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Twenty-two years of precision agriculture: a bibliometric review

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Abstract

Precision Agriculture is a leading international journal on advances in precision farming. Established in 1999, it focuses on natural resource variability, engineering technology, profitability, environment, and technology transfer. It serves as an effective platform for disseminating original and fundamental research and understanding in the continuously evolving field of precision farming. With the onset of the technological era, the agriculture sector has witnessed remarkable changes in the use of drones, artificial intelligence and the latest automation and technology-driven developments. To gauge the journal's influence, the authors conducted a comprehensive overview of Precision Agriculture papers from 1999 to 2021. The journal reached its 22nd year of publishing in 2021. The study undertaken is a first-hand attempt to outline the current state of the art and develop a comprehensive understanding of the theoretical foundations, concepts and recent developments in this field. The findings show the fast-paced growth that this journal has experienced, thereby attracting and encouraging researchers and authors to contribute to developing this field.

Keywords Bibliometric analysis · Remote sensing · VOSviewer · Bibliographic coupling · Sustainable agriculture

Introduction

Precision Agriculture is a premier single-blind peer-reviewed journal published by Springer Nature. The journal marked the completion of 22 years in 2021, giving an impetus to the authors to conduct a bibliometric investigation of the journal and delve into its productivity and influence.

The International Society of Precision Agriculture defined precision agriculture as "*a management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality,*

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profitability and sustainability of agricultural production" (https://ispag.org/about/definition). The International Conference on Precision Agriculture (ICPA) started as a workshop called "Soil Specific Crop Management: A workshop on Research and Development Issues" in 1992. The founder of ICPA, Prof Pierre Robert, initiated the journal in 1999 with the publisher, Kluwer Academic Publishers (later taken over by Springer Nature). Dr John Stafford and Prof. James Lowenberg deBoer are the current editors-in-chief of the journal. Table 1 provides an overview of the editors through the 22 volumes. At the 10th annual meet, the conference gave birth to the International Society of Precision Agriculture. Precision Agriculture is the only journal covering multidisciplinary and contemporary research on various topics relating to precision agriculture, including productive and sustainable agricultural production. Springer Nature agreed to designate Precision Agriculture as the Society's official journal. It has an impact factor of 5.77 (2021). Precision Agriculture (hereafter, PRAG) has now earned a *CiteScore* of 9.9 (Scopus), ranking it 7th out of 59 titles in multidisciplinary agricultural journals. The *CiteScore* indicates that PRAG articles published between 2018 and 2021 obtained an average citation of 9.9 in 2021. Currently, the journal has an *SJR* (SCImago Journal Rank) of 1.169 and a *SNIP* (Source Normalized Impact per Paper) of 1.947. *SNIP* measures the citation impact of a journal's publications by weighting citations based on the total number of citations in a field of study.

Based on the journal's published papers between 1999 and 2021, this review offers a reflective summary of its intellectual structure, acknowledging the expanding importance and recognition of precision farming using a bibliographic analysis. The authors have used the Scopus database to perform the bibliometric analysis using VOSviewer software (Visualization of Similarities) (van Eck & Waltman, 37) and Bibliometrix by R Studio (Aria & Cuccurullo, 4) to map the bibliographic information. Scopus is a comprehensive database consisting of the most extensive corpus of papers from a multidisciplinary perspective, and it has been used by several other bibliometric studies (Bhukya et al., 6). The authors have attempted to address this bibliometric study by answering the following underlying research questions:

RQ1: How has the journal fared in terms of its influence and productivity regarding:

a) The annual number of publications
b) Enumeration of the annual citation count.

RQ2: Which have been the most cited articles since the journal's inception?
RQ3: What are the PRAG research components, and how have they varied over time: introspection into the published listings of authors, affiliations and countries.
RQ4: What have been the main themes and associations of this journal?

a) A probe into the intellectual construct of the journal using keywords analysis.
b) An investigation of the co-authorship networks in terms of authors, countries and institutions.

RQ5: What are the trends and contexts being followed by the papers: an analysis of the documents using Bibliographic Coupling.

This review may necessitate the usage of bibliometrics and objective analytical methodologies because it allows for recognizing certain milestones in the journey of PRAG.

Table 1 Overview of editors between 1999 and 2021

Editors	Volumes	Affiliation	Country
John Stafford	1–23	Silsoe Solutions, Ampthill, Bedford	United Kingdom
Pierre Robert	1–4	Department of Soil, Water and Climate, Precision Agriculture Center, University of Minnesota	United States
Margaret Oliver	6–11	Department of Soil Science, University of Reading	United Kingdom
James Schepers	12–14	Department of Agronomy and Horticulture, University of Nebraska	United States
Paul Carter	15–17	Washington State University	United States
James Lowenberg deBoer	18–23	Harper Adams University	United Kingdom

The study attempts to contribute to the existing literature on precision agriculture in a pivotal way. Precision agriculture encapsulates all those processes that emphasize creating advances for the agriculture sector, focusing on better productivity and sustainable agricultural processes.

