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Analysis And Contemporary Perspectives of Yágodin's Agrochemistry and its Integration with Current Environmental Principles and Challenges

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ABSTRACT: Agrochemistry is an essential discipline that studies the chemical composition and biochemical processes of soils and plants in order to optimize agricultural production under sustainability criteria, ensure adequate plant nutrition, and preserve soil fertility. In this context, the work *Agrochemistry I and II*, edited by B. A. Yagodin and published by Mir Publishers, represents a classical reference in the education and dissemination of this science, particularly in the Spanish-speaking sphere, by integrating theoretical foundations and practical applications. The objective of this research was to analyze the validity, coherence, and relevance of the principles and recommendations contained in both volumes by contrasting them with recent scientific evidence and current environmental regulations, in order to identify areas for improvement and propose guidelines for modern agrochemistry. The methodology included a critical and systematic content analysis, complemented by a bibliometric study of the state of the art using RStudio. A Scopus database comprising 494 publications in the field of agricultural sciences (1980–2025) was used, applying "Agroquímica B. A." as the search criterion. The results indicate that the foundations proposed by Yagodin remain relevant and are associated with current issues such as soil chemical processes, plant nutrition, fertilizer dynamics, soil acidification, and phosphorus availability. Furthermore, convergence was observed with sustainable nutrient management approaches and emerging technologies such as biochar, controlled-release fertilizers, and digital monitoring. The bibliometric analysis highlighted Italy, France, and Mexico in terms of citation counts, and Japan, the United States, and the United Kingdom in scientific output. It is concluded that integrating Yagodin's contributions with recent evidence strengthens an updated agrochemical approach capable of addressing contemporary environmental and productive challenges.

KEYWORDS: Agrochemicals, staple crops, nutrition, soils, yield

INTRODUCTION

Contemporary agrochemistry studies have revisited and expanded upon numerous principles formulated since the mid-20th century, incorporating new approaches derived from biogeochemistry, microbial ecology, and soil science. Currently, understanding the interactions between the physical, chemical, and biological components of the soil is essential for explaining nutrient dynamics and the functioning of agroecosystems. Advances in analytical techniques have allowed for a more precise description of the mechanisms that control the solubility, mobility, and availability of essential plant elements. Likewise, agricultural intensification and the continuous use of fertilizers have created scenarios where soil processes are modified at different scales, requiring a reinterpretation of classic concepts in light of new scientific evidence. In this sense, modern agrochemistry integrates traditional principles with

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recent findings on soil enzyme activity, ion interactions, and the central role of the microbiota in nutrient transformation. This general framework allows us to contextualize the following sections and evaluate both the validity of fundamental concepts and the emerging challenges arising from current agricultural management practices. Agrochemistry is a discipline that merges chemistry and agriculture, exploring how chemical compounds interact with biological systems in crops. This makes it fundamental for optimizing agricultural production, improving food quality, and protecting ecosystems. In this sense, agrochemistry is one of the cornerstones for understanding nutrient dynamics in agricultural ecosystems. For decades, Yagodin's texts, Agrochemistry I and II, have served as the theoretical basis for explaining the chemical transformations that regulate soil fertility and nutrient uptake by plants. However, current challenges stemming from climate change, soil degradation, and excessive reliance on synthetic fertilizers demand a modern reinterpretation of these principles. On the other hand, in the modern era, agrochemistry plays a crucial role in optimizing agricultural production and in the sustainable management of natural resources. Therefore, BA Yagodin's books "Agrochemistry I" and "Agrochemistry II" provide a solid foundation for understanding the principles and applications of agrochemistry. This research allows us to explore the key concepts of this discipline while analyzing its impact on agriculture and its relevance in the current context. It is worth mentioning that these two volumes of BA Yagodin's "Agrochemistry" have been a fundamental reference source for decades for students, technicians, and professionals in agronomy and related sciences throughout the Spanish-speaking world. Their detailed approach covers everything from the basic principles of agrochemistry to its specific applications and considerations regarding the quality and the robust and comprehensive management of natural resources. Although advances in agrochemical science continue today, the fundamentals presented in this work remain valid and continue to be a cornerstone for understanding the complex interactions that determine the productivity and sustainability of agricultural systems. Therefore, its study allows us to understand the importance of proper nutritional management for food security and the protection of natural resources.

