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REVIEW ARTICLE

Understanding the factors influencing the environmental stewardship of precision farming farmers - A systematic literature review

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Abstract

Precision farming has emerged as a transformative approach to enhance resource efficiency and minimize environmental impact as agriculture confronts more and more sustainability concerns. This systematic literature review delves into key factors influencing environmental stewardship in the context of farmers embracing precision farming using the Theory, Contexts, Characteristics and Methods (TCCM) framework. Well-screened data obtained from the Web of Science database published between 2002 and 2024, 40 relevant studies being reviewed through bibliometric and thematic content analysis using R Studio and VOS viewer. Findings revealed a steady increase in precision farming research, led by the United States, Agriculture and Human Values as the most cited journal and Finger's (2019) work has received the most citations. Key findings pointed out that social norms, economic incentives and government policies as significant determinants of farmers' environmental stewardship. Despite advancements, farmers are still confined by resource scarcity, knowledge gap and differences of opinion about environmental issues. This review marks the necessity of targeted interventions as a panacea to the barriers, encouraging ecological resilience and sustainability in agriculture.

Keywords: agriculture; environmental stewardship; farmers; precision farming

Introduction

Promoting improved human-environment interactions through stewardship is increasingly critical for terrestrial, marine, aquatic and aerial environments in both rural and urban areas (1). Around the world, individuals, communities, environmental groups and governments are taking actions such as creating protected areas, replanting trees, reducing harmful activities and promoting sustainable products to steward the environment. Environmental stewardship encompasses conservation, active restoration and sustainable resource management at various scales, from local to global efforts. Despite the global nature of many environmental issues, local actions remain vital for sustainability, as local people play a central role in caring for their immediate environment, which they often depend on for subsistence and livelihoods (2). Emphasizing environmental stewardship and long-term viability, sustainable agriculture has become a crucial solution for global food security and ecological sustainability. By adopting sustainable practices, it addresses the negative impacts of conventional farming, such as soil erosion, water pollution and biodiversity loss. In response to the urgency of sustainable development, regions worldwide are transforming their agricultural practices to meet sustainability goals (SDG 12 - Responsible Consumption and Production) (3-6).

Precision agriculture (PA) is expected to bring in a significant paradigm shift towards sustainable agriculture (7, 8). PA technologies are crucial for enhancing efficiency while maintaining food production level (SDG 2 - Zero hunger) (9). PA leverages Information Technology (IT), Satellite Technology (ST), Geographic Information Systems (GIS) and remote sensing to enhance agricultural operations and outcomes (10). It employs mobile apps, smart sensors, drones, cloud computing, artificial intelligence, the Internet of Things (IoT) and blockchain to address environmental and socio-economic impacts associated with farming activities (11, 12). In addition to supplying material support for production processes, precision agriculture aims to increase agricultural efficiency (13, 14). PA mitigates environmental impacts (15-18). Precision farming does not just enhance agricultural practices but also encourages sustainable farming by minimizing the overuse of resources like water, fertilizers and pesticides. Many farmers are deeply connected to their homes, local communities and natural surroundings, showing great care for the lands, they manage (19). However, it has been noted that farmers often perceive environmental issues and stewardship actions differently compared to other rural landowners or urban residents (20, 21). By identifying the determinants impacting farmers' inclinations towards embracing sustainable agricultural methods (precision agriculture), significant understandings can be obtained to guide policy interventions and promote the wider uptake of precision farming within similar settings. Understanding the fundamental motivations that propel farmers to embrace these practices is essential for the successful and extensive deployment of such approaches (22-24). Environmental stewardship denotes a state of being mindful and caring towards the environment, while knowledge signifies comprehension of sustainable agricultural techniques (25). Environmental stewardship is the responsible management of natural resources and ecosystems in a manner that ensures sustainability, resilience and ability to support both human and ecological needs (2). It describes the moral and practical obligations of individuals, communities and organizations with respect to the protection and enhancement of the natural environment. Environmental stewardship in precision farming entails adopting practices that are centered on sustainable development. These practices include soil conservation, water management and reduction of greenhouse emissions.

Innovation adoption could accelerate the shift to sustainable farming practices, with precision farming emerging as a key player in improving product quality and sustainable soil management (26). The implementation of PA practices produced noticeably improved economic and environmental effects and that varying degrees of incentives may be effectively targeted to promote adoption (27). Through this endeavour, this paper seeks to enrich the existing literature with a context-specific viewpoint, thereby augmenting the depth of understanding regarding the adoption of precision farming. Such elements may encompass aspects such as technological readiness, economic considerations, sociocultural factors, institutional aspects and personal attitude towards eco-friendly practices.

This paper will contribute to the mission of making agriculture more sustainable and resilient in the face of growing environmental challenges by trying to point out some gaps in present knowledge and suggesting areas for further research. Ultimately, this paper aims to offer a comprehensive perspective on the factors driving farmers' inclination towards sustainable agricultural practices within the realm of precision farming.

The paper starts by outlining the methodology, followed by an analysis of bibliometric statistics and trends in precision farming literature. It then explores the antecedents, mediators and moderators that affect environmental stewardship among precision farming farmers, as well as the theories, contexts and research methods employed in studying precision farming. The paper concludes by suggesting future research directions in precision farming, highlighting the study's implications.

Materials and Methods

Structure of the review

Systematic literature reviews are commonly categorized into domain-based, theory-based and method-based reviews, with domain-based reviews being the most prevalent in precision farming research (28). These reviews offer a synthesis of literature by examining research methods, theories and variables (28-30). Structured systematic literature reviews adhere to rigorous scientific methodologies outlined beforehand, ensuring reproducibility and reliability in synthesizing literature (31). They are deemed effective in assessing the current state of knowledge in a field and identifying research gaps for future exploration (28, 31, 32). Certainly, a Systematic Literature Review (SLR) diverges from conventional literature reviews primarily due to its structured and methodological approach to planning and execution. Distinguished by a rigorous methodology, SLR aims for independent replicability, thereby enhancing the scientific credibility of the subject under review. By meticulously sourcing, appraising and synthesizing all pertinent evidence on a particular research domain, SLRs strive for heightened validity in their result and conclusions (33).

The study utilized the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) method (Fig. 1) to perform a systematic literature review. This review employs the bibliometric analysis and Theory, Contexts, Characteristics and Methods (TCCM) framework to synthesize existing literature in precision farming and suggest avenues for future research (30, 34).