The concepts of sustainability and precision agriculture are indistinguishably linked. The potential for environmental benefits links its inception in farming practices since a GNSS (Global navigation satellite system) was first used on agricultural equipment. Rising pressure for sustainability and food security and a need to reduce environmental degradation has focused awareness on improving the efficiency of farm resources. Intuitively, applying agrochemicals only where and when needed should minimize ecological loading (Bongiovanni & Lowenberg-Deboer, 8). One response to this problem is PATs (Precision agricultural technologies) (Tey & Brindal, 34). Precision farming helps farmers to focus fertilizer and pesticide treatments better instead of applying them uniformly across fields. Precision farming is frequently argued to replace some external physical inputs with information and knowledge, potentially bringing the farm closer to the ideal biological balance. Information technology and the knowledge that allows precision farming to function are, of course, external inputs. Precision farming intends that its use will be less damaging to natural systems than using a uniform application of physical inputs (Bongiovanni & Lowenberg-Deboer, 8).

In 1972, the United Nations defined sustainability in a more general sense as "*aimed to meet the needs of the present without compromising the ability of future generations to meet their own needs*" (*Sustainable Development|International Institute for Sustainable Development*). Sustainability in agriculture is a much talked about topic in precision agriculture. The momentum for this lies behind the SDGs (Sustainable Development Goals) framed by the United Nations in 2015. These are a new set of universal goals, targets, and indicators that UN member states intend to guide their agendas and political actions for the next 15 years.

Precision Agriculture focuses on Goal 2 of the 17 SDGs: Zero Hunger and "*encloses increased investment, including through enhanced regional co-operation, in rural infrastructure, agricultural research and extension services, technology development, and plant and livestock gene banks to enhance agricultural productive capacity in developing countries, particularly least developed countries*".

Precision agriculture has evolved from a concept to a production-scale, multi-task operation conducted on a field-by-field basis over the last three decades. Although the adoption of precision agricultural technologies was rapid at first, it has slowed due to the difficulties and ambiguity surrounding how to exploit the full potential of precision agriculture and hence identify its true value. Early users were primarily self-taught and had a knack for using electronic-based information technologies. As the general user profile has changed and analysis demands have increased, precision agriculture technologies and processes have improved. Users of PATs face a challenge in measuring, collecting and analyzing essential variables and manageable elements in order to devise efficient management decisions (Kitchen et al., 19).

Methodology

Bibliometric analysis is an ideal approach to analyzing and examining the evolution of literature in a particular field, allowing insights into its articles, authors, subjects, sources and intra-relationships from a set of documents based on citations rather than content.

Bibliometric analysis aptly summarizes the bibliographic materials and provides an efficient quantifiable analysis. The studies based on this method have been on the rise in recent years. Accessibility, availability and easy interface of bibliometric software such as VOSviewer and Bibliomertix by R Studio vouch for this method's eminence. It helps and empowers researchers to (a) get a broad overview, (b) discover knowledge gaps, (c) develop fresh research ideas, (d) position their planned contributions to the field, and (e) promote multidisciplinary research (Donthu et al., 13).

The authors searched for "Precision Agriculture" under the heading 'Source title' in the Scopus database in early March 2022, where 955 published documents were identified after screening based on inclusion criteria, viz. year, document type and publication stage.

The authors used Biblioshiny and VOSviewer to collect and analyze the dataset and develop graphical visualizations. Biblioshiny was developed in the R language by Aria & Cuccurullo in 4. Several bibliometric indicators from different perspectives were used to conduct this study. In terms of descriptive analysis, the study analyzed the journal's annual publishing and citation trend and the most cited papers, top authors, institutions, and countries/regions. "The number of citations a research paper receives is an important indicator of its impact on the scientific community" (Svensson, 32). As for network analysis, the study analyzed the keywords of the articles published in PRAG. Following this, the associations amongst the contributory authors, institutions and countries with the help of co-authorship analysis were ascertained. Clusters formed using the bibliographic coupling tool facilitated the identification of the themes of similar documents.

Table 2 consists of publications and citations to give a clear idea of the journals' influence. Following this, recent trends regarding authors, topics and countries have been evaluated for conducting the study. Next, an investigation of the various themes will be presented by performing bibliometric coupling. With the help of network maps from VOSviewer and Biblioshiny, the authors have attempted to present their observations lucidly through this paper.

Analysis and findings

Descriptive analysis

Structure of annual publication and citation

From addressing RQ1 (a&b), Table 2 lists the number of PRAG publications and citations between 1999 and 2021. The journal has witnessed a roughly five-fold growth from its inception till 2021. It rose from 20 in 1999 to 94 in 2021. Between the years 2004 and 2013, the pattern of publishing was variable. 2021 was the most productive year of Precision Agriculture's publishing. Likewise, the journal has shown impressive growth in citations throughout its journey.

Table 2 Annual publication and citation structure of PRAG publications between 1999 and 2021

Year	TP	TC	TC/TP
1999	20	1273	63.65
2000	24	735	30.63
2002	28	867	30.96
2003	28	1108	39.57
2004	35	1332	38.06
2005	32	1582	49.44
2006	28	1448	51.71
2007	24	1177	49.04
2008	28	1051	37.54
2009	38	1447	38.08
2010	45	1743	38.73
2011	59	1942	32.92
2012	46	2894	62.91
2013	40	1245	31.13
2014	41	1407	34.32
2015	40	904	22.6
2016	45	1038	23.07
2017	58	1426	24.59
2018	63	1345	21.35
2019	67	1058	15.79
2020	71	825	11.62
2021	94	304	3.23

This table presents the annual trend of publication and citation in *Precision Agriculture* (1999–2021)

TP total publications, *TC* total citations, *TC/TP* citations per publications

The most cited PRAG articles

Tsay (36) explained that the citations of articles indicate their influence. Table 3 highlights the most influential publications in PRAG between 1999 and 2021. Zhang and Kovacs (44) published the most cited article titled "The application of small unmanned aerial systems for precision agriculture: A review", with 1 067 citations. The paper discussed unmanned aerial systems used to facilitate precision agriculture implementation. This paper is the only one that has received more than a thousand citations. In addition to this, advances in geospatial techniques and other related aspects are the important features of this paper. Following this, the paper titled "Future Directions of Precision Agriculture" (McBratney et al., 27) stands second, with 460 citations.

