions.

4. Discussion:

4.1. Descriptive statistics of the study data, annual trend and countries' contributions

The bibliometric findings demonstrate a clear expansion of global research in sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services in cotton, particularly during the last decade. Publication output remained relatively stable during 2010-2019 but increased markedly after 2020, reflecting growing research interest in stress-response mechanisms and climate-resilient cotton production. The peak output in 2025 further confirms the increasing scientific attention to this field, while the lower publication count in 2026 should be interpreted cautiously due to incomplete indexing. Citation patterns indicate the continued influence of foundational research, with the highest mean total citations per article (40.59) recorded in 2015. The highest mean total citations per year (3.52) in 2022 further demonstrates the recent scientific visibility of the field. China and the United States emerged as the leading contributors, reflecting their strong research capacity and importance in cotton production. Contributions from Pakistan, India, Australia, Brazil, Türkiye, France, Egypt, and Mexico demonstrate that research activity is concentrated across major cotton-producing and research-intensive regions. This pattern highlights the practical importance of improving cotton productivity under drought, salinity, temperature fluctuations, and other environmental stresses. The similar results were given by Aria and Cuccurullo (2017) and Mishra et al. (2021)
The collaboration network demonstrates the increasingly international nature of the field, with particularly strong China-United States collaboration and additional linkages involving Pakistan, Australia, Canada, France, Switzerland, Saudi Arabia, and Mexico. The international co-authorship rate of 18.31% further confirms the importance of cross-border research cooperation. Such collaboration supports the integration of organic farming, natural farming, yield and fibre quality improvement, and ecosystem services approaches for promoting sustainable and resource-efficient cotton production (Khan et al., 2025). The research on cotton sustainable production, integrating organic farming, natural farming, yield and fibre quality, ecosystem services is evolving toward a globally connected, interdisciplinary, and climate-oriented research agenda, with increasing emphasis on integrated molecular approaches, advanced breeding technologies, and the development of climate-resilient cotton cultivars (Usha Rani et al., 2025).

4.2. Life cycle of scientific production

The life-cycle analysis indicates that research on sustainable cotton production remains in an active expansion phase rather than having reached maturity. The logistic model showed a moderate fit ($R^2 = 0.688$) and projected peak scientific productivity of 136 publications in 2042.6, suggesting substantial scope for continued growth. However, because the projection extends beyond the observed period (2010-2026), these estimates should be interpreted as model-based projections rather than definitive forecasts. The estimated carrying capacity of 6,630 publications further indicates considerable long-term research potential (Contreras et al., 2025; Vitale et al., 2025). The expanding research scope reflects a transition from conventional productivity-oriented studies toward a broader sustainability framework incorporating organic and natural farming, soil health, water management, crop rotation, biological inputs, yield stability, fibre quality, and ecosystem services. Recent studies similarly emphasize integrated practices such as cover crops, crop rotation, microbial interventions, improved irrigation, and soil-resource conservation as important components of sustainable cotton production. Evidence from alternative and regenerative farming systems also suggests potential benefits for soil quality, productivity, and economic sustainability, supporting the increasing research interest in diversified cotton production approaches (Yosung et al., 2020; Liang et al., 2025).
The projected growth suggests that future research will become increasingly multidimensional and systems-oriented, integrating soil health, nutrient and water-use efficiency, biodiversity, ecosystem services, climate resilience, yield, fibre quality, and economic performance. This expansion reflects a broader shift toward integrated cotton production systems that balance productivity, resource-use efficiency, environmental sustainability, and ecosystem services.

4.3. Keywords, thematic clustering, and co-occurrence network analysis

The keyword analysis demonstrates that sustainable cotton research is increasingly focused on integrating productivity with resource conservation and environmental sustainability. The prominence of *cotton* and *Gossypium hirsutum* is expected, while the frequent occurrence of *crop yield, cotton yield, seed cotton yield,* and *fiber quality* indicates that maintaining productivity and end-use quality remains a fundamental research objective. However, the strong representation of *soil organic matter, organic carbon, soil quality, nitrogen,* and *fertilizer application* suggests a broader shift toward understanding soil fertility and nutrient management as key components of sustainable production. The similar results were also reported by Wang et al. (2024).

