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Emerging Perspectives in Cropping System–based Nutrient Management: A Scientometric Analysis

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Abstract

In a world grappling with the dual challenge of feeding a burgeoning global population and safeguarding the environment, nutrient management in agricultural systems has emerged as a critical area of research and innovation. Cropping system-based nutrient management plays a crucial role in sustainable agriculture by optimizing nutrient utilization, enhancing crop productivity, and minimizing environmental impacts. In this context, this study aims to provide a comprehensive overview of recent advances in cropping system-based nutrient management strategies. It highlights the integration of various techniques, including precision agriculture, cover cropping, crop rotation, site-specific nutrient management and digital technologies, to improve nutrient use efficiency and mitigate nutrient-related challenges. Through an in-depth analysis of current research, this study emphasizes the importance of tailored nutrient management approaches that consider soil conditions, crop requirements, and environmental sustainability. It also emphasizes the urgent need for further research and widespread adoption of these strategies to ensure food security and environmental preservation. This paper presents a meticulous scientometric analysis spanning the past two decades (2003-2023) to comprehensively examine recent advances in cropping systems-based nutrient management. Drawing upon an extensive body of scientific literature, our analysis unveils key trends, influential research, and emerging areas of interest within this field. We identified a paradigm shift towards precision agriculture, integrated nutrient management, and sustainable farming practices as dominant themes. We found that Indian scientists from IARI are publishing many research papers on the given topic. The Indian Journal of Agronomy and Indian Journal of Agricultural Sciences are leading publishers for articles on nutrient management and cropping systems. Long-term carbon sequestration, organic manure and nutrient use efficiency are trending topics of research, while soil carbon sequestration and analysis of soil carbon pools under different cropping systems are emerging topics of research. By synthesizing the collective wisdom of the past two decades, the current study informs the strategic allocation of resources and the formulation of research priorities, thereby catalysing innovative solutions to the complex challenges at the intersection of food security and environmental sustainability.

Keywords: Cover cropping, Crop rotation, Digital agriculture, Site-specific nutrient management, Integrated nutrient management

Introduction

Global agricultural systems are confronted with the multifaceted challenge of providing adequate food supply to an ever-growing population while conserving the natural resource base (FAO and ITPS, 2015). In this context, the crop nutrient management can play a pivotal role, given its direct influence on crop productivity, soil health, and environmental sustainability (Aulakh, 2010; Meena *et al.,* 2019; Sarkar *et al.,* 2020). The judicious application of nutrients is imperative, not only to maximize crop yields but also to minimize nutrient losses that can lead to water pollution, greenhouse gas emissions, and soil degradation. Recent decades have witnessed a paradigm shift from conventional, uniform nutrient application practices to towards more tailored and system-based approaches, which take into account the inherent variability of soils, crops, and environmental conditions (Goulding *et al.,* 2008; Keshavaiah *et al.,* 2012; Zhang *et al.,* 2021).

Cropping system-based nutrient management has emerged as an integrative approach that seeks to optimize nutrient utilization across diverse agricultural landscapes (Jat *et al.,* 2023). Unlike conventional "one-size-fits-all" fertilization strategies, cropping system-based nutrient management recognizes the dynamic interactions between crops, soils, climate, and management practices (Dwivedi *et al.,* 2003; 2009). This recognition has spurred the development of innovative strategies that not only enhance nutrient use efficiency but also foster the long-term sustainability of agroecosystems (Munda *et al.,* 2008).

Despite the growing global attention, several research gaps remain in understanding and implementing cropping system–based nutrient management. First, there is a lack of comprehensive mapping of global research trends and thematic evolution in this area, particularly concerning the integration of sustainability indicators such as soil organic carbon dynamics, nutrient cycling, and environmental footprints. Second, most existing studies focus on plot- or crop-specific nutrient management rather than system-level nutrient interactions that span across crop rotations, intercropping, and mixed farming systems. Third, limited scientometric assessments exist to quantify research linkages, influential contributors, and emerging themes that can guide future investigations and policy directions.

Addressing these gaps, the present study aims to systematically assess the evolution, structure, and dynamics of research on cropping system–based nutrient management. The objectives of this paper are to:

1. Summarize knowledge in the field of nutrient management under different cropping systems
2. Identify publication trends, influential authors, countries, and institutions contributing to this domain;
3. Examine the thematic focus, keyword co-occurrence, and knowledge clusters within the existing literature;
4. Detect emerging research fronts and potential areas requiring greater interdisciplinary integration.

The utility of this study lies in its ability to provide an evidence-based understanding of how nutrient management research has evolved under various cropping systems. The outcomes will help scientists recognize underexplored research domains, encourage collaboration across disciplines, and promote innovation in nutrient management technologies. For policymakers, the findings will serve as a strategic reference to align agricultural nutrient policies with sustainable development goals (SDGs), resource conservation, and climate-resilient agricultural practices.

A Summary of Nutrient Management under Different Cropping Systems in India

Legume-based cropping systems: Inclusion of crops such as lentils, chickpeas, and beans in a cropping system, have proven effective in reducing the use of chemical fertilizers while enhancing soil fertility. These systems also facilitate crop rotation and reduce greenhouse gas emissions. Chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), and lathyrus (*Lathyrus sativus*) exhibit potential suitability for cultivation across various regions in India, with chickpea emerging as the preferred choice in many states (Kaur *et al.,* 2018). However, challenges related to the availability of short-duration varieties and limited sowing windows hinder their cultivation in a cropping cycle. Additionally, pest and disease pressures, particularly on chickpea, pose significant threats to crop success, underscoring the importance of disease and pest-resistant crop varieties (Shukla *et al.,* 2021). In rice-fallow areas, two primary systems for cultivating pulses are practiced: rice-pulse relay cropping and rice-pulse sequential cropping. Relay cropping involves sowing pulses directly into standing rice crops, while sequential cropping involves sowing pulses after rice harvest. The former, facilitated by zero-till drills, offers advantages in terms of timely sowing and higher yields, particularly for chickpea (Ghosh *et al.,* 2007). The inclusion of legumes in the rice-wheat cropping system has been proposed to address challenges such as declining productivity and nutrient deficiencies. Short-duration summer mungbean varieties have been developed to fit between wheat harvest and rice transplanting, offering economic benefits and reducing the need for nitrogen fertilizers (Singh *et al.,* 2015; Singh and Singh, 2010). Economic studies have shown that incorporating summer mungbean into the rice-wheat system can increase productivity and net returns (Sekhon *et al.,* 2006;

Singh *et al.,* 2011). Furthermore, diversifying cropping systems with pulse crops can enhance soil water conservation, improve soil nitrogen availability, and increase overall system productivity (Gan *et al.,* 2015). Tonitto *et al*. (2006) demonstrated that diversified crop rotations incorporating legume and non-legume cover crops can significantly enhance nitrogen use efficiency in agriculture. While synthetic nitrogen boosts productivity, up to 50% is typically lost, contributing to environmental harm. Their study found that non-legume cover crops reduced nitrate leaching by up to 70%, and legume systems also cut leaching by 40% while sustaining comparable yields. This highlights the potential of diversified rotations to balance productivity with environmental sustainability.