On the other hand, in recent years bibliometric analysis has been found to be a fundamental methodological tool for quantitatively evaluating scientific output, identifying research trends, citation patterns, collaboration networks, and the evolution of knowledge in a specific field. Since its initial conceptualization, bibliometrics has been defined as the application of statistical and mathematical methods to books, articles, and other scientific communication media in order to analyze the dynamics of science and technology (Pritchard, 1969). Currently, this approach is widely used to characterize the state of the art in a discipline, support decision-making in science policy, and guide emerging research agendas (Donthu *et al* ., 2021).

On the other hand, using the R-Studio environment for bibliometric analysis offers significant advantages due to its flexibility, ability to handle large volumes of data, and reproducible approach. R-Studio functions as an integrated development environment for the R language, facilitating the import, cleaning, statistical analysis, and visualization of bibliographic data from scientific databases such as Scopus or Web of Science. This allows for the development of transparent and replicable workflows, a key aspect of contemporary scientific research (R Core Team, 2023). In this regard, one of the main strengths of bibliometric analysis in R-Studio is the availability of specialized packages, particularly Bibliometrix, which provides a comprehensive set of tools for bibliometric analysis and science mapping. This package allows for the calculation of classic indicators of productivity, impact, and collaboration, as well as the generation of co-authorship, co-citation, and keyword co-occurrence network analyses, facilitating the structural and thematic interpretation of scientific literature (Aria & Cuccurullo, 2017). Furthermore, Bibliometrix has proven to be a robust and versatile tool for bibliometric studies across various disciplines, reinforcing its methodological utility. Overall, the application of bibliometric analysis using R-Studio not only contributes to an objective and systematic evaluation of the scientific literature but also allows for the integration of quantitative and visual approaches to understand the evolution, knowledge gaps, and emerging lines of research, strengthening the quality and depth of academic studies. Therefore, the objective of this research was to examine the validity and consistency of Yagodin's claims, principles, and recommendations by comparing them with contemporary scientific evidence and current environmental regulations, in order to identify areas of opportunity and formulate proposals to guide current agrochemical research and practice.

MATERIALS AND METHODS

Geographic location of the research. The research was carried out at the facilities of the Postgraduate College Campus, Veracruz; which is located in the Tepetates area, on the Veracruz-Xalapa federal highway at kilometer 88.5, in the municipality of Manlio

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Fabio Altamirano, Veracruz, Mexico, between the towns of Puente Jula and Paso San Juan. Geographically, it is located at 19° 11' 53" North Latitude and 96° 19' 47" West Longitude at an elevation of 32 meters above sea level (García, 2004).

Stages of the analysis of volumes I and II of BA Yagodin.