Notably, McBratney also features in the list of authors who have the most published papers in the journal. The next is the paper titled "Precision Agriculture and Sustainability" (Bongiovanni & Lowenberg-Deboer, 8), with 339 citations. The paper discussed the concept of sustainability through agriculture. The American Society of Agronomy (1989) definition stated, "*Sustainable Agriculture as the one tha*t, *over the long term, enhances environmental quality and the resource base in which agriculture depends*; *provides for*

Table 3 Most cited precision agriculture articles between 1999 and 2021

TC	Author	Title	Year
1067	Zhang, C., Kovacs, J.M	The application of small unmanned aerial systems for precision agriculture: A review	2012
460	McBratney, A., Whelan, B., Ancev, T., Bouma, J	Future directions of precision agriculture	2005
339	Bongiovanni, R., Lowenberg-Deboer, J	Precision agriculture and sustainability	2004
324	Hunt Jr., E.R., Cavigelli, M., Daughtry, C.S.T., McMurtrey III, J.E., Walthall, C.L	Evaluation of digital photography from model aircraft for remote sensing of crop biomass and nitrogen status	2005
257	Huang, W., Lamb, D.W., Niu, Z., (…), Liu, L., Wang, J	Identification of yellow rust in wheat using in-situ spectral reflectance measurements and airborne hyperspectral imaging	2007
239	Primicerio, J., Di Gennaro, S.F., Fiorillo, E., (…), Matese, A., Vaccari, F.P	A flexible unmanned aerial vehicle for precision agriculture	2012
206	Bellvert, J., Zarco-Tejada, P.J., Girona, J., Fereres, E	Mapping crop water stress index in a 'Pinot-noir' vineyard: Comparing ground measurements with thermal remote sensing imagery from an unmanned aerial vehicle	2014
205	Daberkow, S.G., McBride, W.D	Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US	2003
200	Franke, J., Menz, G	Multi-temporal wheat disease detection by multi-spectral remote sensing	2007
197	Gonzalez-Dugo, V., Zarco-Tejada, P., Nicolás, E., (…), Intrigliolo, D.S., Fereres, E	Using high resolution UAV thermal imagery to assess the variability in the water status of five fruit tree species within a commercial orchard	2013
194	Lee, W.S., Slaughter, D.C., Giles, D.K	Robotic Weed Control System for Tomatoes	1999
189	Thorp, K.R., Tian, L.F	A review on remote sensing of weeds in agriculture	2004
180	Mcbratney, A.B., Pringle, M.J	Estimating Average and Proportional Variograms of Soil Properties and Their Potential Use in Precision Agriculture	1999
174	Hague, T., Tillett, N.D., Wheeler, H	Automated crop and weed monitoring in widely spaced cereals	2006
168	Tey, Y.S., Brindal, M	Factors influencing the adoption of precision agricultural technologies: A review for policy implications	2012
167	Cambardella, C.A., Karlen, D.L	Spatial Analysis of Soil Fertility Parameters	1999
161	Brevik, E.C., Fenton, T.E., Lazari, A	Soil electrical conductivity as a function of soil water content and implications for soil mapping	2006
148	Gómez-Candón, D., De Castro, A.I., López-Granados, F	Assessing the accuracy of mosaics from unmanned aerial vehicle (UAV) imagery for precision agriculture purposes in wheat	2014

Table 3 (continued)

TC	Author	Title	Year
145	Behmann, J., Mahlein, A.-K., Rumpf, T., Römer, C., Plümer, L	A review of advanced machine learning methods for the detection of biotic stress in precision crop protection	2015
144	Lindblom, J., Ljung, M., Anders J., Lundström, C	Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies	2017

This table lists the top 20 cited papers published in *Precision Agriculture* (1999–2021)

TC total citations

Table 4 Top 20 productive authors in precision agriculture between 1999 and 2021

Authors	Affiliation	Country	TP	TC	TC/TP	h	g
Tisseyre B	Université de Montpellier	France	25	494	19.76	12	22
Mcbratney Ab	The University of Sydney	Australia	15	677	45.13	12	15
Alchanatis V	Agricultural Research Organization of Israel	Israel	12	690	57.5	12	12
Fountas S	Department of Natural Resources Management and Agricultural Engineering	Greece	12	676	56.33	12	12
Yang C	USDA Agricultural Research Service	United States	12	492	41	11	12
Cohen Y	Agricultural Research Organization of Israel	Israel	11	607	55.18	11	11
López-Granados F	CSIC—Instituto de Agricultura Sostenible (IAS)	Spain	11	483	43.91	8	11
Raun Wr	Oklahoma State University	United States	11	275	25	9	11
Ehlert D	Leibniz-Institut für Agrartechnik und Bioökonomie e.V. (ATB)	Germany	9	265	29.44	9	9
Kitchen Nr	USDA Agricultural Research Service	United States	9	202	22.44	7	9
Lowenberg-Deboer J	Harper Adams University	United States	9	548	60.89	6	9
Molin Jp	Universidade de São Paulo	Brazil	9	218	24.22	7	9
Schepers Js	University of Nebraska–Lincoln	United States	9	224	24.89	8	9
Castrignanò A	Consiglio Nazionale delle Ricerche	Italy	8	209	26.13	7	8
De Baerdemaeker J	KU Leuven	Belgium	8	326	40.75	7	8
Lamb Dw	University of New England Australia	Australia	8	593	74.13	6	8
Serrano Jm	University of Évora	Portugal	8	89	11.13	6	8
Söderström M	Sveriges lantbruksuniversitet	Sweden	8	166	20.75	6	8
Escolà A	Universitat de Lleida	Spain	7	181	25.86	7	7
Gerhards R	Universität Hohenheim	Germany	7	208	29.71	6	7