Integrated nutrient management: It encompasses organic and inorganic fertilizers, crop residues, and organic materials, and has been found to enhance yield, improve soil quality, and reduce greenhouse gas emissions in lowland rice-rice cropping systems (Paramesh *et al.,* 2023). Substituting 25% of nitrogen with farmyard manure (FYM) in the fertilization calendar can increase grain yield in acidic soils on the west coast of India (Paramesh *et al.,* 2023). The combination of inorganic fertilizer and FYM is considered optimal for higher crop yields and increased soil carbon sequestration. In the maize-wheat cropping system, the application of biochar integrated with inorganic fertilizer (INM) has proven to be a sustainable technique for enhancing productivity. The integrated nutrient approach (75% NPK + 5 ton ha^{-1} biochar) is considered the most economical and productive process, improving nutrient availability, dry matter accumulation, and grain yields (Sarwar *et al.,* 2023). Nutrient management approaches that involve adjusting nutrient application rates based on crop requirements have been successful in increasing system productivity and maintaining soil fertility in legume-based cropping system.

Precision agriculture: Precision agriculture facilitated by cutting-edge technologies like GPS (Global Positioning System), GIS (Geographic Information System), and remote sensing, provides the capability for precise, site-specific application of fertilizers, thereby curtailing wastage and ameliorating soil nutrient imbalances (Gebbers and Adamchuk, 2010). In an insightful exploration, Hedley (2015) looked into using wireless soil sensors to help farmers use water better and grow more crops. This technology helps farmers use the right amount of water for their fields, so they can save water and grow better crops. A comprehensive review undertaken by Shafi *et al.* (2019) highlights the immense potential of precision agriculture in enhancing nutrient use efficiency, curtailing environmental repercussions, and bolstering financial viability within agricultural operations. Notwithstanding these prospects, (Bhakta *et al.*, 2019) aptly acknowledges the presence of challenges in the widespread adoption of precision agriculture. Addressing these hurdles is vital to realizing the full spectrum of benefits that precision agriculture can bestow upon modern farming practices.

Cover cropping: Cover cropping with leguminous species enhances nutrient conservation and soil health by fixing atmospheric nitrogen and providing organic matter (Abdollahi and Munkholm, 2014; Daryanto *et al.,* 2018). In tropical agricultural systems, the integration of leguminous cover crops has garnered attention for their potential to enhance nutrient cycling, particularly nitrogen (N) fixation from the atmosphere. This approach holds promise for low-input tropical agriculture and adapting to climate change (Kambauwa *et al.,* 2015). However, studies reveal variations in nutrient release patterns from these cover crops. Perin *et al.* (2006) conducted research in Vicosa, Brazil, to assess the N release from leguminous cover crops like sunn hemp (*Crotalaria juncea*) and non-leguminous alternatives such as millet (*Pennisetum glaucum*), without additional N fertilizer. They found that combining leguminous and non-leguminous cover crops could potentially slow down N release. When applying 90 kg N ha^{-1} of N fertilizer to corn after cover cropping, sunn hemp exhibited significant N fixation, releasing 174 kg N ha^{-1}, while the mixed cover crop released 89 kg N ha^{-1} of fixed N. Sunn hemp also displayed faster N release but resulted in higher corn yields of 8.4 Mg ha^{-1} compared to 6.6 Mg ha^{-1} with sunn hemp alone, indicating potential N loss to the environment.

Lehmann *et al*. (2000) investigated the contributions of leguminous cover crops, such as tropical kudzu (*Pueraria phaseoloides*), to N cycling in an agroforestry system in central Amazonian Brazil. They noted that tropical kudzu served as a scavenger crop, recovering 31% of the fertilizer N, yet minimal N transfer occurred to indigenous fruit trees due to their limited lateral root activity. Tirado-Corbalá *et al.* (2018) examined decomposition rates of legume cover crops, lablab *(Lablab purpureus),* and Velvet bean *(Mucuna pruriens*) in Puerto Rico. They discovered that both cover crops contributed to inorganic N supply, with lablab decomposing faster than Velvet bean, suggesting Rongai as a preferable N source for fast-growing crops. In addition to N, cover crops play a pivotal role in enhancing the cycling of macro- and micro-nutrients in tropical regions. Crusciol *et al*. (2015) demonstrated that Palisade grass cover crops improved soil nutrient content, leading to increased nutrient uptake in subsequent crops like soybean and corn. Chikowo *et al*. (2011) conducted a comprehensive review of management practices in sub-Saharan Africa and observed that improved fallows and cover crops could elevate N availability and uptake. Nevertheless, correlations between N availability from cover crops and N uptake were relatively weak (0.25) when compared to N fertilizer. Ashworth *et al.* (2020) conducted a 15-year study to investigate the impact of diverse cropping systems, including various crops and cover crops, under a no-tillage regime on soil properties. They assessed soil strength, chemical properties of cover crop residues, and compaction in two types of silt loam soil. Findings revealed that surface soil properties were predominantly influenced by long-term cover crops and poultry litter, while crop rotations had a stronger impact on sub-surface soil chemistry. High-nitrogen cover crops were favourable for soil biota, while corn rotations increased soil carbon and nitrogen content. Soil compaction varied across cropping systems, with continuous cotton exhibiting the highest compaction. This research provides critical insights into soil management for conservation practices. Cover cropping creates a distinct agroecosystem compared to bare fallow fields, potentially impacting the soil microbiome. Despite a growing body of primary research on the topic, there was a lack of comprehensive quantitative research synthesis. A meta-analysis of 60 relevant studies was conducted, revealing that cover cropping significantly increased soil microbial abundance, activity, and diversity by 27%, 22%, and 2.5%, respectively, compared to bare fallow. The effect sizes varied based on agricultural factors such as cover crop termination and tillage methods. The study highlights the potential for enhanced soil microbiome health under cover cropping, contingent on appropriate management practices, but suggests the need for further research to address heterogeneity between studies and to deepen our understanding of this relationship (Kim *et al.,* 2020).

Site-Specific Nutrient Management (SSNM): It is a precision approach that optimizes nutrient utilization by considering site-specific factors, seasonal variations, and crop growth dynamics. It aims to reduce the reliance on synthetic inorganic fertilizers and incorporate organic amendments to enhance nutrient cycling and microbial activity (Dobermann *et al.,* 2002; Pasuquin *et al.,* 2014). Studies have shown that combining organic amendments with reduced chemical fertilizer use increases microbial biomass, nutrient availability, nitrogen use efficiency, and crop yields (Dwivedi *et al.,* 2003, 2009; Yadav *et al.,* 2000). The convergence of agronomy, ecology, and technology has led to significant advancements in cropping system-based nutrient management. These novel approaches, including precision agriculture, cover cropping, crop rotation, organic farming, and digital technologies, are vital components for addressing the complex challenges faced by modern agriculture.