- **Design.** A mixed-methods analysis was conducted (qualitative textual analysis + systematic review/bibliographic mapping + technical-chemical evaluation of the substances mentioned). This combination allows us, firstly, to describe the content and discourses of the volumes; to situate them within the current scientific literature; and secondly, to evaluate the environmental risks/implications of the principles and substances discussed. (James *et al* ., 2016)
- **Record of the work developed:** An essay was written considering the integration of the two volumes of Agroquímica I and II by BA Yágodin, implicitly reflecting on research questions, inclusion/exclusion criteria, search strategy and analysis plan.
- **Interpretation of Results.** The interpretation of the results was carried out through a structured narrative synthesis that integrates the quantitative and qualitative findings extracted from Volumes I and II of *Agroquímica* (Yágodin, 1982 and 1986). The robustness of the inferences was assessed by describing the internal consistency between chapters, the degree of empirical support cited by the author, and the contextual applicability to current agricultural systems. Any assertion that depends on historical data or translations was explicitly noted to preserve methodological transparency. The interpretive discussion was completed with a section on critical appraisal of the evidence, in which the level of certainty of the main ideas was considered using criteria parallel to those of systematic reviews (clarity of the source, risk of bias due to historical context, and agreement with subsequent studies). Finally, open questions and lines of future research were noted to validate or refine the applications recommended by Yágodin in contemporary agroecosystems.
- **Bibliometric analysis.** A state-of-the-art analysis was performed, as well as bibliometric maps using RStudio software. The database was obtained from the Scopus platform and included publications corresponding to the period 1980–2025, considering the keywords “Agrochemicals” and “BA” as search criteria. With this information, the corresponding metrics of the aforementioned words were generated, as well as the bibliometric maps of these concepts with the VOSviewer program (Van Eck & Waltman, 2023).
- **Information Analysis.** In this section, a systematic review of the contents of both volumes was first conducted to identify the main thematic units. This phase involved active reading and note-taking, structured by chapter and key term; extraction of main ideas, hypotheses, and empirical data; and comparison with contemporary literature through searches in academic databases to situate Yágodin's concepts within subsequent developments. To ensure the rigor of the research, an analysis sheet was used for each chapter (author, year, central thesis, evidence presented, explicit limitations), and the exact page numbers were recorded to facilitate textual citations and to verify the accuracy of the interpretation. In this case, Volume I has 418 pages and Volume II 462 pages. Second, a critical analysis and integrative synthesis were constructed. This was generated from the analysis sheets, and comparative matrices were developed that relate Yágodin's postulates to current empirical evidence and regulations. These matrices allowed us to identify: relevant contributions, outdated concepts, methodological gaps, and recommendations for future research. Throughout the document, academic citation style (as required by the journal or institution) was followed, and a complete list of references used as supporting documentation was included.

RESULTS AND DISCUSSION

General Analysis of Agrochemistry Volume I: Fundamentals and Bases of Plant Nutrition and Soil Fertility

The first volume of Agrochemistry by BA Yagodin lays the theoretical foundation for this discipline. Authors such as P. Smirnov and A. Peterburgski also contributed to this volume, providing essential knowledge about the soil/plant relationship and the principles governing fertilizer use to optimize crop nutrition. Its 418 pages cover the following crucial topics:

- General Principles of Agrochemistry: Introduces the object of study, its relationship with other sciences and its importance for agriculture.
- Chemical Composition of Plants: Details the essential elements for plant development, their classification (macro and micronutrients) and their physiological functions.
- Soil as a Medium for Plant Growth:
  - Soil Properties: Delves into the granulometric composition, structure, density, and other physical properties of the soil that influence the availability of nutrients and water.

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- Soil Organic Matter: Its fundamental role in fertility, nutrient cycling and the improvement of soil properties.
- Soil Absorption Capacity: Explains the processes of ion exchange and how the soil retains and supplies nutrients to plants.
- Soil Acidity and Alkalinity: Discusses soil pH, its implications for nutrient availability, and methods for correcting it.

❖ Plant Mineral Nutrition:
- Nutrient Absorption by Roots: Mechanisms by which plants take nutrients from the soil.
- Essential Nutrient Cycle: The biogeochemical cycles of key elements such as Nitrogen (N), Phosphorus (P), and Potassium (K), as well as other macro and micronutrients, are described in detail.

❖ Fertilizers and their Application:
- Classification and Characteristics of Fertilizers: The different types of mineral (nitrogenous, phosphate, potassium, complex, microelements) and organic fertilizers are studied.
- Interaction of Fertilizers with the Soil: Processes of transformation, fixation, and mobilization of the nutrients provided by the fertilizers.
- Methods and Times of Fertilizer Application: Foundations for efficient and rational fertilization.
- Diagnosing Fertilization Needs: Methods for determining the nutritional deficiencies of crops and the appropriate doses of fertilizers.