This table provides details regarding the most productive authors, author's affiliated institutions and countries in *Precision Agriculture* between 1999 and 2021

TP total publications, *TC* total citations, *TC/TP* citations per publications, *h* h-index, *g* g-index *basic human food and fibre needs*; *is economically viable*, *and enhances the quality of life for farmers and the society as a whole*" (American Society of Agronomy, 45).

Contributing authors, institutions and countries

Table 4 lists the top 20 authors based on their number of publications and, in the case of a tie, the authors having a greater count of citations will appear first. Bruno Tisseyre is the author with the most contributions: Prof Bruno Tisseyre is a viticulture professor at Montpellier supAgro and has published a total of 25 articles with 494 citations. His first paper was "Management zone delineation using a modified watershed algorithm".

The other most productive authors have been A. McBratney, V. Alchanatis and S. Fountas. A. McBratney contributed 15 articles with 677 citations. V. Alchanatis and S. Fountas both contributed 12 articles. Their citation count was 690 and 676, respectively.

The 20 most influential affiliations of journal authors are illustrated in Table 5. USDA (U.S. Department of Agriculture) Agricultural Research Service occupies the first place with a count of 55 articles, followed by the University of Florida and the University of Nebraska-Lincoln, with 32 articles each.

Finally, the most influential countries are shown in Table 6. Authors from the USA hold the first position regarding publication count, with 332 articles. In comparison,

Table 5 Top 20 most productive institutions in Precision Agriculture between 1999 and 2021

Affiliation	Country	TP
USDA Agricultural Research Service	USA	55
University of Florida	USA	32
University of Nebraska-Lincoln	USA	32
INRAE	France	30
Consejo Superior de Investigaciones Cientificas	Spain	26
The University of Sydney	Australia	26
Information—Technologies—Analyse Environnementale—Procédés Agricoles	France	26
Montpellier SupAgro	France	23
CSIC—Instituto de Agricultura Sostenible IAS	Spain	22
Agricultural Research Organization of Israel	Israel	21
Wageningen University & Research	Netherlands	20
Universität Bonn	Germany	20
University of California	USA	19
Leibniz-Institut für Agrartechnik und Bioökonomie e.V. ATB	Germany	19
Iowa State University	USA	18
Universidade de São Paulo	Brazil	18
Oklahoma State University	USA	17
University of Florida Institute of Food and Agricultural Sciences	USA	17
United States Department of Agriculture	USA	17
Purdue University	USA	16

This table presents the top institutions affiliated with *Precision Agriculture* authors between 1999 and 2021

TP total publication

Table 6 Top 20 most productive countries in Precision Agriculture between 1999 and 2021

Country	TP	TC	TC/TA
United States	332	9360	28.19
Germany	94	3695	39.31
China	90	2449	27.21
Spain	80	2449	30.61
Australia	72	3161	43.9
France	54	1026	19
Brazil	50	715	14.3
United Kingdom	49	1150	23.47
Italy	39	1231	31.56
Canada	32	1735	54.22
Belgium	28	799	28.54
Denmark	27	887	32.85
Israel	27	1071	39.67
Greece	24	838	34.92
Netherlands	23	913	39.7
Sweden	19	739	38.89
India	16	449	28.06
Portugal	16	234	14.63
Japan	14	214	15.29
Chile	9	271	30.11

This table presents the most productive and influential countries in PRAG

TP total publications, *TC* total citations, *TC/TP* citations per publications

Germany is second in line with a count of 94 articles. The analysis showed that most papers and research came from developed countries.

Network analysis

Keywords analysis

The study used keyword analysis tools to identify the most frequently used author's keywords. The author's keywords represent the theme of the research articles and provide a direction to scale the issues involved in the articles (Comerio & Strozzi, 10). Figures 1 and 3 depict the co-occurrence network of author keywords developed by VOSviewer. The co-occurrence network is represented through nodes and links, where the node's size represents the keyword's degree of connectedness with other keywords. The authors have broadly distinguished the results into two time periods of 11 years each to understand the underlying theme better. Figures 2 and 4 represent the keywords of the period between 1999–2010 and 2011–2021, respectively. The authors have also used the most frequent keywords tool from Biblioshiny to indicate the individual occurrence of