Digital agriculture: It encompasses an array of advanced technologies, including sensor-based systems and data analytics, and has emerged as a cornerstone of contemporary farming practices (Basso and Antle, 2020; Sinitsa *et al.,* 2021). At the heart of this agricultural revolution lies the integration of real-time monitoring and data-driven decision-making, enabling precise nutrient management tailored to specific crop requirements, soil conditions, and environmental variables (Jones *et al.,* 2017). This holistic approach ensures the optimal application of fertilizers, reducing wastage and minimizing the environmental footprint of agricultural activities (Shepherd *et al.,* 2020). The significance of digital agriculture in nutrient management within diverse cropping systems cannot be overstated. It empowers farmers to adapt and fine-tune nutrient management strategies, promoting sustainable and efficient crop production while mitigating the risk of nutrient imbalances or losses (Gebbers and Adamchuk, 2010). In essence, digital agriculture serves as an indispensable tool for advancing nutrient management practices, enhancing agricultural sustainability, and meeting the ever-increasing global demand for food.

The integration of the Internet of Things (IoT) and machine learning (ML) has further amplified the transformative potential of digital agriculture (Sarker, 2021). ML, an emerging technology, plays a pivotal role in deciphering patterns within vast datasets, enabling predictions directly from this data (Ayodele, 2010; Singh *et al.,* 2016). A primary contribution of machine learning in this context is its ability to predict crop yields, leveraging factors like fertilizer rates, genetic data, and environmental and land management variables (Ayodele, 2010; Singh *et al.,* 2016). These predictions are invaluable for optimizing farming practices, enabling informed decisions on fertilizer application and resource allocation. Beyond yield prediction, machine learning's integration into agriculture aligns with the broader digital transformation of the sector, harnessing diverse data sources available in the agricultural domain (Barbedo, 2019). While crop disease detection has traditionally been a focus for data scientists, other areas, such as nutrient management, are now gaining prominence. Accurate diagnosis of a crop's current nutritional status and nutrient requirements is foundational for efficient farm management (Dhal *et al.,* 2022; Goulding *et al.,* 2008). Machine learning algorithms analyse data from various sources, including IoT sensors, weather data, and historical information, to provide precise insights into nutrient requirements. This comprehensive approach enhances our understanding of agricultural systems, including the nuanced aspects of nutrient needs, while also incorporating economic considerations into decision-making. The implications of accurate nutrient management are profound, impacting both the environment and the economic sustainability of farms. Imbalances in nutrient levels, whether excessive or deficient, can lead to yield losses, resource underutilization, and the degradation of soil organic carbon content (Dhal *et al.,* 2022). Leveraging ML-powered insights, farmers can optimize fertilizer recommendations, resulting in increased yields, reduced environmental impact, and improved revenue. These technologies not only enable accurate predictions of crop yields but also revolutionize nutrient management practices. With precise diagnoses and recommendations at their disposal, farmers can enhance productivity, minimize environmental footprints, and secure the economic sustainability of their operations. As digital agriculture continues to evolve, it holds the promise of effectively addressing some of the most pressing challenges facing modern farming (Ennaji *et al.,* 2023).

Nutrient Management in Salt-Affected Soils

Salt-affected soils occupy approximately 6.74 million hectares in India, comprising 3.78 million hectares of sodic soils and 2.96 million hectares of saline soils (Chhabra, 2021). These soils exhibit inherently low fertility, particularly deficient in nitrogen (N), calcium (Ca), zinc (Zn), iron (Fe), and manganese (Mn), necessitating integrated nutrient management (INM) strategies in conjunction with reclamation efforts (Rai *et al.,* 2021).

Nutrient Dynamics in Saline Soils

Salinity profoundly influences soil fertility and plant nutrition through multiple mechanisms. Saline soils contain elevated concentrations of chloride (Cl^-) and sulfate (SO_4^{2-}) anions along with calcium (Ca^{2+}), sodium (Na^+), and magnesium (Mg^{2+}) cations, which collectively impair plant growth. High salt concentrations increase the osmotic potential of the soil solution, thereby restricting water and nutrient uptake by plants. Micronutrient availability is similarly compromised under saline conditions. Specifically, elevated Cl^- levels exert antagonistic effects on the uptake of nitrate (NO^{3-}), hydrogen phosphate (HPO_4^{2-}), and sulfate ions. Furthermore, sulfate precipitates iron as insoluble iron sulfates, rendering it unavailable in the soil solution, while both sulfate and chloride ions suppress nitrate assimilation by plants (Bhadwaj *et al.*, 2021).

Nutrient Constraints in Sodic Soils

Sodic soils are characterized by high concentrations of sodium carbonates and bicarbonates, which binds Ca^{2+} from the soil system, resulting in excess Na^+ that creates antagonistic effects on K and Ca nutrition. Competition between Na^+ and Ca^{2+} for exchange sites displaces K^+ into the soil solution, promoting its leaching to deeper soil layers. Additionally, elevated concentrations of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and calcium carbonate ($CaCO_3$) substantially reduce the availability of micronutrients, particularly Fe and Zn (Bhadwaj *et al.*, 2021).

Nitrogen Management Strategies

Nitrogen deficiency represents a primary constraint on crop productivity in sodic soils. Farmers can effectively minimize nitrogen losses in alkaline soils by applying a minimal basal dose of 40 kg N ha^{-1} followed by three equal split applications of the recommended 120 kg N ha^{-1} for rice and wheat (Bhadwaj *et al.*, 2021). Supplemental nitrogen applications during first and second irrigations (top-dressing) have been shown to alleviate N deficiency while simultaneously enhancing the uptake of phosphorus, potassium, and zinc. Furthermore, combining urea with organic manures provides superior benefits compared to urea application alone (Singh and Ram, 2000).

Phosphorus Availability and Management

Phosphorus availability is notably limited in salt-affected Vertisols. Applications of single superphosphate and farmyard manure (FYM) have demonstrated beneficial effects on phosphorus availability. Organic amendments reduce soil pH and enhance the solubility of fixed phosphorus, thereby increasing plant-available P in the soil (Gaffar *et al.*, 1992).

Integrated Nutrient Management Approaches

Practical implementation of INM involves strategically combining organic amendments—including farmyard manure, compost, and green manures—with chemical fertilizers. Sesbania green manuring integrated with urea-N application substantially reduces nitrogen losses under sodic conditions (www.gkvsociety.com). Long-term field trials conducted at CSSRI-Karnal have revealed that incorporating Sesbania green manure with 50% of the recommended NPK fertilizer dose achieved rice yields equivalent to 100% NPK alone, while concurrently increasing soil organic carbon and available NPK concentrations.