Search strategy

Following the methodology outlined in a previous study (35), an initial search was conducted on the Web of Science database using the following search string: "Factors" AND "environmental responsibility" OR "environmental stewardship" AND "farmers" AND "smart farming" OR "precision agriculture" OR "digital agriculture". This search found a total of 12707 records. Subsequently, 7280 records were omitted due to restricted access, resulting in a selection of 5427 accessible records. Of these, 4389 were identified as research articles. Among these research articles, 82 were deemed relevant to disciplines encompassing Sociology, Applied Psychology, Multidisciplinary Psychology, Multidisciplinary Humanities, Interdisciplinary Social Sciences, Area Studies, Economics, Management, Business Finance, Communication, Environmental Studies, Ecology and Development Studies. Employing a quality assessment criterion focusing on the relevance of titles to the review topic, 42 documents were excluded, leaving 40 records for inclusion in the literature review on precision farming as depicted in Fig. 1.

The bibliometric analysis was conducted using RStudio (version 2023.09.1+494) with the Bibliometrix package (version 4.2.1) and VOSviewer (version 1.6.19) was used for network visualization and cluster mapping. R studio is used for effective data management, visualisation and bibliometric analysis. A text mining component of the VOS viewer helps create and display co-occurrence networks by emphasising significant terms taken from scientific literature. Coloured circles used in VOS viewer's label view to represent different research elements. The significance and hierarchical placement of each item are shown by variations in the circle

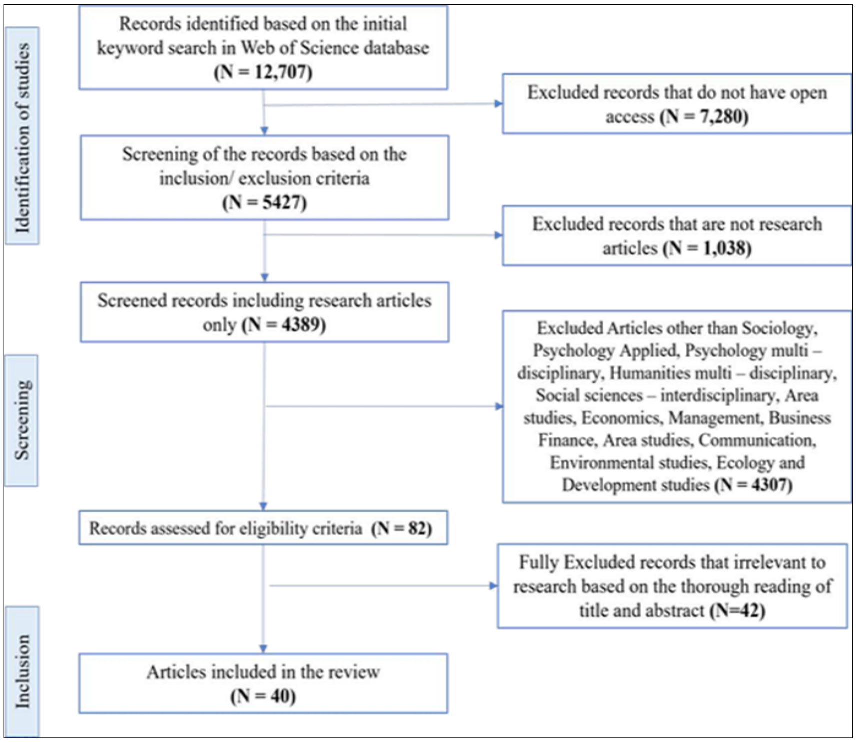

Fig. 1. PRISMA flowchart.

and text sizes (36).

Findings and Discussion

Findings of bibliometric analysis

The chosen articles for this review were studied across the span of 2002 to 2024, sourced from a diverse pool of 31 journals. The forty documents selected for this review exhibit an average citation rate of 23.9 per document. Cumulatively, these research papers cite a total of 2363 references.

The evolution of precision farming research across time

Analyzing the temporal distribution of research publications on a particular concept or domain provides valuable insights into the evolution of academic inquiry within that area. As the precision farming research found to be emerged in 2002, this year marks the commencement point for our systematic literature review. The chosen research papers have the period from 2002 to 2024. Fig. 2 illustrates the chronological distribution of the selected research papers across various publication years.

As illustrated in Fig. 2, the research into precision farming began in 2002. Notably, a marked increase in publication frequency was observed in 2018, with five publications recorded. However, minor fluctuations ensued between 2019 and 2021, followed by a notable upsurge in 2022, which saw the emergence of eight publications and a further increase to nine publications in 2023. An increase in publications over time usually indicates a rise in interest and understanding of the significance of precision farming. This expansion may be attributed to shift in priority areas for funding, technology and public knowledge on sustainable agricultural techniques.

Countries scientific production

Fig. 3 illustrates the distribution of scientific output by country in the field of precision farming. The United States of America leads with 11 publications, followed by Canada (4). Germany and Switzerland (3 each) and Italy and Sweden (2 each). Additionally, Brazil, Brunei, China, Ghana, Greece,

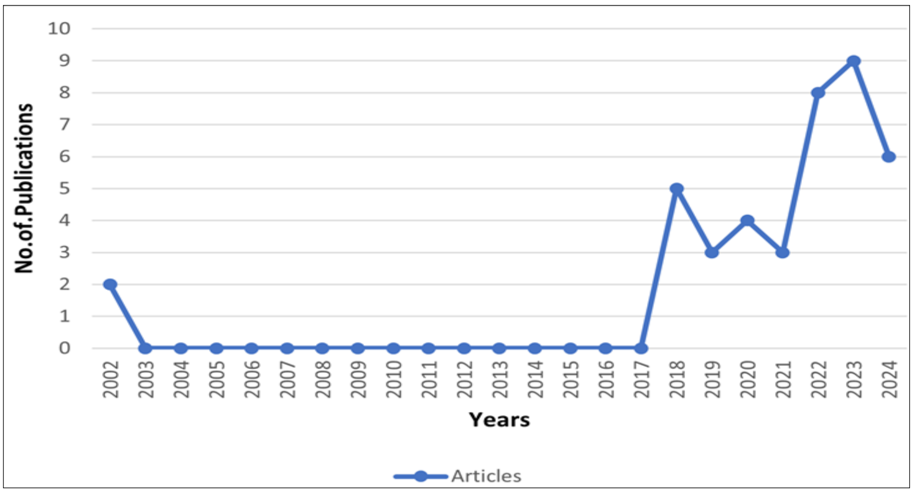

Fig. 2. Year-wise publications on precision farming.