The co-occurrence network shows that the major research dimensions are strongly interconnected. The central role of *cotton*, along with yield, irrigation, drip irrigation, and fibre quality, highlights the importance of efficient water and resource management. The association of *Gossypium hirsutum* with soil organic matter, soil carbon, crop rotation, soil fertility, and nutrient management further emphasizes the importance of soil health in sustainable cotton production (Basal et al., 2009). The occurrence of *water use efficiency* and irrigation-related terms highlights the growing emphasis on efficient water management (Sivanesan et al., 2025). The presence of physiological, metabolic, and biochemical terms also indicates expanding interest in crop responses and ecological interactions. The thematic structure reflects a shift from yield-focused research toward integrated sustainable cotton production, linking productivity, fibre quality, soil health, nutrient management, water-use efficiency, and ecosystem services.

4.4. Three-field thematic plot and topic trend analysis

The three-field thematic and topic trend analyses demonstrate a clear broadening and diversification of sustainable cotton research over the study period. The strong association of leading authors with *cotton, crop yield, fibre quality, soil quality, irrigation,* and *organic carbon* indicates that research has increasingly moved beyond yield maximization toward integrated evaluation of productivity, quality, and resource conservation. The prominence of soil-related and nutrient-management terms suggests that maintaining soil fertility and organic carbon is increasingly recognized as an essential component of long-term cotton sustainability (Constable, 2004).

The temporal evolution of topics provides further evidence of this transition. Early research focused largely on basic field management, rainfall, tillage, water supply, and seed yield, reflecting an emphasis on improving crop establishment and productivity. The subsequent emergence of *residue management, manure, soil organic matter, soil carbon, enzyme activity,* and *fertilizer application* indicates growing recognition of soil biological and chemical processes in sustainable production. From 2019 onwards, the increasing prominence of *irrigation, water-use efficiency, organic carbon, soil quality,* and *fibre quality* suggests a more integrated approach to resource management and crop performance (Sellami and Terribile, 2023; Surya and Krishnan, 2025).

The appearance of *quality control, efficiency, nitrogen fertilizers, fertilization, arid regions, subirrigation,* and *physiological models* during the most recent period further indicates that research is responding to resource limitations and environmental stresses. This progression suggests increasing interest in optimizing inputs rather than simply increasing their use. The findings indicate a transition from conventional agronomic and productivity-oriented research toward integrated, resource-efficient, and sustainability-focused cotton production systems (Velasco-Muñoz et al., 2019). Future research is likely to increasingly connect soil health, water and nutrient efficiency, fibre quality, productivity, and ecosystem functions within holistic farming-system frameworks.

Conclusions:

The present bibliometric analysis provides a comprehensive overview of the global research landscape on sustainable cotton production, integrating organic farming, natural farming, yield and fibre quality, and ecosystem services during 2010-2026. The analysis of 989 publications revealed a clear expansion of scientific interest, particularly after 2020, with publication output reaching its highest level in 2025. China and the United States emerged as the leading contributors, while the collaboration network demonstrated increasing international connectivity among major cotton-producing and research-intensive countries. The life-cycle analysis further indicated that the research domain remains in an active growth phase, with substantial potential for future expansion.

Keyword and thematic analyses demonstrated that sustainable cotton research is progressively shifting from a predominantly yield-oriented perspective toward an integrated approach encompassing fibre quality, soil health, organic carbon, nutrient management, irrigation, water-use efficiency, and ecosystem functions. The co-occurrence network and three-field analysis confirmed strong interconnections among productivity, resource-use efficiency, soil sustainability, and crop quality. Temporal topic trends further showed a transition from conventional field management and yield improvement toward organic inputs, soil carbon, residue management, efficient irrigation, nutrient optimization, physiological responses, and production under resource-limited environments.