Similarly, applying FYM or vermicompost (approximately 10 t ha^{-1}) in combination with partial NPK fertilization enhances both crop yields and soil health. CSSRI reports indicate that 10 t ha^{-1} FYM plus 50–100% NPK significantly increased rice yields compared to fertilizer-only treatments (www.cssri.res.in). Additionally, vermicompost application (2.5 t ha^{-1}) combined with 50% NPK resulted in 17–26% higher wheat yields and a 17% increase in maize yields, while simultaneously stimulating microbial activity (www.cssri.res.in).

Synergistic Reclamation and Conservation Practices

Organic matter additions complement gypsum-based reclamation of sodic soils. While gypsum application (10–15 Mg ha^{-1}) serves as the standard amendment to supply calcium and reduce soil pH, concurrent application of FYM or pressmud accelerates the reclamation process and reduces gypsum requirements (Kumar and Sharma, 2020). In reclaimed lands, adoption of conservation tillage practices, particularly zero-tillage with residue retention, has further improved soil structural properties. One field trial documented that no-till management increased soil aggregate mean diameter by approximately 54% compared to conventional tillage (Sundha *et al.*, 2025).

This summary of knowledge highlights that cropping system–based nutrient management represents a transformative step toward achieving sustainable agricultural intensification. Integrating approaches such as legume inclusion, integrated and site-specific nutrient management, precision and digital agriculture, and cover cropping not only improves nutrient use efficiency but also enhances soil health, mitigates environmental degradation, and ensures long-term productivity. The synergy between traditional agronomic principles and modern technological innovations — such as remote sensing, IoT, and machine learning — has opened new frontiers for real-time, data-driven decision-making in nutrient management. Despite these advancements, the current body of research still exhibits gaps in system-level understanding, particularly regarding the interactions between soil–plant–microbe dynamics, nutrient cycling, and climate variability. Therefore, the need for interdisciplinary research integrating agronomy, soil science, ecology, and data science remains paramount. After this brief review of research papers published under nutrient management in cropping systems, we conducted a Scientometric analysis of the research landscape, which holds great promise for guiding future research endeavours in this critical yet significant field. By identifying the most influential research papers, prolific authors, and impactful journals, this analysis can inform researchers, policymakers, and stakeholders about the state of the art in nutrient management. Additionally, it can shed light on the growing importance of precision agriculture, integrated nutrient management, and sustainable farming practices. Such insights can guide the allocation of resources and the formulation of research priorities, ultimately contributing to the development of innovative and sustainable solutions to future global agricultural challenges.

Scientometric Analysis

A Scientometric study of past 20 years (2000 - 2023) was conducted to understand the advances in the area of nutrient management under different cropping systems (Fig. 1). The following query was given in scopus database on 28th August, 2023: (TITLE-ABS-KEY (“Cropping systems”) AND TITLE-ABS-KEY (“Nutrient Management”)) AND PUBYEAR > 2002 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, ”ar”)) AND (LIMIT-TO (SUBJAREA, ”AGRI”) OR LIMIT-TO (SUBJAREA , ”ENVI”)) AND (LIMIT-TO (LANGUAGE , ”English”)) and 671 documents were found.

For the Scientometric analysis, the R software’s bibliomatrix package was employed (Aria and Cuccurullo, 2017). This package provided a clear and systematic workflow for data retrieval, analysis, and visualization. Additionally, the network analysis was conducted using the VOSviewer software (Van Eck and Waltman, 2017).

General Overview of Data

The table 1 presents a comprehensive overview of Scientometric data about nutrient management under different cropping systems as mentioned in the query, covering the period from 2003 to 2023,

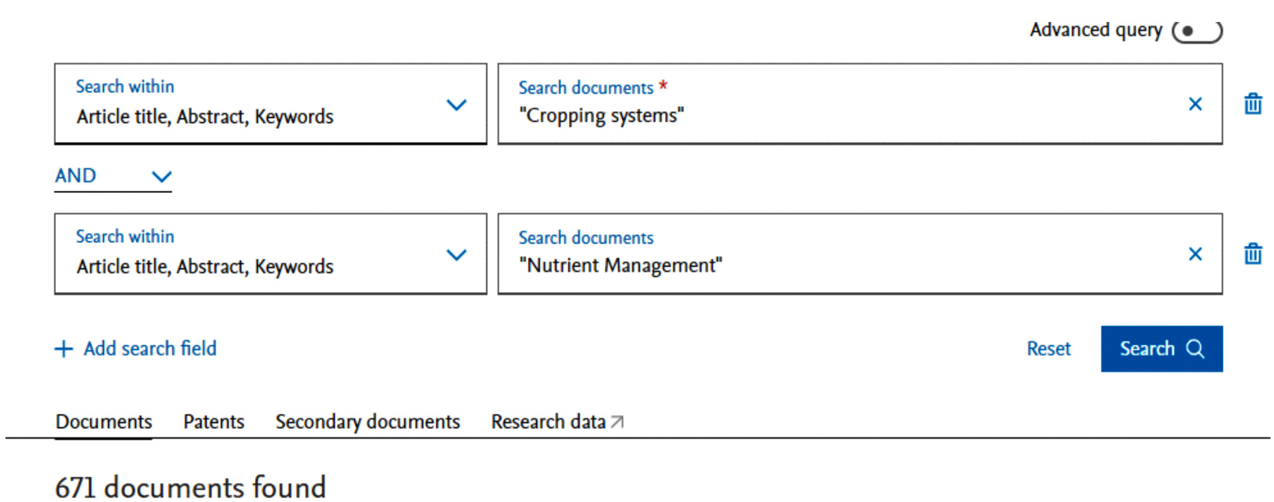

Fig. 1 Query used for finding relevant documents

Table 1. Main information regarding documents produced for "nutrient management" and "cropping systems"

Description	Results
Timespan	2003:2023
Sources (Journals, Books, etc)	170
Documents	671
Annual Growth Rate %	7.18
Document Average Age	7.85
Average citations per doc	16.51
References	23806
DOCUMENT CONTENTS	
Keywords Plus (ID)	1957
Author's Keywords (DE)	1704
AUTHORS	
Authors	2208
Authors of single-authored docs	25
AUTHORS COLLABORATION	
Co-Authors per Doc	5.21
International co-authorships %	18.33
DOCUMENT TYPES	

extracted from 170 different sources, including journals, books, and other publications. In total, 671 documents were analysed, showing an annual growth rate of 7.18% and an average document age of 7.85 years. These documents received an average of 16.51 citations each and contained a substantial 23,806 references. The document contents were associated with 1,957 unique Keywords Plus (ID) and 1,704 author-provided Keywords (DE). The research involved contributions from 2,208 different authors, with 25 documents being single-authored. On an average, each document had 5.21 co-authors, and approximately 18.33% of the documents featured international co-authorships. Notably, all 671 documents in the dataset were classified as articles. This observation suggested the interdisciplinary nature of research articles, as diverse expertise and perspectives are often represented by higher authorship numbers (Aria *et al.,* 2017). Furthermore, the significant collaboration between authors from different countries, indicated by the international co-authorship percentage of 18.63%, supported this finding. Such international collaboration was typically observed in topics with global significance rather than regional focus (Bhattacharjee *et al.,* 2023).