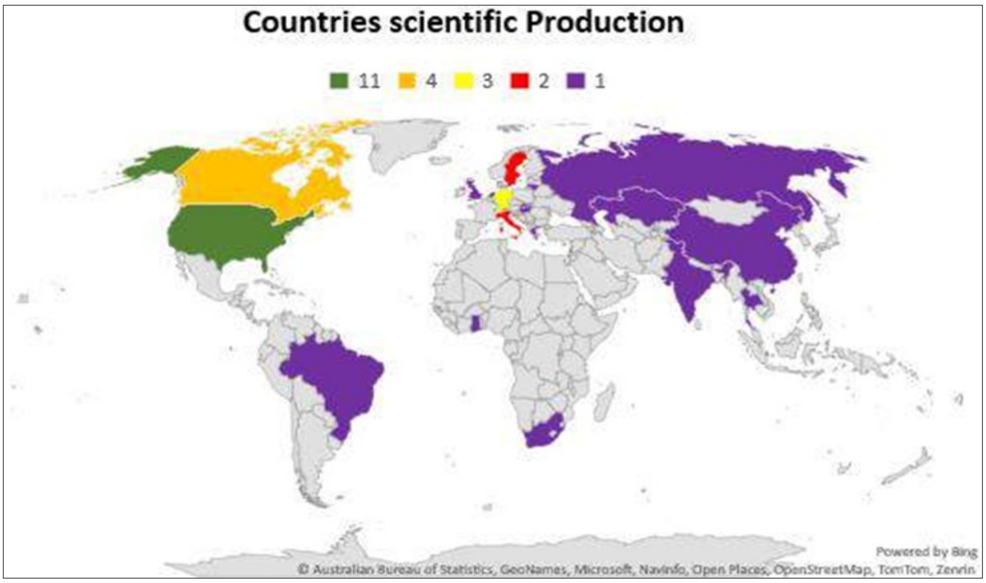

Fig. 3. Map showing countries scientific production in precision farming.

Hungary, India, Kazakhstan, Lithuania, the Netherlands, Russia, Slovakia, South Africa, Thailand and the United Kingdom published one each.

Most relevant sources

Research conducted on precision farming publications between 2002 and 2024, as depicted in Fig. 4, revealed that *Agriculture and Human Values* emerged as the leading journal in this field, with a total of four articles. Following closely, *Applied Economic Perspectives and Policy* published three articles. The analysis highlights agriculture and economics related journals as the primary publishers of noteworthy precision farming articles.

Most global citations

Fig. 5 illustrates the ten most frequently referenced articles within the Precision farming domain. Notably, the work on Precision Farming at the nexus of agricultural production and the environment stands out as the most cited, accumulating a total of 184 citations (37). Following the above, the paper on opportunities and challenges for big data in agricultural and environmental analysis has garnered 150 citations (38). Moreover, the work Big Data in agriculture: A challenge for the future exhibits the highest mean citation rate per annum, averaging 133 citations annually (39). The paper on digitalization and the third food regime follows with an average of 72 citations per year (40). The most referenced works focus on key areas in agricultural research, which delve into the intersection of precision farming with agricultural production and environmental sustainability. Meanwhile, it also explores the potential benefits and obstacles associated with using big data in agricultural and ecological contexts (37, 38).

Keyword occurrence

Co-word analysis, a method within content analysis, relies on identifying co-occurrence patterns of keywords across a collection of articles. Its objective is to uncover connections among the ideas incorporated within the themes addressed in the textual corpus (41). This approach facilitates the construction of a strategic diagram, which accentuates the relative significance of topics pertinent to precision farming. Utilizing the VOS viewer, the network of prevalent keywords within our selected articles was analyzed. As depicted in Fig. 6, the most frequently encountered keywords are depicted as

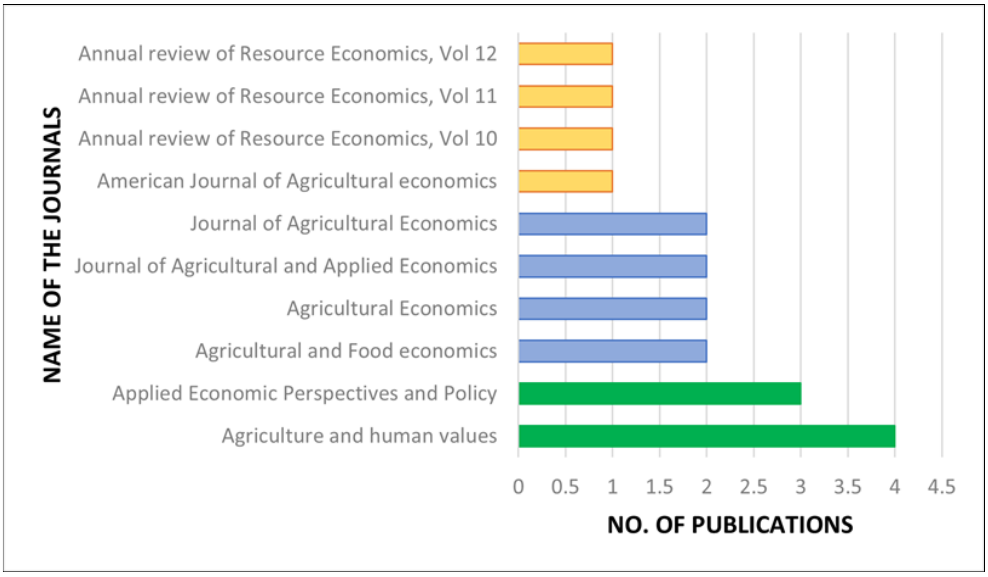

Fig. 4. Widely published journals.