These results and findings indicate that sustainable cotton production is evolving into a multidisciplinary and systems-oriented research domain that seeks to balance productivity with environmental sustainability and resource conservation. Future research should strengthen the integration of organic and natural farming practices with precision water and nutrient management, soil biological health, biodiversity, ecosystem services, climate resilience, and fibre quality. Greater integration of field experiments with molecular breeding, functional genomics, phenomics, digital agriculture, and life-cycle assessment could further support the development of resilient and resource-efficient cotton production systems. Strengthening international collaboration and interdisciplinary research will be particularly important for translating scientific advances into locally appropriate and economically viable sustainable cotton production practices. Thus, the present study provides a useful knowledge base for identifying emerging research priorities, research gaps, and future directions toward more productive, climate-resilient, and environmentally responsible cotton production systems.

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References

1. Aria, M., & Cuccurullo, C. (2017). *bibliometrix: An R-tool for comprehensive science mapping analysis*. Journal of Informetrics, 11(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007
2. Aria, M., Alterisio, A., Scandurra, A., Pinelli, C., & D'Aniello, B. (2021). *The scholar's best friend: research trends in dog cognitive and behavioural studies*. Animal Cognition. https://doi.org/10.1007/s10071-021-01448-2
3. Basal, H., Dağdelen, N., Ünay, A., & Yilmaz, E. (2009). Effects of deficit drip irrigation ratios on cotton (*Gossypium hirsutum* L.) yield and fibre quality. *Journal of Agronomy and Crop Science, 195*(1), 19–29. https://doi.org/10.1111/j.1439-037X.2008.00340.x
4. Brumă, I. S., Jelea, A. R., Rodino, S., Bertea, P. E., Butu, A., & Chițea, M. A. (2023). A bibliometric analysis of organic farming and voluntary certifications. *Agriculture, 13*(11), 2107. https://doi.org/10.3390/agriculture13112107
5. Cassman, K. G., & Grassini, P. (2020). A global perspective on sustainable intensification research. *Nature Sustainability, 3*(4), 262–268. https://doi.org/10.1038/s41893-020-0507-8
6. Constable, G. A. (2004). Research's contribution to the evolution of the Australian cotton industry. In T. Fischer et al. (Eds.), *New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress* (pp. 1–9). The Regional Institute Ltd.
7. Contreras, R., Puertas, R., & Martinez-Gomez, V. (2025). Bibliometric analysis of emerging trends and future prospects in sustainable agriculture. *Discover Sustainability, 6*, 951. https://doi.org/10.1007/s43621-025-01901-7
8. Cuccurullo, C., Aria, M., & Sarto, F. (2013). *Twenty years of research on performance management in business and public administration domains*. Academy of Management Proceedings, 2013(1), 14270. https://doi.org/10.5465/AMBPP.2013.14270abstract
9. Honfoga, B. G. (2018). Diagnosing soil degradation and fertilizer use relationship for sustainable cotton production in Benin. *Cogent Environmental Science, 4*(1), 1422366. https://doi.org/10.1080/23311843.2017.1422366
10. Khan, M. A., Anwar, S., Abbas, M., Aneeq, M., de Jong, F., Ayaz, M., Wei, Y., & Zhang, R. (2025). Impacts of climate change on cotton production and advancements in genomic approaches for stress resilience enhancement. *Journal of Cotton Research, 8*(1), 17. https://doi.org/10.1186/s42397-025-00223-3
11. Liang, X., Yu, S., Ju, Y., Wang, Y., & Yin, D. (2025). Integrated management practices foster soil health, productivity, and agroecosystem resilience. *Agronomy, 15*(8), 1816. https://doi.org/10.3390/agronomy15081816
12. Mishra, M., Sudarsan, D., Santos, C. A. G., Mishra, S. K., Kar, D., Baral, K., & Pattnaik, N. (2021). *An overview of research on natural resources and indigenous communities: A bibliometric analysis based on Scopus database (1979–2020). Environmental Monitoring and Assessment, 193*(2), 59. https://doi.org/10.1007/s10661-020-08793-2
13. Power, A. G. (2010). Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*(1554), 2959–2971. https://doi.org/10.1098/rstb.2010.0143
14. R Core Team. (2025). *R: A language and environment for statistical computing* (Version 4.5.1) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/
15. Saha, A., & Biswas, S. (2026). Organic farming versus natural farming for sustainable crop production: A systematic review. *Journal of Experimental Agriculture International, 48*(7), 621–635. https://doi.org/10.9734/jeai/2026/v48i74361
16. Saharan, P. B. S., Brar, B., Duhan, J. S., Kumar, R., Marwaha, S., Rajput, V., & Minkina, T. (2022). Molecular and Physiological Mechanisms to Mitigate Abiotic Stress Conditions in Plants. *Life, 12*. https://doi.org/10.3390/life12101634
17. Scarpin, G. J., Bhattarai, A., Hand, L. C., Snider, J. L., Roberts, P. M., & Bastos, L. M. (2025). Cotton lint yield and quality variability in Georgia, USA: Understanding genotypic and environmental interactions. *Field Crops Research, 325*, 109822. https://doi.org/10.1016/j.fcr.2025.109822
18. Sellami, M. H., & Terribile, F. (2023). Research evolution on the impact of agronomic practices on soil health from 1996 to 2021: A bibliometric analysis. *Soil Systems, 7*(3), 78. https://doi.org/10.3390/soilsystems7030078
19. Sivanesan, M., Somasundaram, S., Raju, M., Anantharaju, P., Bharathi Raja, S., & Rani, T. (2025). Advancing irrigation practices for sustainable cotton production: A comprehensive review of methods, models and water use efficiency. *Plant Science Today, 12*(3). https://doi.org/10.14719/pst.7750
20. Surya, K., & Krishnan, R. (2025). Trends and patterns of publications in the Indian Journal of Agricultural Sciences through bibliometric analysis. *Madras Agricultural Journal, 112*(10–12), 64–78. https://doi.org/10.29321/MAJ.10.901221
21. Usha Rani, S., Sujeetha, T. N., Annie Sheeba, J., Kanjana, D., Prakash, A. H., Prasad, Y. G., Asokhan, M., Selva Ganapathi, R., & Nagarajan, D. (2025). Climate change and its impact on cotton production: A systematic literature review. *Journal of Water and Climate Change, 16*(9), 2760–2785. https://doi.org/10.2166/wcc.2025.018
22. Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., Batlles-delaFuente, A., & Fidelibus, M. D. (2019). Sustainable irrigation in agriculture: An analysis of global research. *Water, 11*(9), 1758. https://doi.org/10.3390/w11091758
23. Venugopalan, M. V., Rajendran, T. P., Chandran, P., Goswami, S. N., Challa, O., & Damre, P. R. (2010). Comparative evaluation of organic and non-organic cotton (*Gossypium hirsutum*) production systems. *Indian Journal of Agricultural Sciences, 80*(4), 287–292. https://doi.org/10.56093/ijas.v80i4.220