Annual Scientific Production

The annual scientific production in the field of nutrient management and cropping systems is illustrated in Fig. 2. The analysis of the initial years included in the search indicated a gradual development and it followed a linear growth equation mentioned in Fig. 2, with a notable increase observed from the early 2010s onwards.

Analysis of journal

The analysis of journals revealed a significant distribution of articles across different journals, with the "Indian Journal of Agronomy" leading the way with 94 articles (14% of total articles) (Fig. 3). Following closely, the "Indian Journal of Agricultural Sciences" contributed 62 articles to the dataset. Notably, "Field Crops Research," "Communications in Soil Science and Plant Analysis," and "Journal of Plant Nutrition" also

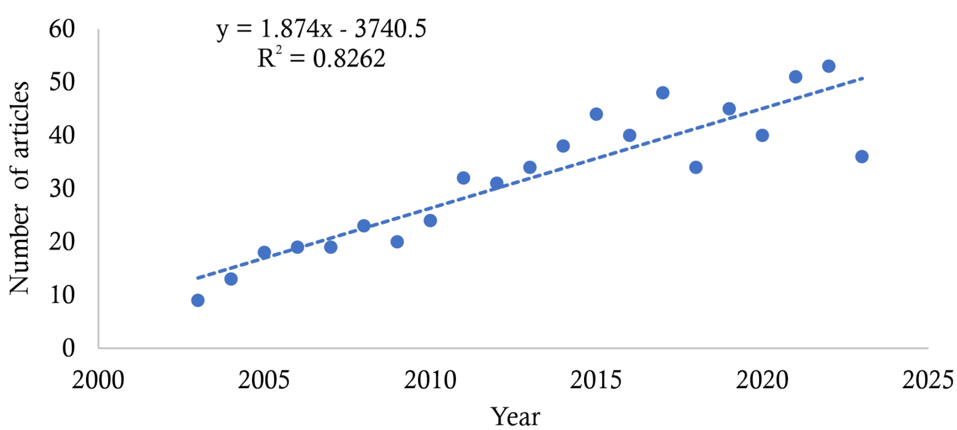

Fig. 2 Scientific production of articles in the area of nutrient management under cropping systems

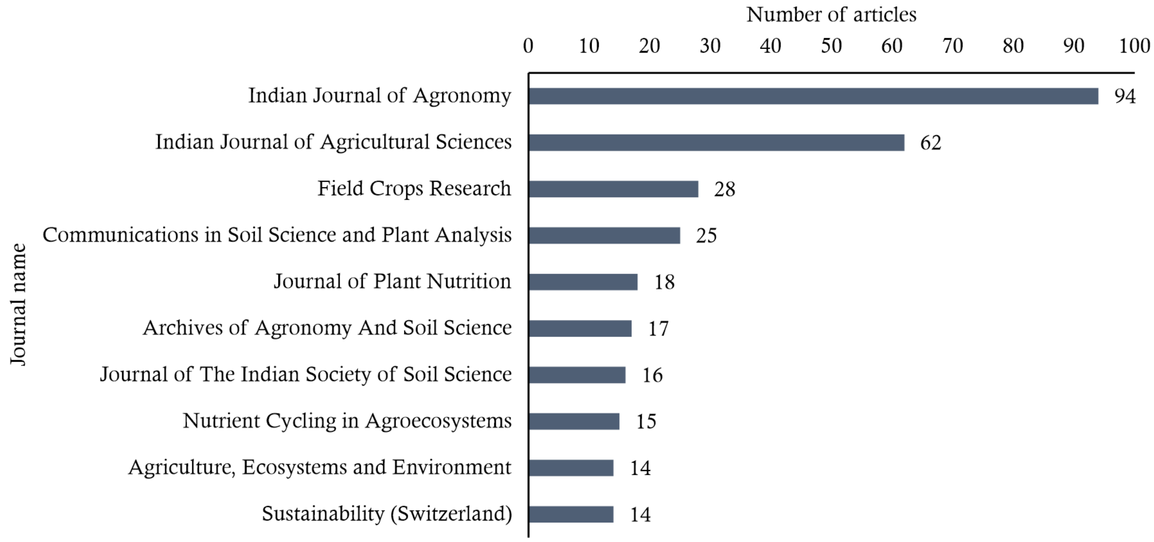

Fig. 3 Core journals publishing articles in the area of nutrient management and cropping systems

made substantial contributions with 28, 25, and 18 articles, respectively. This diverse set of journals demonstrated the multidisciplinary nature of the research, encompassing fields such as agronomy, agricultural sciences, soil science, and plant nutrition. These findings provided valuable insights into the sources and dissemination of research in these domains, contributing to a deeper understanding of the research landscape in these areas.

Analysis of authors

A comprehensive analysis was conducted based on the number of articles authored by various individuals (Fig. 4). Among the notable contributors, Ghosh, P.K. stood out with 14 articles, followed closely by Dwivedi, B.S., Meena, M.C., Shivay, Y.S., and Singh, A.B., each having authored 12 articles. Additionally, Rana, D.S. had contributed 11 articles, while Datta, S.P. had authored 10. Noteworthy contributions were also evident from Garnayak, L.M., Mishra, R.P., and Parihar, C.M., who have each authored 9 articles. These prolific authors had made substantial contributions to the body of research in the field, and their work was a significant part of the academic discourse in the field of nutrient management under different cropping systems.

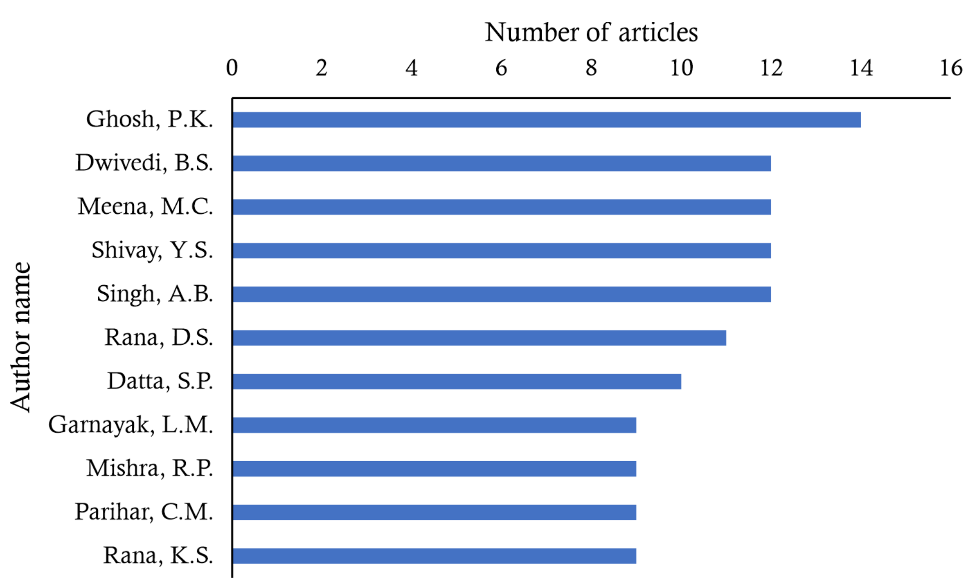

Fig. 4 Top 10 authors in the area of nutrient management under different cropping systems