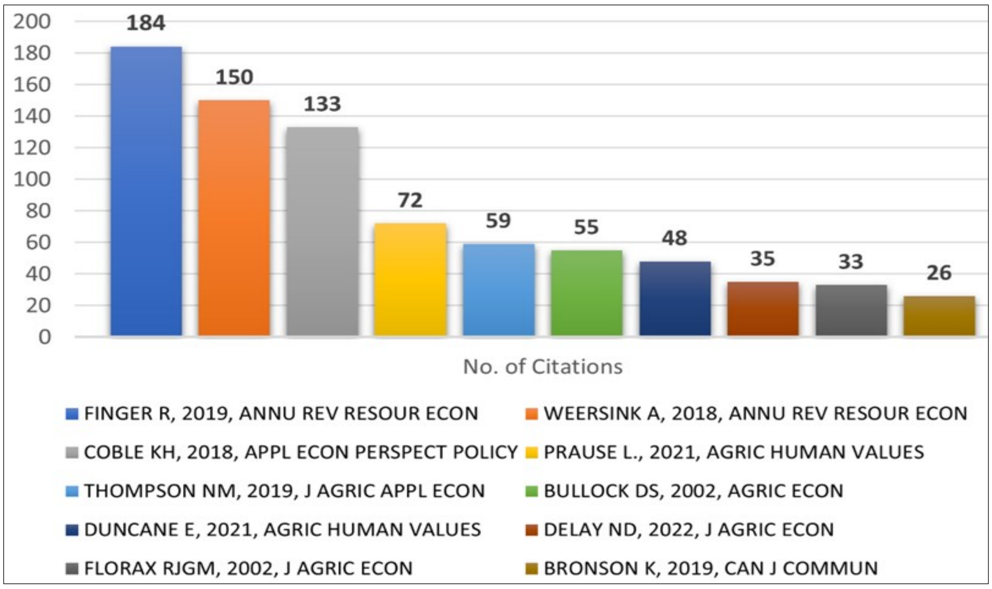

Fig. 5. Most globally cited articles.

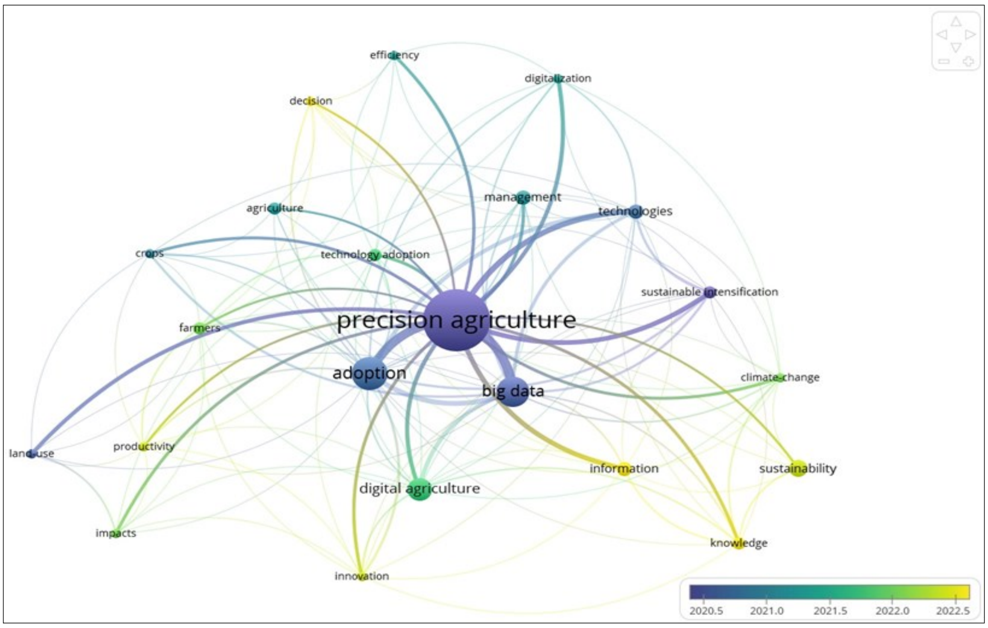

Fig. 6. Map of keywords generated by VOS viewer.

circles, with their size proportional to their frequency of appearance. Links between the circles indicate associations between the words, while nodes of the same colour form clusters representing related keywords. The thickness of these links reflects the strength of their associations; thicker links denote stronger connections and higher frequency of co-occurrence in the publications. Furthermore, the distance between two nodes inversely correlates with the frequency of occurrences between the keywords.

The generated map identifies four distinct clusters: Cluster 1 (7 keywords), Cluster 2 (4 keywords), Cluster 3 (5 keywords) and Cluster 4 (6 keywords). Cluster 1, depicted in Violet, centers around the term “precision agriculture” and includes keywords such as “adoption,” “big data,” “technologies,” “sustainable intensification,” “land use” and “crops”. By implementing pertinent technologies, this cluster illustrates how precision agriculture affects sustainable agricultural management. Cluster 2, denoted in Blue, has “management” as its most noticeable node, accompanied by terms like “digitalisation”, “agriculture” and “efficiency”. Here, the management provides real-time data that allows for precise control over agricultural operations. This is made possible by the integration of digitalisation with the aid of cutting-edge technologies like AI, IoT, drones, etc., as a result, efficiency can be attained through improved crop yields, reduced waste and optimised resource use. The terms “farmers”, “climate change”, “impacts”, “digital agriculture” and “technology adoption” are included in Cluster 3, which is shown in Green. This cluster demonstrates how forward-thinking farmers are in utilising data-driven approaches and digital agriculture to mitigate the effects of climate change. Their use of technology contributes to their increased resilience. This technological adoption step is crucial for mitigating and responding to the negative effects of climate change on agriculture. The keywords “information”, “knowledge”, “decision”, “innovation”, “productivity” and “sustainability” are included in Cluster 4, which is highlighted in Yellow. This cluster highlights how information from cutting-edge technologies aids in knowledge acquisition and decision-making regarding an innovation, which leads to increased productivity and ensures the best use of resources with an aim to minimise environmental impact.