Detailed description of Volume I:

The book *Agrochemistry (Volume I)*, written by Yagodin, is a fundamental work in the field of agricultural sciences, specifically in the study of the chemical processes involved in crop production and management. This volume focuses on establishing the theoretical and practical foundations of agrochemistry, addressing essential topics such as soil composition, plant nutrients, fertilizers, and their interaction with agricultural systems. This essay aims to analyze the most relevant aspects of the first volume, highlighting its contribution to agrochemical knowledge and its application in modern agriculture.

One of the cornerstones of Volume 1 is its focus on soil composition and properties. Yagodin dedicates a significant portion of the book to explaining the chemical structure of soil, highlighting its role as a dynamic medium where physical, chemical, and biological processes occur that influence plant growth. The author describes how the mineral and organic components of soil interact to form a complex system that determines nutrient availability for crops. This analysis is crucial for understanding how fertilizers and other agrochemicals can be optimized to improve agricultural productivity without compromising soil sustainability.

Regarding plant nutrients, Yágodin presents a detailed classification of the elements essential for plant growth, dividing them into macronutrients (such as nitrogen, phosphorus, and potassium) and micronutrients (such as iron, zinc, and manganese). The author explains the specific functions of each nutrient in plant metabolism and how its deficiency or excess can affect crop development. This approach not only provides a solid theoretical foundation but also offers practical tools for diagnosing and correcting nutritional problems in agricultural soils.

Another highlight of Volume 1 is its treatment of fertilizers. Yágodin analyzes different types of fertilizers, from traditional to synthetic, and describes their mechanisms of action in the soil and plants. The author also addresses topics such as fertilizer use efficiency, the relationship between dosage and response, and the environmental impacts associated with excessive or inappropriate application. This comprehensive approach reflects the importance of balancing agricultural productivity with the conservation of natural resources, a highly relevant issue today.

In addition to its technical content, the book is distinguished by its pedagogical approach. Yagodin uses clear and accessible language, accompanied by diagrams, tables, and practical examples that facilitate the understanding of even the most complex concepts. This makes Volume 1 of *Agrochemistry* a valuable tool for both students and professionals in the agricultural sector. In conclusion, Yagodin's Volume 1 of *Agrochemistry* is an essential work for understanding the fundamentals of chemistry applied to agriculture, as its focus on soil composition, plant nutrients, and fertilizers provides a solid foundation for the sustainable management of agricultural systems. Furthermore, its didactic style and practical approach make it an invaluable resource for those seeking to delve deeper into the study of agrochemistry. This work not only contributes to the advancement of scientific knowledge but also promotes more efficient and environmentally friendly agricultural practices.

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General Analysis of Agrochemistry Volume II: Practical Applications, Production Quality and Environmental Aspects

Volume II of Yagodin's work complements the first, focusing on more applied aspects and the quality of agricultural production; and although there is some discrepancy in the sources regarding its length (some indicate around 102 pages and others up to 464 pages, making a total of 880 pages between both volumes), its content focuses on the following:

- Specific Crop Agrochemistry: Application of agrochemical principles to the nutritional management of different crop groups (cereals, legumes, horticultural crops, fruit trees, industrial crops, etc.), considering their particularities and requirements.
- Quality of Agricultural Production:
  - Influence of Agrochemical Factors on Quality: How mineral nutrition and fertilizer use affect the qualitative characteristics of agricultural products (protein content, vitamins, sugars, etc.).
  - Quality Control of Agricultural Products: Methods and criteria for evaluating the quality and safety of crops. The potential accumulation of undesirable substances (such as nitrates) and how to minimize it are discussed.
- Rational Use of Agrochemicals and Environmental Protection:
  - Efficiency in the Use of Fertilizers: Strategies to maximize the use of nutrients by plants and reduce losses.
  - Environmental Impact of Agrochemicals: The risks of water and soil contamination from improper handling of fertilizers and other agricultural chemicals are addressed.
  - Sustainable Agrochemical Practices: Guidelines for agriculture that reconciles productivity with environmental conservation.
- Methodology of Agrochemical Research: Possibly includes chapters dedicated to methods of analysis of soils, plants and fertilizers, as well as the design and conduct of field and laboratory experiments in agrochemistry.