Trending topics

The analysis conducted on the Scopus database revealed distinct trends in research topics within the field. Prior to 2010, the most prominent subjects included sorghum, wheat, and green manure. Subsequently, from 2010 to 2015, research focus shifted towards topics such as rice-wheat cropping systems, nitrogen, farmyard manure (FYM), soybean, soil fertility, potassium, productivity, and phosphorus. In the period after 2015 until 2020, emerging trends encompassed nutrient management, integrated nutrient management (INM), grain yield, and soil organic carbon. Notably, nutrient use efficiency, carbon sequestration, and organic manure emerged as the most extensively researched subjects in the context of nutrient management within cropping systems, reflecting evolving priorities in agricultural research (Fig. 5).

In this Scientometric analysis, a three-field plot was constructed to elucidate the intricate interplay among top authors' countries (AU_CO), prominent keywords (ID), and leading journals (SO) within the domain of nutrient management across diverse cropping systems. The investigation unveiled India as the foremost contributor to research in this field, followed by China, the USA, Pakistan, Bangladesh, Italy, Australia, Canada, the Netherlands, and Saudi Arabia. Noteworthy research themes encompassed wheat, fertilizer application, nitrogen, phosphorus, organic manure, and *Zea mays* (maize). Prominent journals featured in this analysis included "Field Crop Research," "Communications in Soil Science," "Nutrient Cycling in Agroecosystems," "Agriculture, Ecosystems, and Environment," "Indian Journal of Agronomy," "Sustainability," and others (Fig. 6).

Thematic mapping of keywords

A thematic map of keywords, organized into four distinct quadrants for the purpose of categorizing related topics is presented in Fig. 7. In the lower left quadrant of the map, we observed the presence of emerging themes, including discussions on rainfed lowlands, soil carbon sequestration, and carbon pools. These were areas of research and exploration that were gaining prominence and warranted further investigation. Moving to the lower right quadrant, we encountered fundamental themes encompassing topics such as site-specific nutrient management, integrated nutrient management, carbon management index, nutrient use efficiency, as well as considerations related to nitrogen, phosphorus, crop yield, and water quality. These topics served as the foundational components of the broader subject matter. The

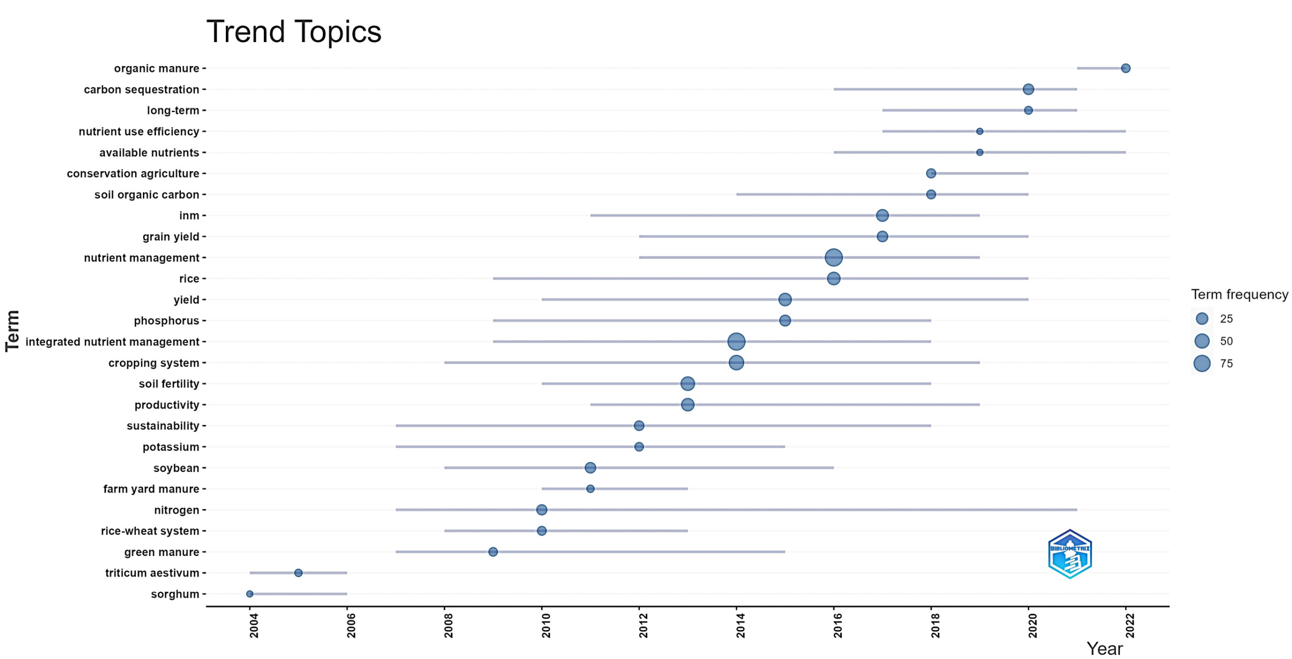

Fig. 5 Trending topics in the field of nutrient management under different cropping systems with respect to time