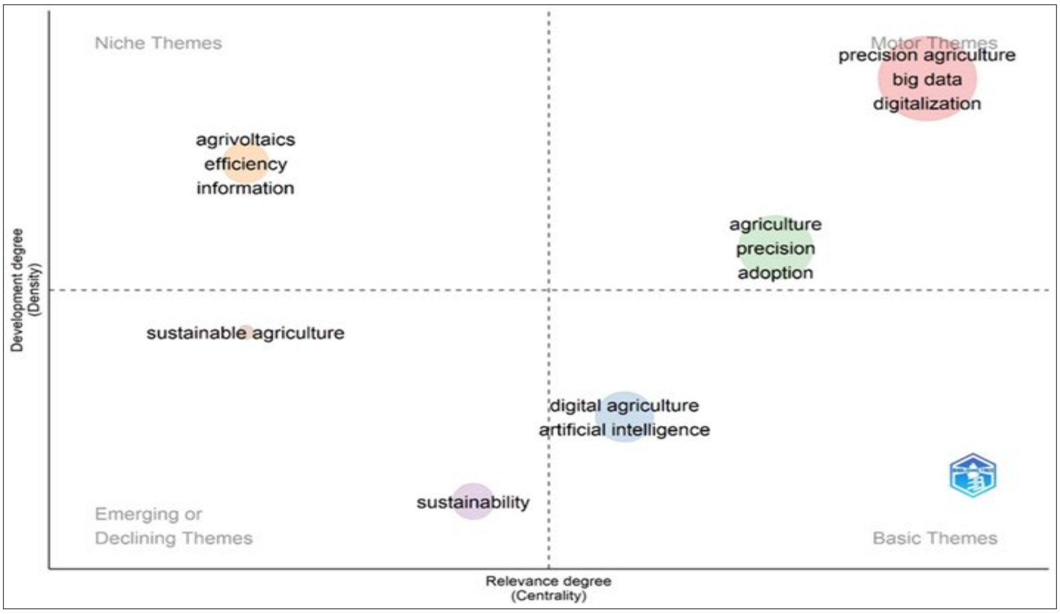

Fig. 7. Thematic map generated by R Bibliometrix.

To identify themes, the thematic analysis utilizes clusters of authors' keywords and explores their interrelationships. These themes are characterized by two key attributes: density and centrality. Density is represented on the vertical axis, while centrality is shown on the horizontal axis (Fig. 7). Motor themes, which are seen in the upper right quadrant, are terms that are important motivators. Examples of these are Adoption, Big Data, Digitalisation and Precision Agriculture. This demonstrates how quickly emerging technologies and data-driven approaches are being integrated, which is crucial for optimising resource use, enhancing environmental results and advancing sustainable agricultural practices. Their prominent position highlights how important it is to mould the future of ecologically conscious farming. The efficiency, agrivoltaics and information found in niche themes, which are located in the upper left quadrant, emphasise how precision farming technologies integrates resource optimisation, renewable energy (agrivoltaics) and data-driven techniques to increase environmental resilience. This approach promotes a balance between agricultural productivity and ecological preservation. In the lower left quadrant are issues that are either emerging or declining: sustainability and sustainable agriculture. This indicates a trend towards integrating eco-friendly methods with precision farming, emphasising environmentally beneficial techniques. As such, it highlights how crucial sustainability is becoming for improving environmental stewardship in modern farming methods. Artificial intelligence and digital agriculture are two fundamental concepts in the lower-right quadrant that are pervasive in this field of study and have low density and high centrality.

Co-occurrence network

An efficient method for comprehending knowledge structures and research trends is keyword co-occurrence analysis. Understanding primary and secondary publications involves identifying nodes in the diagram based on their size. The line connecting two nodes represents a relationship between the corresponding groups, indicating the co-occurrence of the two keywords. A shorter line signifies a stronger connection, whereas a longer line reflects a weaker one (42, 43). The connections between relevant keywords for the study are depicted in the network diagram shown in Fig. 8. Different colours are used to identify and set apart various keyword groups or clusters. While Fig. 8 shows a variety of keywords associated with a common topic, the magnitude of these keywords corresponds to how frequently they occur. Furthermore, the frequency with which certain keywords appear together in research publications is used to group and cluster them with other phrases.

As for the blue cluster, its key concepts are "Information Systems, Technologies and Precision Agriculture." The connections linked to the terms associated with "technologies", "systems", "adoption" and "big data" emphasize too that possessing big data and planting a technology would mean quite such a great deal in precision farming. The purple colour clusters contain certain interesting details concerning the "Attitude" of the respondents about the usefulness of prediction models and system management in precision farming.

"Farmer–centric" factors are located in the orange cluster. This group concerns farmers regarding the introduction of modern farming techniques and the expectations of efficiency. It also stresses the necessity to delve into the use of these tools by the farmers and the results that such utilization brings forth. The red cluster encompasses "Land Usage, Investment, Outcome and People". It draws attention to the financial and human behaviour aspects related to precision farming, including capital investment and reallocation of land use. "Gender, Climate and Knowledge" relate to each other through the green cluster. It means that economic, social and environmental aspects have also been integrated in the study. Variables such as gender and knowledge might also be used to demonstrate the effect of social and educational influences on environmental care.

The network shows that research on environmental stewardship in precision farming focuses on how farmers use new technologies and big data. As could be seen from the different keywords like behavioural factors, gender and