Detailed analysis of Volume II.

The book *Agrochemistry*, written by Yagodin, is a fundamental work in the field of agricultural science, and its second volume delves deeper into essential aspects related to the application of chemical principles in agriculture. This volume, in particular, focuses on topics such as nutrient dynamics in the soil, the interaction between fertilizers and crops, and methods for optimizing agricultural productivity sustainably. Through a scientific and practical approach, Yagodin offers a comprehensive view of how chemistry can be used to improve soil quality and, consequently, crop yields.

One of the highlights of Volume II is its detailed analysis of essential plant nutrients, in which Yagodin explains how elements such as nitrogen, phosphorus, and potassium, as well as micronutrients, play a crucial role in crop growth and development. The author not only describes the biological functions of these elements but also addresses how they can be efficiently supplied through fertilizers. This approach allows readers to understand the importance of balancing the soil's chemical composition to avoid both nutrient deficiencies and excesses, which could have negative environmental impacts.

Another central theme of the book is the interaction between fertilizers and soil, in which Yágodin emphasizes that the effectiveness of fertilizers depends not only on their chemical composition but also on the physical and biological characteristics of the soil. For example, soil pH, texture, and the presence of microorganisms can influence the availability of nutrients to plants. The author proposes methods for evaluating these conditions and adjusting fertilization practices accordingly. This holistic approach is particularly relevant in a global context where soil degradation and the need for sustainable agriculture are growing concerns.

Furthermore, Volume II addresses the environmental impact of agrochemical use; however, the author does not ignore the challenges associated with the excessive application of fertilizers, such as water pollution and ecosystem disruption. In this regard, Yágodin advocates for the responsible use of agrochemicals, promoting techniques such as balanced fertilization and the integration of ecological farming practices. This approach reflects a growing awareness of the need to balance agricultural productivity with environmental conservation.

In terms of style, Yagodin combines precise technical language with clear and accessible explanations, making the book useful for both students and professionals in agronomy; in addition, the inclusion of case studies and practical examples allows readers to apply theoretical concepts to real-world situations, making this combination of theory and practice one of the work's greatest strengths.

In conclusion, Volume II of Yágodin's *Agrochemistry* is an invaluable contribution to the study of chemistry applied to agriculture.

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Through rigorous analysis and a balanced perspective, the author not only provides tools to improve agricultural productivity but also fosters a responsible and sustainable approach to the use of natural resources. Furthermore, it guides the reader toward the practical application of agrochemical knowledge, emphasizing the production of quality products and the need for environmentally responsible agricultural management. Therefore, in a world where food security and sustainability are urgent challenges, this book stands as an essential guide for those seeking to understand and improve the relationship between chemistry and agriculture.

BIBLIOMETRIC ANALYSIS

The bibliometric analysis was conducted considering the period from 1980 to 2025, identifying a total of 494 documents corresponding exclusively to the area of agricultural sciences, using the keywords "Agrochemicals BA" as the search criterion. Regarding citations per year, an average of 42 citations was observed for the period 1980–1989, followed by an average of 33 citations between 1990 and 2005; finally, for the period 2006–2025, the average number of citations decreased to 8. Furthermore, the countries with the highest number of citations were Italy, France, and Mexico. As for the scientific output associated with the analyzed topic, Japan had the highest frequency with 70 publications, followed by the United States (12), the United Kingdom (9), South Korea (5), Brazil (6), Thailand (4), and France (4), while Argentina, Canada, China, and Egypt each registered two publications.