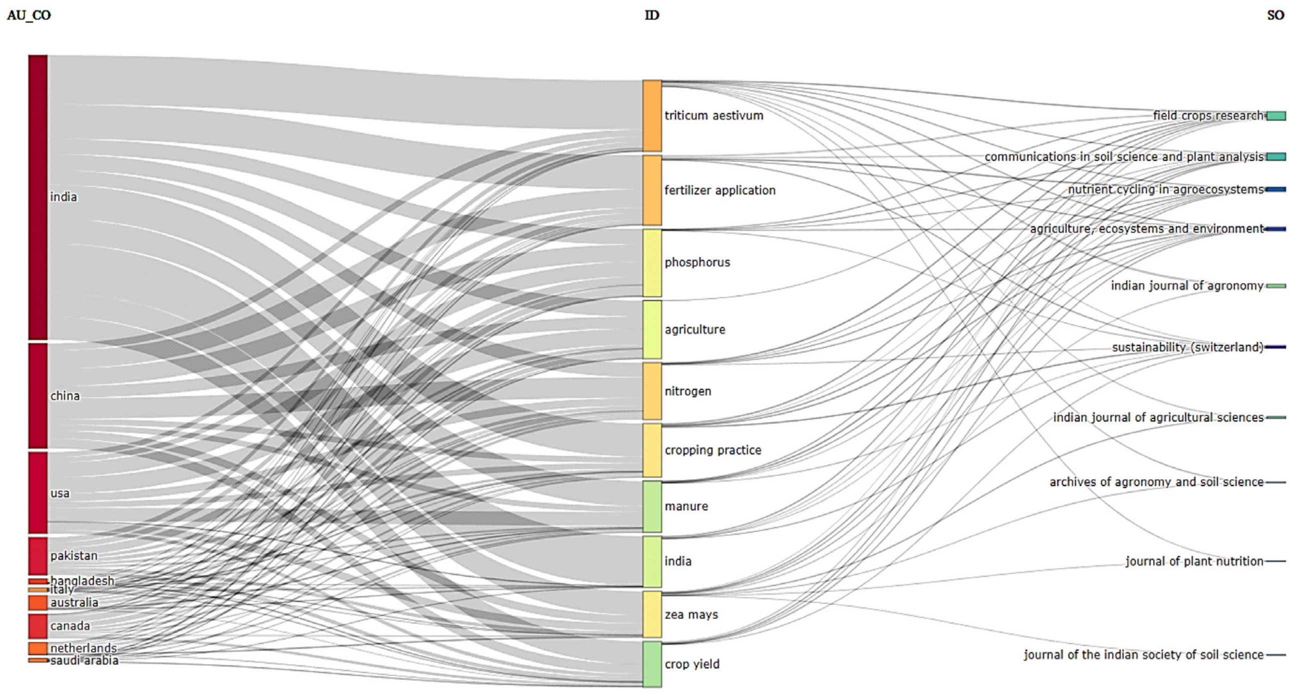

Fig. 6 Analysis of top 10 countries, keywords and journals publishing in the area of "Nutrient management" and "cropping systems"

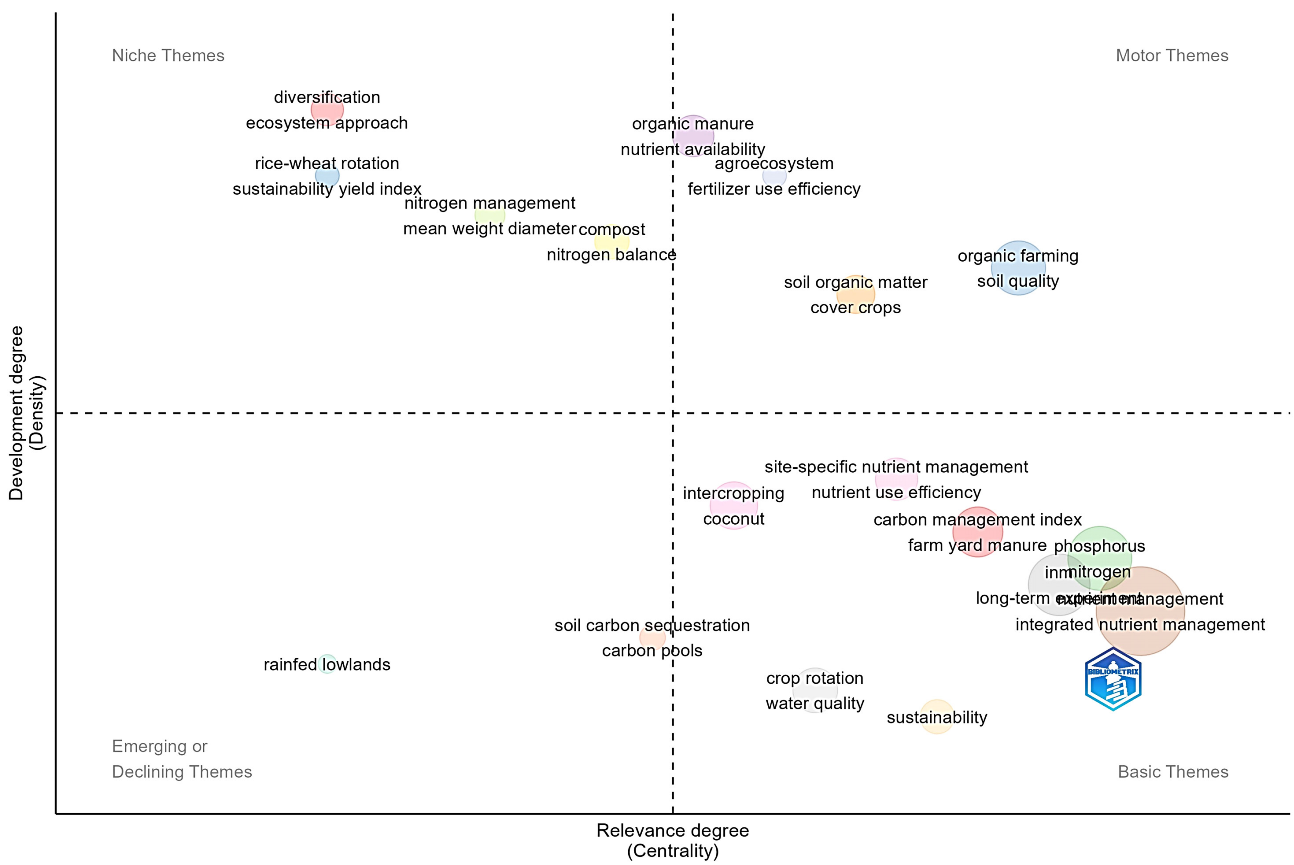

Fig. 7 Thematic mapping of keywords related to nutrient management under diverse cropping systems

upper left quadrant contained niche themes, which signified more specialized and specific areas of interest within the field. This included diversification, adopting an ecosystem approach, the rice-wheat rotation method, sustainability index assessment, and nitrogen management practices. These themes represented more targeted areas of study within the broader context. Lastly, the upper right quadrant was associated with overarching and widely recognized themes that are central to the field. These encompassed discussions related to organic manure, nutrient availability, agroecosystems, fertilizer use efficiency, soil organic matter, cover crop utilization, organic farming practices, and soil quality assessment. These themes were considered pivotal and had a significant impact on the overall landscape of research in this domain.

The country collaborative map showed the strong collaboration among India, Australia, USA, China, Canada, Brazil, Argentina, UK and European counties such as France, Germany and Norway. Several countries had fostered collaborative ties and were actively involved in joint research endeavours, demonstrating a collective commitment to advancing knowledge and practices within this particular field. Notably, Australia, South Africa, and Brazil were also active in conducting research related to nutrient management under diverse cropping systems. However, it was evident that these nations had limited engagement in collaborative efforts with foreign counterparts (Fig. 8). This observation suggested that their research efforts were primarily focused on domestic initiatives, and they had yet to establish extensive international partnerships within the realm of nutrient management. In essence, the global collaboration network among countries in the field of nutrient management under diverse cropping systems highlighted the importance of sharing ideas, expertise, and resources, thereby facilitating the continuous progress and dissemination of knowledge within this specialized area of study.