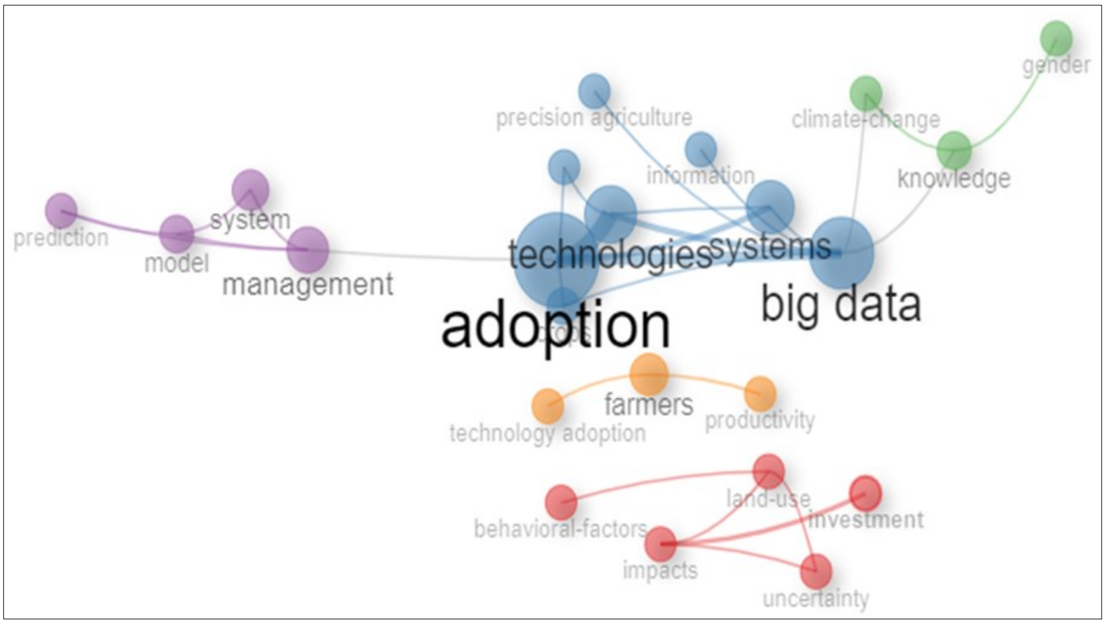

Fig. 8. Co-occurrence network of keywords generated by Bibliometrix in R studio.

climate, the field covers many areas. This highlights that the research looks at both the technology besides social and economic aspects of precision farming. It could be inferred from Fig. 8 that some gaps already existing within the literature, in particular underrepresented clusters or links, might help researchers in future precision farming research.

The review highlights several key insights in the domain of precision farming/agriculture. It underscores the potential of emerging technologies and data-driven approaches to optimize resource utilization, enhance environmental outcomes and promote sustainable agricultural practices. Precision farming technologies, when integrated with resource -efficient strategies, renewable energy solutions such as agrivoltaics and advanced data analytics, contribute significantly in building environmental resilience. The convergence of eco-friendly methods with precision agriculture paves the way for practices that are both productive and environmentally sustainable. Furthermore, the role of artificial intelligence and digital agriculture is found to be pervasive in this field, characterized by low density yet high centrality, indicating their critical but underexplored influence. Importantly, the review also reveals existing research gaps and underrepresented thematic clusters within the precision agriculture literature, pointing to promising directions for future scholarly investigation.

Findings of TCCM analysis

Theoretical perspectives (T)

Theories are regarded as a tool for the growth of scholarly knowledge because they give scholars a path forward for answering a research question (44). This systematic literature analysis provides various insights into the theoretical foundations of precision farming research, using the TCCM framework (30, 34). An integrated approach concerning different theoretical perspectives is necessary to understand the factors behind the environmental stewardship among farmers engaging in precision farming. This part discusses key theories, which have been found in the literature and shows how technology adoption, consumer behaviour and social norms are addressed in the agricultural environment.

Diffusion of innovations theory

Agricultural Knowledge and Innovation Systems (AKIS) play a vital role in understanding the Diffusion of Innovations theory (45). Innovation is increasingly seen as a relational process, where joint efforts and resource contributions from multiple stakeholders are essential to facilitate technology adoption. From this perspective, it becomes clear that the integration of information technology with robust knowledge systems significantly enhances the promotion of agricultural technologies and supports environmental protection. Consequently, farmers are more likely to adopt precision farming technologies when embedded in strong knowledge networks. The application of Diffusion of Innovations theory has also been extended to the study of consumer perceptions of Precision Agriculture (PA) technologies (46). Findings suggest that a more refined understanding of consumer preferences is crucial for the effective promotion of PA technologies, which are expected to foster greater environmental stewardship among farmers. Further, emerging advanced technologies offer substantial potential for the sustainable intensification of food and renewable energy production and understanding the motivating or inhibiting factors behind technology use is key, particularly in the context of innovations like Precision Agriculture (47). In this regard, policy incentive mechanisms have been shown to facilitate optimal adoption, reinforcing the need for a supportive environment that enhances farmers' environmentally responsible practices.

Random utility theory

Random utility theory has been applied to understand farmers' decision-making processes concerning the adoption of precision agriculture technologies, revealing that these decisions are influenced by a broader concept of utility one that encompasses factors beyond profit maximization (48).

Norm activation theory

Social norms have been identified as a key factor influencing consumers' attitude and intentions toward adopting sustainable technologies, as explained through the lens of norm activation theory (49). This theory suggests that social norms play a crucial role in guiding user behaviour and decision-making. Specifically, adherence to these norms can significantly shape farmers' environmental stewardship practices, influencing their willingness to adopt precision farming technologies that promote sustainability.

Technology acceptance model (TAM)

TAM has been employed to analyse societal acceptance of precision farming technologies, with a focus on perceived risks and opportunities as key determinants of both attitudes and behavioural acceptance of innovations (50). This model highlights the two-dimensional nature of acceptance, emphasizing the importance of attitudinal and behavioural factors in the adoption of new technologies.

The above findings suggest that the successful adoption of precision farming technologies is closely linked to the presence of robust knowledge networks among farmers, which facilitate awareness, access to information and informed decision-making. Additionally, a nuanced understanding of consumer preferences is essential for the targeted promotion of Precision Agriculture (PA) technologies, thereby enhancing farmers' commitment to environmental stewardship. Notably, farmers tend to prioritize the practical utility and effectiveness of these technologies over mere profit considerations, indicating a shift toward value-based adoption. Social norms also play a pivotal role, as farmers' adherence to community-driven practices can significantly influence their environmental behaviours and contribute to the sustainability of farming systems. Furthermore, attitudinal and behavioural determinants are found to be critical in shaping the adoption trajectory of precision farming practices, emphasizing the need for integrative approaches that consider both socio-psychological and economic dimensions.

Contexts (C)

Contexts are the subset of conceptual and physical conditions that are relevant to a specific entity. Contexts, as defined by the TCCM framework, as the conditions that comprise the research setting (34). Over the years, research on precision farming has covered a wide range of contexts and offered an enhanced understanding. Spatial variability in crop characteristics has been found to significantly influence farmers' adoption of precision agriculture (PA) techniques (51). These regional differences highlight the importance of developing site-specific recommendations to maximize both economic returns and ecological benefits. In the Sahel region of West Africa, characterized by sandy, acidic soils with low fertility, the application of PA is critical for addressing the challenges in crop production, particularly millet. It has been emphasized that acknowledging soil variability under such ecological constraints is essential for improving yields while maintaining environmental integrity (52). Similarly, in the arid Kostanay region of Kazakhstan, local climatic conditions dictate the feasibility and success of PA technologies. Farmers in this region have observed improvements in water use efficiency and crop yields through the adoption of PA practices, indicating that climatic suitability plays a pivotal role in adoption outcomes (53). Furthermore, the AKIS framework facilitates a multistakeholder and multicultural approach, promoting the dissemination of knowledge and innovation. This shared learning environment enhances the adoption of PA tools, especially when accounting for the geographical context in which farming decisions are made (45).