The higher average number of citations recorded during the period 1980–1989 (42 citations) and subsequently between 1990 and 2005 (33 citations) suggests that the theoretical and methodological foundations of classical agrochemistry had a significant influence during the final decades of the 20th century. This trend is consistent with the consolidation of agrochemistry as a formal scientific discipline, in which the principles of plant nutrition, soil chemistry, and mineral fertilization were widely adopted and cited in the specialized literature (Pritchard, 1969; Aria & Cuccurullo, 2017). The decrease in the average number of citations from the period 2006–2025 (8 citations) onward can be interpreted as a shift in research priorities rather than a loss of conceptual relevance. In recent years, agrochemistry has evolved towards interdisciplinary approaches that integrate environmental sustainability, agroecology, climate change mitigation and efficient use of nutrients, which has diversified lines of research and reduced direct dependence on classic works, without implying their obsolescence (Tilman *et al* ., 2002; Donthu *et al* ., 2021).

The country-by-country analysis shows that Italy, France, and Mexico account for the highest number of citations, suggesting a strong academic tradition in agrochemical and soil science studies in these regions. In the case of Mexico, this result can be attributed to the importance of soil fertility management in diverse agricultural systems and the continued use of educational approaches based on classic literature adapted to local conditions. Meanwhile, the high scientific output observed in Japan, followed by the United States and the United Kingdom, reflects these countries' capacity to generate applied and technological research, particularly in areas such as controlled-release fertilizers, digital soil monitoring, and nutrient use efficiency—priority topics in contemporary agrochemistry (Tilman *et al*., 2002). Overall, the bibliometric results confirm that agrochemistry has shifted from a predominantly descriptive and experimental approach toward more comprehensive and sustainable models. Nevertheless, the fundamental principles developed in classic works continue to serve as a conceptual basis for new scientific approaches. Thus, bibliometric analysis not only allows the identification of trends and citation patterns, but also contextualizes the validity of agrochemical knowledge within the current challenges of agricultural production and environmental sustainability (Aria & Cuccurullo, 2017; Donthu *et al*., 2021).

On the other hand, Figure 1 shows the co-occurrence network (left side) and the four-field thematic map (right side) generated with R-Studio for the concept of Agrochemistry BA. This map displays the main concepts, keywords, authors, and other related topics within a set of scientific publications, allowing us to identify the thematic structure and knowledge dynamics in a research field. In this type of network, the observed nodes represent the analyzed elements, and the links reflect their co-occurrence in the documents. A higher frequency of co-occurrence indicates a closer conceptual relationship. Likewise, the presence of clusters or communities within the network reveals consolidated, emerging, or peripheral lines of research, while the centrality and size of the nodes allow us to identify the key concepts that articulate the field of study. In this sense, in Figure 1 (right side), the driving themes that are at the forefront of this analysis are shown in the upper right corner. Furthermore, the conceptual structure of each of the four research fields is visualized, classifying the topics according to their degree of development and importance through centrality and density indicators, which facilitates the identification of dominant, basic, specialized and emerging topics, as well as guiding the analysis of the state of the art and the definition of future lines of research in a scientific article.

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Figure 2 presents an integrated view of the relationship between countries (central field), keywords (left garden), and authors (right garden), considering the 15 most prominent elements in each field. This allows for the identification of patterns in scientific production and collaboration, revealing which countries concentrate the greatest research activity, which thematic terms dominate the area of study, and which authors are the most influential, as well as the existing connections between them. Taken together, this section facilitates the interpretation of the intellectual structure of the analyzed field, highlighting the central nodes and the most relevant interactions within the scientific literature.

The results show that scientific production is concentrated in certain countries that act as hubs within the field; these countries are closely linked to dominant themes and highly influential authors, reflecting both thematic specialization and consolidated collaborative networks. This structure highlights the existence of central nodes that guide scientific development and set research trends, facilitating the identification of strategic actors and priority lines of study. In this sense, the analysis confirms that bibliometric visualizations allow us to understand the intellectual and relational organization of a scientific field, as well as its main knowledge flows (Aria & Cuccurullo, 2017).