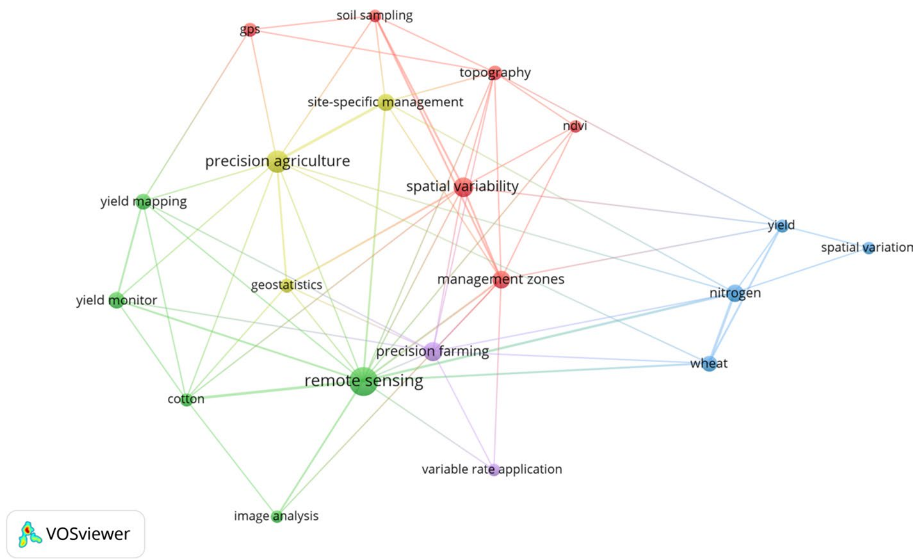

Fig. 1 Keyword network of PRAG articles published between 1999 and 2010

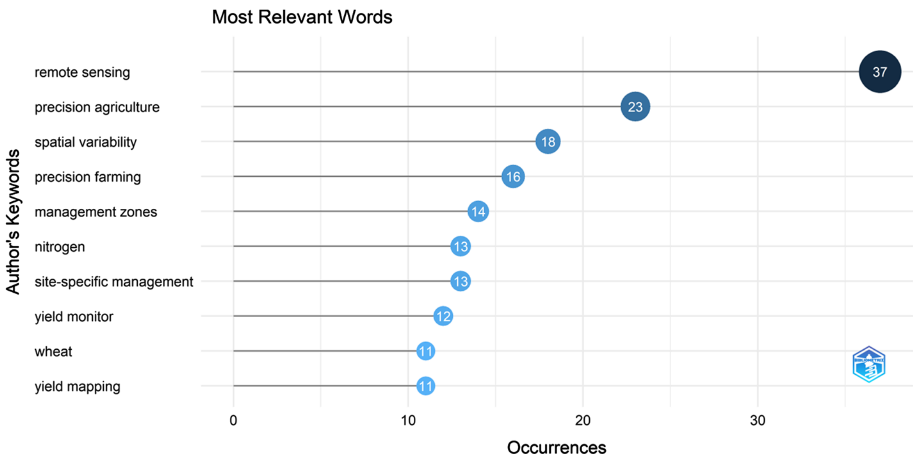

Fig. 2 Most relevant author keywords plot of PRAG articles published between 1999 and 2010

keywords. The top 20 keywords for each time frame have been shown. The analysis is described below:

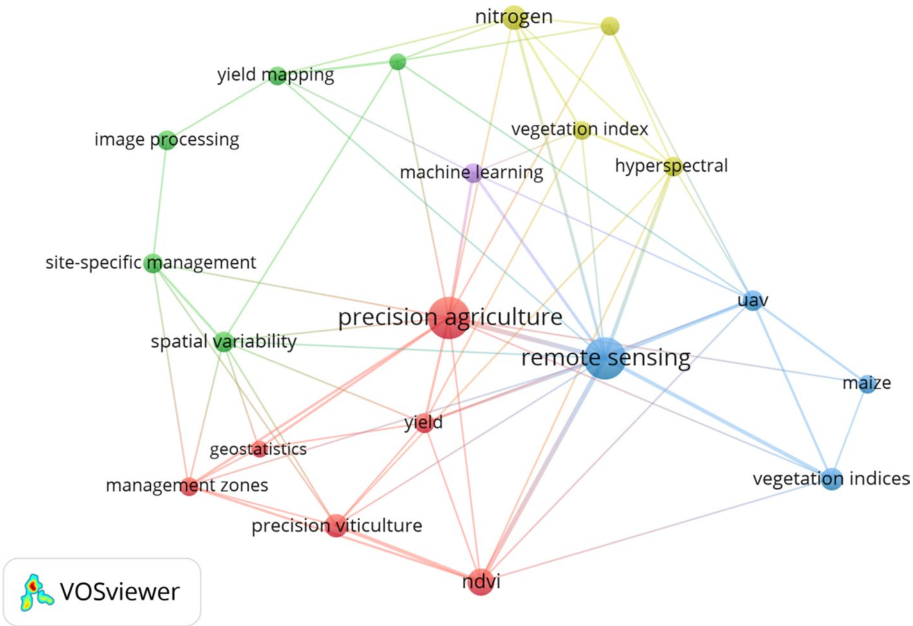

Fig. 3 Author keyword network of PRAG articles published between 2011 and 2021

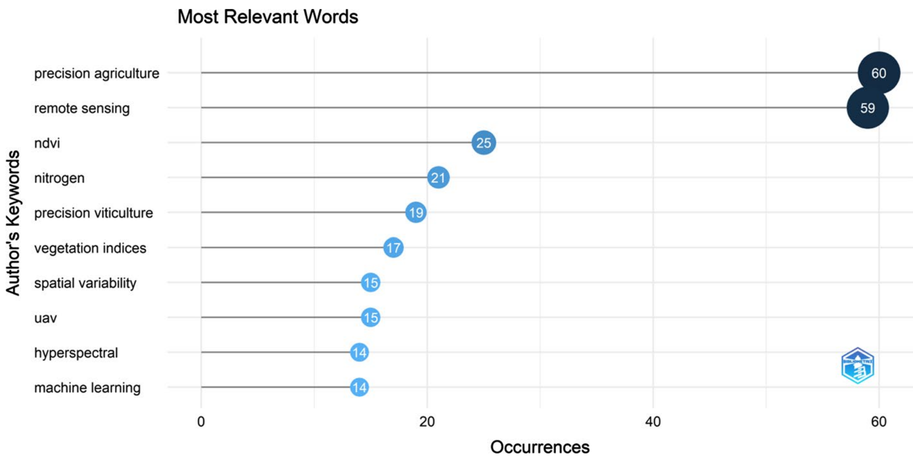

Fig. 4 Most relevant author keywords plot of PRAG articles published between 2011 and 2021

1999–2010

The authors have chosen seven as the minimum number of keyword occurrences to enable the presentation of 20 keywords on the map (see Fig. 1). Remote sensing, precision agriculture, spatial variability and precision farming are the most frequently used keywords. Needless to say, these keywords represent the central theme of this journal. In contrast, the density of the link represents co-occurrence. A graph for the most frequently used keywords developed by Biblioshiny enables a greater understanding of the themes depicted through keywords (see Fig. 2).

2011–2021

A total of 624 articles appeared in the search result for this time frame. The threshold of this analysis was kept at 10 (minimum number of occurrences of a keyword). Out of 2061 keywords, 21 meet the threshold. Figure 3 shows the network map by VOSviewer. Unsurprisingly, precision agriculture is the most recurrent keyword, followed by remote sensing, NDVI (stands for normalized difference vegetation Index), precision viticulture, vegetation indices, and spatial variability, among others. It is noticeable that terms like remote sensing, spatial variability and nitrogen have been amongst the most used keywords by the authors (Fig. 4).

Clustering of precision agriculture articles based on bibliographic coupling

About bibliographic coupling, Martyn (25) asserts, "With the arrival of the Science Citation Index on the bibliographic scene, interest is developing in the extent to which relationships between published papers are suggested by the citations they contain". Kessler (18) introduced bibliographic coupling to the scientific community through a series of studies and research articles that largely presented it as a mechanism for combining technical and scientific materials, enabling scientific information provision and document retrieval. He posited that "when two or more scientific papers share one or more references, they are linked". Encyclopedia of Linguistics, Information, and Control defines bibliographic coupling as "An association between two documents, established when they are found to have in common a high proportion of keywords, descriptors, citations, or other simple indications of what they are concerned with" (Meetham, 49). For this review, citations are the only common unit dealt with because this is the only standard attribute of papers used by Kessler (18) in his theory and by a majority of subsequent applications of the approach. Cleverdon et al (47) considered bibliographic coupling as an accurate mechanism of citation indexing since it progressively narrows the class of documents as the demand for common references grows in number. It is crucial to note that when two articles quote the same third article, they both debate and emphasize the same issues. VOSviewer was used to cluster the data, using a clustering resolution of 1.00 and a minimum cluster size of 1 document. Eight interconnected clusters with separate labels have developed in the displayed bibliometric network based on shared references and patterns to figure out the premise. The minimum number of citations was capped at five and, out of 955 articles, 776 articles were found to have associations, which formed the primary eight clusters. The remaining articles were excluded because; they did not meet the desired criteria. The 8 clusters are described in the following paragraphs.