Based on country context, Global research on precision farming has been thriving with impressive contributions made over different countries. Significant research works have been conducted in the USA (47, 48, 51, 54, 55), UK (56), China (57), India (49), Italy (45, 46) and other European countries (50, 58-62).

Characteristics (C)

The concepts are summarised and their relevance to precision farming is discussed in the section that follows. The discussion focuses on the antecedents, mediators and moderators that have been used in earlier research studies on precision farming over the years.

Antecedents to adoption

Farmers show a greater propensity to adopt PFTs when they perceive economic benefits such as lower production costs and enhanced yield (48). The expense involved in the use of precision agriculture technologies and the availability of incentive policies are essential antecedents that influence adoption decisions (46). The abilities of farmers to use new technologies and the perceived complexity can also determine the probability of adoption of PFTs. Familiarity is often associated with increased adoption of technologies (45). The availability of advisory services, training and financial support systems (such as credit and agricultural extension services) has been stressed as an important factor that accelerates the process of innovation adoption (45, 63). Factors such as education and farm size are major determinants of farmers' ability to adopt PFTs. Other determinants, including age, gender and experience in farming; however, are found to have an apparent varying degree (63). Cost factor, perception of the nature of technology, value added extension/information/advisory/training supports, financial support besides the economic indicators of farmers' life do play crucial roles in accepting precision farming/agriculture.

Mediating variables

AKIS aims at educating and empowering farmers so that they can make informed decisions on the adoption of PA Technologies (45). Consumer awareness and concern about the environmental impact of agricultural practices are key influences for adopting PA technologies, which indicates that there can be societal values that mediate farmers' choices at the individual level (46).

Moderating variables

Group membership and involvement in farmer-based organizations are significant cultural factors influencing the adoption of technology (63). The adoption of technology is further reliant on the attitude and perception a farmer holds for the technology, as in the case of precision farming. When institutions or related organizations provide resources such as training opportunities and consultations, it will increase the propensity of the adoption process, which plays a role as a moderating variable that affects the relationship between antecedents and adoption. The adoption of PA can be affected by external environmental factors that moderate their influence, such as the quality of the local soil and climate variation (52, 64). Indeed, financial leverage, such as the debt-to-asset ratio and the overall economic conditions, can greatly influence the adoption of precision farming, as it influences farmers' perception of risk and their capacity to invest (54).

Methods (M)

Of the 40 papers analyzed, a variety of methodologies were employed in past studies on precision farming, reflecting diverse research designs, sampling methods, data collection and analysis techniques. This section discusses the synopsis of the key methodological approaches identified in the literature.

Research design and data collection

Quantitative approaches

Several research studies have employed quantitative approaches to analyze precision farming. For example, purposive sampling was used to identify informants, ensuring that insights were collected from individuals with relevant expertise on the study topic (60). In another study, a non-stratified random sampling approach was utilized, with online questionnaires serving as the primary data collection tool (45). Additionally, a quantitative research approach was employed to assess preferences and utility derived from the attributes of precision agriculture technologies, where both online and face-to-face surveys were commonly used as data collection instruments. Convenience sampling was employed, targeting urban consumers to emphasize a concentrated demographic approach. Furthermore, quota sampling was used to target farmers from specific districts, enabling a more precise understanding of certain agricultural settings (63, 65).

Exploratory designs

Exploratory designs have also been prominent in studies investigating the role of data-driven technologies in farming (66). Such methods are valuable for identifying key variables and themes in the context of precision agriculture.

Mixed-method approaches

Many studies have employed mixed-method approaches to explore the factors influencing precision agriculture (PA). For example, critical discourse analysis was applied to understand perceptions of precision agriculture by systematically examining texts to reveal underlying thought structures (59). Other studies have utilized participatory approaches, engaging targeted farmers in focus group discussions to gather qualitative data on their perceptions and experiences with digital agricultural technologies (67). These approaches have helped strengthen the understanding of stakeholder views and contributed to the development of farmer-centered solutions.

Experimental designs

Experimental approaches have been applied to understand technology adoption in precision farming. For example, on-farm agronomic experiments were employed to estimate yield responses while eliminating the need for detailed pre-existing site-specific information (51). Additionally, optimization models were evaluated using real-time data from financial institutions, providing valuable insights into the practical applications of these technologies (57). These approaches demonstrate the versatility of experimental design in addressing various questions in precision farming.

Analysis techniques

The studies conducted on precision farming have employed a variety of analytical techniques, including statistical, modeling and thematic approaches. To study adoption behaviour, descriptive statistics and logit models alongside binomial logistic regression have been applied (45). Advanced methods such as latent class modeling, choice experiments and best-worst scaling have been used to identify user preferences (46, 63). More complex analytical strategies, including endogenous switching regression, quasi-experimental designs, cluster analysis and stochastic frontier methods, were adopted to address selection bias and estimate technical efficiency (54, 63). Thematic and discourse analysis were utilized to interpret qualitative data and participant perspectives (59, 67). Cost-effectiveness analysis and simulation models were employed to examine adoption behaviour (47), while Structural Equation Modeling (SEM) was applied to assess the influence of social norms on consumer behaviour in sustainable practices (49).

The examination of TCCM analysis offers insights into the theoretical underpinnings, contextual considerations, characteristic features and methodological approaches that pave the way for future research endeavours in this dynamic field. Fig. 9 paves the way for future research, emphasizing that existing research needs more focus on emerging theories, contexts, characteristics and methodologies.

Implications

The findings from this systematic literature review highlights the interplay of technological, economic, social and policy-related factors influencing the environmental stewardship behaviour of precision farming farmers. Understanding this can help design targeted interventions that may improve the adoption of precision agriculture practices. By focusing on factors such as the availability of technological readiness and knowledge diffusion, stakeholders would concern themselves more with education and awareness that can empower farmers to adopt innovative technologies. Apart from economic incentives and policy support being key drivers, it means government and its agricultural institutions need to prepare financial frameworks and subsidy packages that promote sustainable farming practice. All these efforts lead to improvements in resource-use efficiency, reduced environmental effects and alignment with the broader goals of sustainable agriculture development.