Figure 1. Co-occurrence network (left side) and four-field thematic map (right side) generated with R-Studio of the Agroquímica BA concept

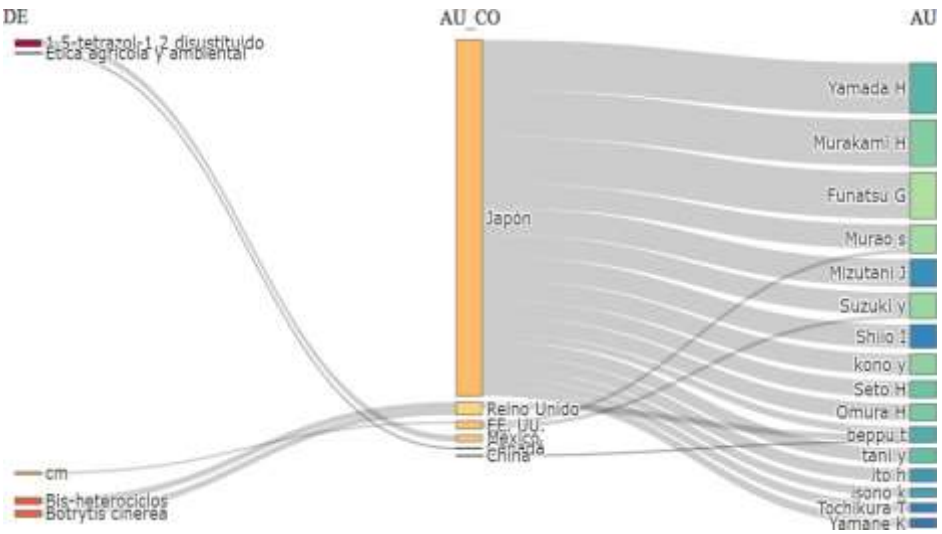

Figure 2. Three-field plot considering countries in the middle field, keywords in the left field, and authors in the right field, generated with R-Studio from the top 15 outstanding data points in each field.

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The co-occurrence network for the concept of Agrochemistry BA, generated with VOSviewer (Figure 3) , shows the conceptual organization of the field based on the frequency and association of key terms present in the analyzed literature. The network reveals the formation of well-defined thematic clusters, which represent knowledge cores related to soil chemical processes, plant nutrition, fertilization, and nutrient management, reflecting the conceptual structure and dominant lines associated with the agrochemistry proposed by Yágodin. In this sense, from a discussion perspective, the presence of central nodes with high co-occurrence indicates core concepts that articulate the field and act as bridges between different subtopics, suggesting a consolidated theoretical basis and a strong interrelation between the chemical, biological, and agronomic components of the soil-plant system. Likewise, the proximity and density of the links between terms reveal the evolution and complementarity of research approaches, confirming that agrochemistry is an integrative field that supports the development of more efficient and sustainable agricultural practices. Therefore, the use of co-occurrence networks allows the identification not only of conceptual trends, but also of gaps and opportunities for future research, strengthening the critical analysis of scientific knowledge (Van Eck & Waltman, 2010; Aria & Cuccurullo, 2017).

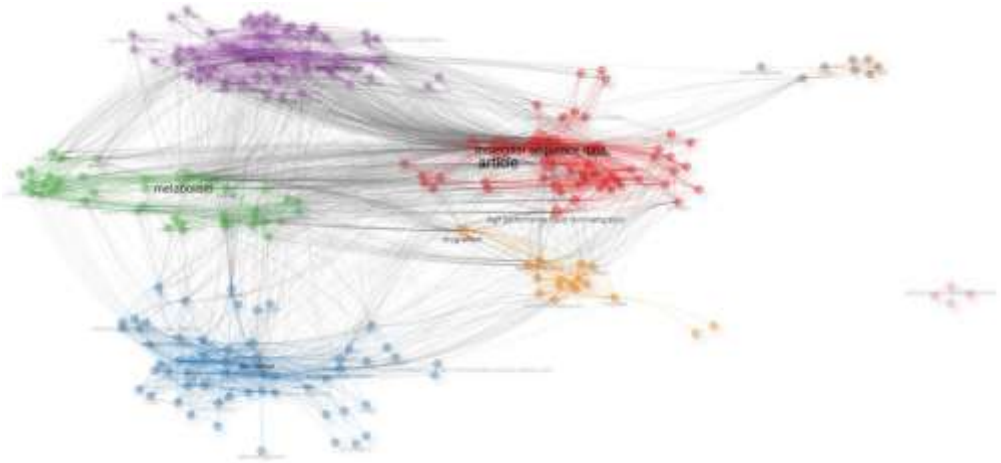

Figure 3. Co-occurrence network of the Agroquímica BA concept, generated with VOSviewer