Knowledge Gaps

Identifying knowledge gaps in nutrient management in diverse cropping systems is crucial for advancing sustainable agriculture and enhancing crop productivity. Here is some potential knowledge gaps based on previous research:

1. **Crop-specific nutrient requirements:** Existing research often provides generalized nutrient recommendations for specific crops. There is a need for more precise information about the nutrient requirements of diverse

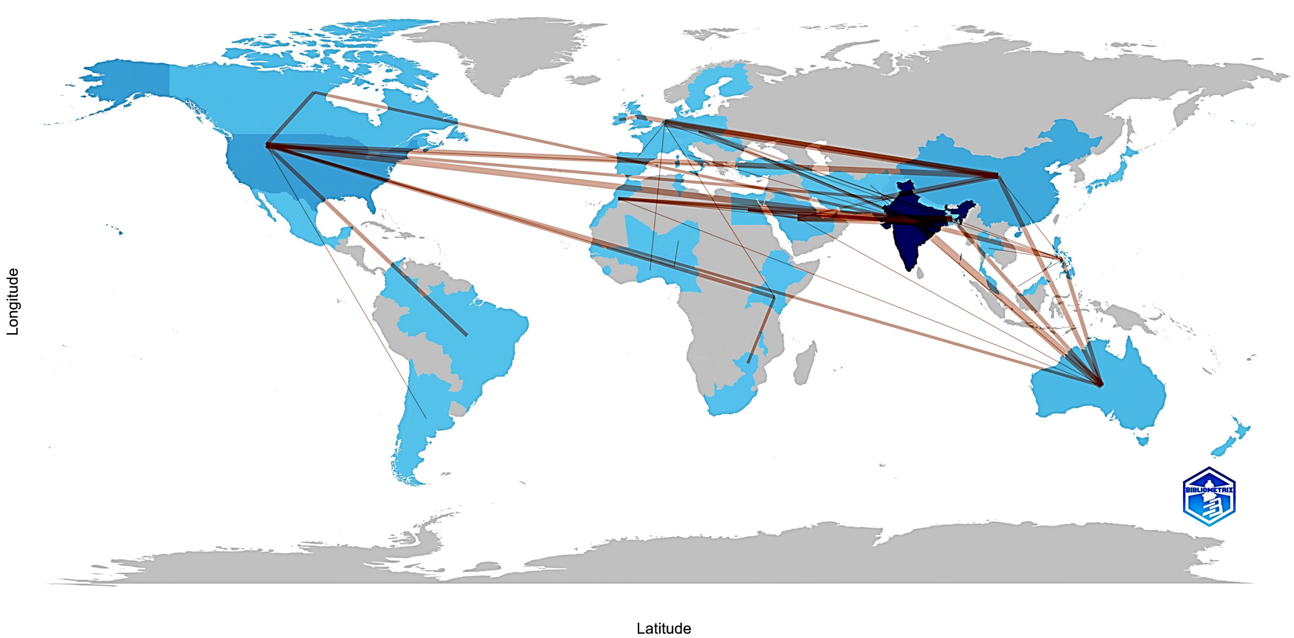

Fig. 8 Country collaboration network on the research related to nutrient management under diverse cropping systems

crop varieties within different cropping systems. Tailoring nutrient management practices to specific crops can optimize yields and minimize waste (Dwivedi *et al.,*2009; Gan *et al.,* 2015) .

2. **Integration of organic nutrient sources:** While organic nutrient sources like compost and cover crops are known to improve soil health and nutrient availability, knowledge gaps exist in their optimal integration. Research should focus on determining the most effective organic nutrient management practices, including application rates, timing, and combinations with synthetic fertilizers (Singh *et al.,* 2015).
3. **Nutrient imbalances:** Understanding nutrient imbalances and their consequences within diverse cropping systems is critical. Research should investigate how imbalances in macronutrients (e.g., nitrogen, phosphorus, potassium) and micronutrients affect crop growth and yield, and develop strategies for correcting these imbalances (Aulakh *et al.,* 2010; Chikowo *et al.,* 2011).
4. **Nutrient loss mitigation:** Nutrient losses through leaching, runoff, and volatilization are of significant concerns. Identifying efficient techniques and technologies to mitigate nutrient losses, such as controlled-release fertilizers or precision application methods, is an ongoing knowledge gap (Ghosh *et al.,* 2007).
5. **Climate resilience:** Climate change affects nutrient dynamics, making it important to research how altered weather patterns, including droughts, floods, and temperature fluctuations, impact nutrient availability and crop response within diverse cropping systems.
6. **Nutrient management in agroforestry systems:** In agroforestry systems, nutrient interactions between trees, crops, and livestock are complex. Research is needed to develop nutrient management strategies that optimize productivity and ecological benefits in these integrated systems.
7. **Digital agriculture for nutrient management:** The adoption of digital technologies in agriculture is growing. Research should explore how precision agriculture tools, such as remote sensing and data analytics, can be harnessed to optimize nutrient management decisions in diverse cropping systems (Basso and Antle, 2020).
8. **Sustainable nutrient practices for smallholder farmers:** Many smallholder farmers lack access to resources for optimal nutrient management. Research should focus on cost-effective, sustainable, and scalable nutrient management practices tailored to the needs and constraints of small-scale agriculture (Goulding *et al.,* 2008).
9. **Long-term impacts on soil health:** Investigating the long-term effects of different nutrient management practices on soil health, including soil structure, microbial diversity, and carbon sequestration, is vital for ensuring sustainable agriculture over time.

Addressing these knowledge gaps will contribute to more efficient and sustainable nutrient management in diverse cropping systems, promoting agricultural resilience, food security, and environmental sustainability.

Conclusions

The adoption of cropping system-based nutrient management practices is pivotal for achieving sustainability in agriculture, as it not only optimizes nutrient utilization and enhances crop productivity but also mitigates adverse environmental impacts. Nutrient management under salt-affected soils require combined application of organic amendments with chemical fertilizers and appropriate agronomic practices to overcome inherent fertility constraints and complex ion interactions. This comprehensive Scientometric analysis highlighted the integration of diverse techniques, ranging from precision agriculture to cover cropping, crop rotation, organic farming, and digital technologies, all of which contributed to improving nutrient use efficiency and addressing nutrient-related challenges. The identification of prolific authors, influential journals, and impactful research papers provided a roadmap for researchers, policymakers, and stakeholders. Such insights would facilitate informed decisions regarding the allocation of resources and the formulation of research priorities. The findings from synthesizing the collective knowledge of the past two decades, offers a forward-looking perspective that is essential for navigating the complex terrain of modern agriculture in a manner that ensures a resilient future for both humanity and our planet.

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