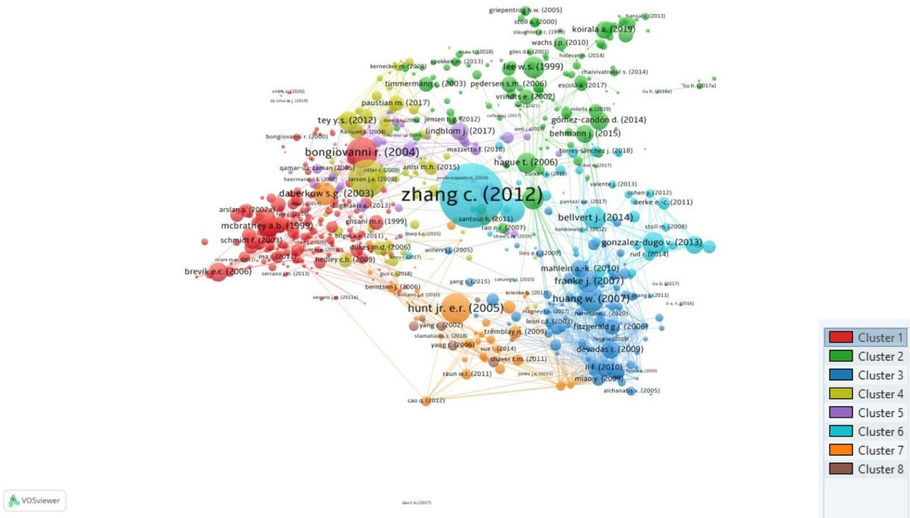

Fig. 5 Bibliographic coupling network of PRAG articles

Cluster1: soil analysis, precision agriculture and geospatial techniques

The cluster has 245 articles with 6 697 citations, shown in red colour in Fig. 5. Specifically, the papers in this cluster focus on soil properties, emphasizing spatial variability. Spatial variability refers to the fact that a quantity measured at multiple spatial locations has values that differ. With its large data requirements, precision agriculture requires methods of obtaining fine-scale knowledge about the spatial variability of soil; however, the costs involved in sampling and subsequently analyzing soil at such intensity can present a financial problem to growers (McBratney et al., 26). Other themes include geospatial variability (Araújo e Silva Ferraz et al., 3), yield and its related aspects (Blackmore & Moore, 7) and scientific experimentation for the application of precision agriculture (Whelan & McBratney, 40). Spatial variability, geospatial techniques, soil sampling, yield analysis and yield variability, farmer zones management and a particular emphasis on soil properties and farming are the significant topics of this cluster. The most cited article in this cluster is Bongiovanni and Lowenberg-Deboer (8), with 339 citations indicating a positive relationship between sustainability and precision agriculture.

Cluster 2: weed control, weed detection, robotic assistance in fields, UAV imagery, real-time problem detection, weed detection and image processing

The second-largest cluster has 150 articles with 5 182 citations shown in green in Fig. 5. Lee et al (23) is the most cited paper in this cluster with 199 citations. Thorp and Tian (35) provided directions on the various means of weed control. Conventional mechanical cultivation lagged due to its inability to remove weeds from the seed line selectively. The need for a robotic weed control system was aroused for two reasons. First, hand labour is costly and an automated weed system is economically feasible. Secondly, it leads to reduced chemical use. Apart from weed control and detection being the primary themes, this cluster also highlights the usage of robots, unmanned aerial vehicles, image processing, and resolution of crop-specific issues. One of the most constructive approaches for acquiring crop and weed spatial information is through remotely sensed images that can be processed, classified and divided into a series of sub-plots for further applications according to specific weed patterns (Gómez-Candón et al., 15).

Cluster 3: wheat, spectral imaging, disease detection, disease monitoring and vegetation indices

The 114 items in cluster 3 received 4 128 citations, shown in blue links in Fig. 5. The most cited paper (Huang et al., 16) received 257 citations. This article discusses the strategies feasible to enhance the timely avoidance of diseases affecting winter wheat in China. It is prone to yellow rust, a fungal disease that causes pustules (leaf lesions) that appear in patches. This disease reduces the yield quantity and quality, consequently leading to losses. It requires considerable effort to detect and monitor diseases on wheat crops.

Vegetation Indices (VI) are dimensionless radiometric measures to enable accurate geographical and time-based comparison of changes in terrestrial photosynthetic activity and canopy structural comparison. VI is used to assess a canopy's overall photosynthetic capacity and productivity (Vincini & Frazzi, 38; Vincini et al., 39). VIs are vital parameters for assessing crop growth under precision agriculture. The applications of vegetation indices are varied, like global vegetation monitoring, land cover and evaluating changes in the land cover. Vegetation index data can be utilized as an input for modelling global biogeochemical and hydrological processes and regional climate.

Cluster 4: adoption, future directions, precision farming and precision agriculture adoption

The cluster consists of 85 articles and 3 306 citations, presented graphically in mustard colour in Fig. 5. The cluster provides the course of action for adoption and future directives. It explicitly addresses the issues related to the uptake of precision technologies in agriculture. Precision farming (PF) enables the management of spatial and temporal variability within a field, cost reduction, yield quantity and quality, enhancement and environmental impact reduction (Reichardt & Jürgens, 28). Computer-based decision-support systems can help farmers manage fertilizers, crops and pesticides. Several studies have shown the economic and ecological benefits of precision agriculture (PA) tools over traditional procedures (Silva et al., 31); therefore, it is worth looking at what factors encourage or discourage PF usage.

The amount of transition that farmers must consider following PA adoption may cause problems. For instance, agricultural machinery must frequently be changed, involving current computer technologies. Furthermore, appropriately understanding PA data can be complex. For these reasons, despite the PA industry's best efforts to persuade farmers to use PA tools to aid their farm management, several surveys have found that farmers are hesitant to adopt PA (Daberkow & McBride, 12; Fountas et al., 14; Reichardt & Jürgens, 29). Ex-post studies (Daberkow & McBride, 12; Kutter et al., 21; Larson et al., 22; Reichardt & Jürge ns, 2008) have proved the benefits of precision farming adoption. Over time, the emphasis has shifted from "farming by soil" (Robert, 30) to variable-rate technology, vehicle guidance systems, product quality and environmental management and will continue to evolve.

Cluster 5: precision viticulture, vineyard, management zones and spatial resolution

Cluster 5 consists of 64 items and 1 911 citations, shown by purple links in Fig. 5. Precision viticulture (PV) was originally used to undertake yield mapping in the United States (Wample et al., 53) and Australia (Bramley & Proffitt, 9). Like most PA applications, PV is a cyclical process that includes data collection analysis, management zone demarcation, management decisions, and evaluation of the implemented techniques. The effect of soil and other abiotic elements on grapevine characteristics (yield, vigour and grape composition) is regarded as equivalent within management zones (Kitchen et al., 20). Yield and grape quality sensors in France were described by Tisseyre et al (52). In Chile (Ortega et al., 50) and Spain (Arnó et al., 5), researchers examined the spatial variability of grape yield. PV strives to manage vineyards on a sub-field level based on the actual demands of each section of the field.