Soil Agrochemistry: Transformations, Impacts and Recent Trends

Based on the principles established by Yagodin, the interaction between the solid, liquid, and gaseous phases of the soil constitutes the axis that defines nutrient availability. Properties such as cation exchange capacity, adsorption, chelation, and pH explain the processes that regulate the retention, mobility, and transformation of essential elements. This work remains an essential reference for evaluating the effects of agricultural management (Baquero José, 1995). In parallel, the biogeochemical transformations of nitrogen, phosphorus, and potassium depend largely on soil microbial activity. Recent evidence shows that the continuous application of nitrogen fertilizers causes sustained decreases in pH and reduces microbial enzyme activity, while phosphorus remains a particularly limiting nutrient due to its fixation in soils with extreme acidity or alkalinity (Zhang *et al*., 2024).

Plant mineral nutrition relies on diffusion, mass flow, and active transport processes, the efficiency of which is modulated by ionic interactions that can either promote or restrict absorption. Within this framework, nitrogen fertilizers alter soil chemistry through nitrification and denitrification reactions, while phosphate fertilizers tend to transform into less soluble forms depending on the pH. In light of these limitations, controlled-release and/or slow- release fertilizers have gained importance by improving nutrient use efficiency and reducing losses due to physicochemical processes (Beerling *et al*. 2023).

Among the environmental impacts associated with the intensive use of fertilizers are soil acidification, nitrate leaching, and water pollution. In this regard, long-term studies report reductions of up to 15% in soil pH under continuous nitrogen fertilization schemes (Liu *et al*., 2025) and (Kumar *et al*., 2025), highlighting the need for more balanced management strategies.

Regarding emerging technologies, biochar has shown positive effects on phosphorus availability and the regulation of soil processes. Recent research indicates that magnesium-enriched biochar increases phosphorus availability and improves soil enzyme activity (Ibrahim *et al*., 2024; Zhang *et al*., 2025). This is complemented by innovations such as coated fertilizers, the use of drones, digital

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monitoring systems, and machine learning-based models, which allow for more precise management decisions. Looking ahead, the main challenges include increasing nitrogen use efficiency, improving phosphorus availability through biogeochemical mechanisms, and reducing the environmental impacts of intensive fertilization.

CONCLUSIONS

Agrochemicals play a fundamental role in sustaining food security for a constantly growing global population. However, their contribution can only be maintained if the challenges associated with the use of chemical inputs in agriculture are addressed comprehensively, particularly those related to environmental pollution, pest resistance, and risks to human health.

Yagodin's principles remain essential for understanding soil chemistry, but modern agrochemistry requires integrating recent advances in biogeochemistry, digital agronomy, and sustainable practices; this is considered a transition to systems with a smaller environmental footprint and is indispensable to ensure the future productivity of agricultural soils.

Analysis of *Agrochemistry I* and *Agrochemistry II* confirms the relevance of agrochemistry for understanding and optimizing the use of chemical inputs in agricultural production; therefore, its contributions offer solid foundations for facing current challenges related to productive efficiency and environmental sustainability with modern responsible management practices to strengthen food security and reduce negative impacts on ecosystems.

Bibliometric analysis using RStudio and SCOPUS data on volumes I and II of BA Yágodin's *Agroquímica* allowed for an objective evaluation of its impact, trends, themes and scientific relevance, providing a clear vision of its contribution to the development of agrochemistry.

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