Limitations of the study

Despite its holistic approach, this study has a few limitations that must be acknowledged. First, the review is based on published literature up to 2024; consequently, any new reports or research conducted since then was not taken into consideration. The review was limited in scope as it was bounded by articles available in the open sources, which consequently left out certain investigations reported on restricted or limited-access outlets. Moreover, limitations on the availability of certain articles may have resulted in the omission of pertinent research, highlighting the importance for upcoming research to explore more diverse data sources. Thus, limitations indicate further research work should integrate diverse data sources and considered emerging trends in PA and environmental stewardship.

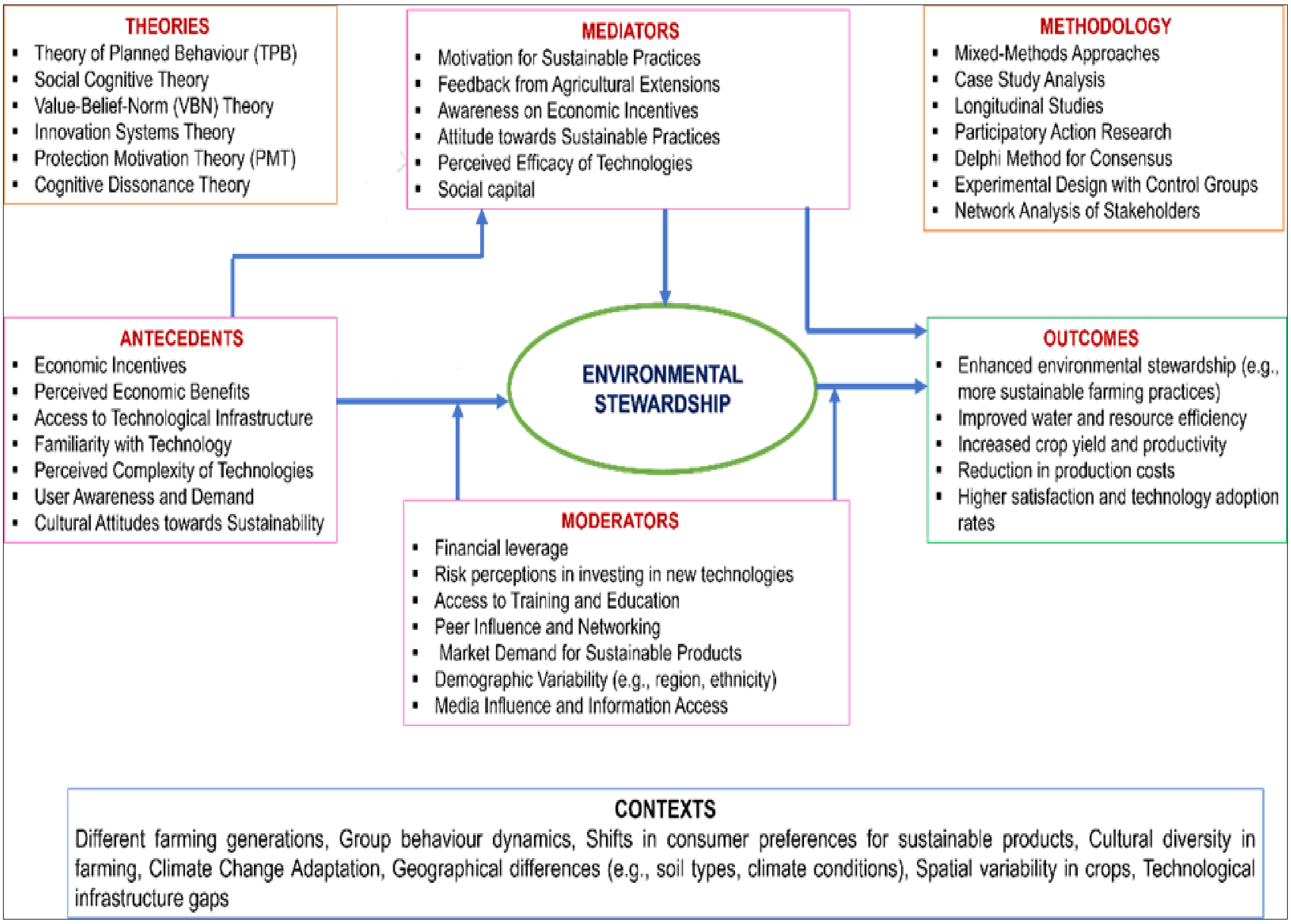

Fig. 9. Future research agenda.

Conclusion

This systematic literature review highlights the various multifaceted factors that influence the nature of environmental stewardship of farmers involved in precision farming. Synthesizing all extant research, we determine key determinants of factors such as technological readiness, economic incentives, social norms and policy frameworks that relate to factors influencing attitude and behaviour toward adopting sustainable practices. The paper concludes that the findings underscore the aspect that community networks and government support inform and foster an environment that fosters the effective implementation of PA technologies.

Our analysis reveals that the intrinsic value of farmers and their perceptions about environmental stewardship have a significant influence on the adoption of precision farming practices while underlying motives of economic profit are quite paramount. Moreover, the review identifies gaps in current literature and implies a need for more subtle research on the nature and scale of interplay between sociocultural factors and technology adoption. In addition, this study marks a precursor for further research into building the prominence of precision farming in realizing sustainable agriculture. It is expected to identify factors influencing farm choice decisions and inform policymakers, researchers and practitioners on how to devise targeted interventions to encourage more sustainable environmental practices at larger scales. At a time when agricultural challenges are gaining momentum and complexity globally, this insight is pivotal for building ecological sustainability and food security.

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Authors' contributions

IV carried out the entire paperwork, data processing and analysis; KC guided the research by formulating the paper concept, gave corrections and approved the final manuscript. MND contributed by developing the ideas and reviewed the manuscript; RV contributed by developing the ideas and reviewed the manuscript; PM contributed by developing the ideas and reviewed the manuscript and VG contributed by developing the ideas and reviewed the manuscript.

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