24. Vitale, G. S., Iacuzzi, N., Zingale, S., Lombardo, S., Tuttolomondo, T., & Guarnaccia, P. (2025). Environmental sustainability of cotton: A systematic literature review of life cycle assessments. *Journal of Agriculture and Food Research, 22*, 102069. https://doi.org/10.1016/j.jafr.2025.102069
25. Vitale, G. S., Iacuzzi, N., Zingale, S., Lombardo, S., Tuttolomondo, T., & Guarnaccia, P. (2025). Environmental sustainability of cotton: A systematic literature review of life cycle assessments. *Journal of Agriculture and Food Research, 22*, 102069. https://doi.org/10.1016/j.jafr.2025.102069
26. Wang, N., Zhan, J., Feng, K., Qi, J., & Nan, H. (2024). Higher yield sustainability and soil quality by reducing chemical fertilizer with organic fertilizer application under a single-cotton cropping system. *Frontiers in Plant Science, 15*, 1494667. https://doi.org/10.3389/fpls.2024.1494667
27. Yosung, L., Swamy, G. N., Ramesh, G., Gupta, S., & Mohiuddin, M. (2020). Integrating water management, nutrient inputs, and plant density: A holistic review on optimizing cotton yield under variable agroecosystems. *Plant Science Review, 1*. https://doi.org/10.51470/PSR.1