Using precision viticulture, vineyards are managed at a sub-field scale according to their actual needs. Based on fuzzy clustering techniques, Tagarakis et al. (2012) delineated management zones and developed a simplified approach for comparing zone maps. "Promoting sustainable intensification in precision agriculture: a review of decision support systems development and strategies" by Lindblom et al (24) is the most cited paper of this cluster with 144 citations.

Cluster 6: unmanned aerial vehicle, water, irrigation and thermal imagery

The cluster consists of 58 articles with 3 679 citations shown in pink in Fig. 5, and contains the most cited paper by Zhang and Kovacs (44), with a total of 1 067 citations. Most precision agriculture research focuses on developing novel sensors and devices that can detect crop and soil parameters remotely in near-real-time. Despite recent improvements in the spatial resolution of some satellite sensors, such as Ikonos and Quickbird, some severe issues remain regarding the difficulties of taking repeated measurements during the crop cycle (Yang et al., 42). In the last decade, small-scale unmanned aerial vehicle platforms have provided new crop management and monitoring solutions capable of rapidly delivering high-resolution photos, mainly where small production areas must be watched (Zhang & Kovacs, 44).

To achieve the required crop responses, site-specific irrigation can be characterized as a technique in which irrigation timing and amount match actual crop needs within the management unit. The ability to map the variability of crop water status and the development of site-specific water application technology will be vital to increasing productivity in terms of yield and quality per unit of applied water. Implementing site-specific irrigation technologies could help alleviate agricultural water shortage issues. Thermal imaging is an excellent remote sensing technology that can be used for field investigations (Alchanatis et al., 2).

Cluster 7: yield response, nitrogen, sensing and canopy sensors

There are 53 articles in the cluster with a total of 1 958 citations as shown in orange in Fig. 5. Precision nitrogen management (PNM) is a critical component of advanced nutrient management and precision agriculture for long-term agricultural and social success. Management zone demarcation, proximal and remote sensing, crop growth modelling, spatial analysis, variable rate technology, soil science, meteorology, plant nutrition, reduction of greenhouse gas emissions and agronomy are all part of PNM research. Proximal sensing, or gathering data at a close distance, could be a useful tool for monitoring crop nitrogen levels in real-time.

Sensors are frequently placed on satellites, aerial platforms or ground-based platforms. Since the 1970s, satellite equipment has been widely employed for precision farming. Ground-based systems are referred to as proximal remote sensing systems since they are located close to the target surface in comparison to aerial or satellite-based platforms (land surface or plant). The paper by Hunt et al (17), with 261 citations, was the most cited paper in this cluster.

Cluster 8: grain sorghum, airborne imagery and satellite imagery

The smallest cluster of 7 items with 314 citations is shown in brown in Fig. 5. Yang et al (43) was the most cited paper in this cluster, with 64 citations which discusses increased availability of hyperspectral imagery that necessitates the evaluation of its potential for precision agriculture applications. This cluster consists of articles which discuss grain sorghum. Grain sorghum is a good crop choice for fields that dry out slowly in the spring and require longer planting dates, which sorghum prefers compared with maize. Drought tolerance is higher in grain sorghum than in maize or soybean, making it a viable option for drought-prone farms. Grain sorghum uses less nitrogen on marginal soils than maize and produces equivalent yields (Yang & Everitt, 41).

Yang et al (42) is this cluster's second most cited paper. It discusses the contrast between satellite imagery and airborne imagery for mapping sorghum by methods of aerial videography. Aerial videography can be used to enhance or replace in-field spatial variability data. Within-season data from digital videography can be used for quick visual interpretation and computer processing. The visible and infrared regions of the electromagnetic spectrum are typically sensed by video imaging systems used in vegetation monitoring. Biomass, leaf area index (LAI) and crop production have all been estimated using spectral responses in the green, red, and near-infrared (NIR) spectra (Anderson & Yang, 46). Furthermore, statistical clustering of digital video pictures into zones of homogeneous spectral response is possible (Anderson & Yang, 46). These regions can then be used as field management zones. The number of plant tissue and soil samples was increased by dividing the area into homogeneous plant growth sections. Due to increased spatial and spectral resolutions of remotely sensed imagery, remote sensing applications in precision agriculture have gradually increased in recent years. Because of its more acceptable spatial and spectral resolution than satellite imagery, airborne multispectral imagery has been more commonly used for precision agriculture.

Fig. 6 Co-authorship network of authors publishing in PRAG

Co-authorship network analysis

Co-authorship is the major standard representation of scholarly collaboration, resulting in higher-quality output than could be done by an individual (Acedo et al., 1). These collaborations form social networks, which can be used to discover smaller groups of researchers on various topics (Crane, d 11).

Figure 6 shows the co-authorship networks of PRAG authors. The thickness of the link and size of the node represents the frequency of association between two authors and the degree of association with other authors, respectively.

The authors Tisseyre, Mcbratney, Alchanatis, Fountas, Blackmore, Escola, Rosell, Huang and Guillaume feature prominently, thus revealing a high level of connectedness to other authors.

Figure 7 shows the co-authorship network among institutions affiliated with PRAG authors. It can be inferred from the network graph that the most connected network is between the University of Florida, Auburn University United States, the Institute of Agricultural Engineering Israel, Oklahoma State University and North Dakota State University. They are the eminent and main contributors to this journal.

Figure 8 shows the co-authorship network among nations affiliated with PRAG authors. It is evident that the USA, Spain, Australia, United Kingdom and Greece form the main contributors. Other prominent nations include France, Italy, Belgium and Chile.

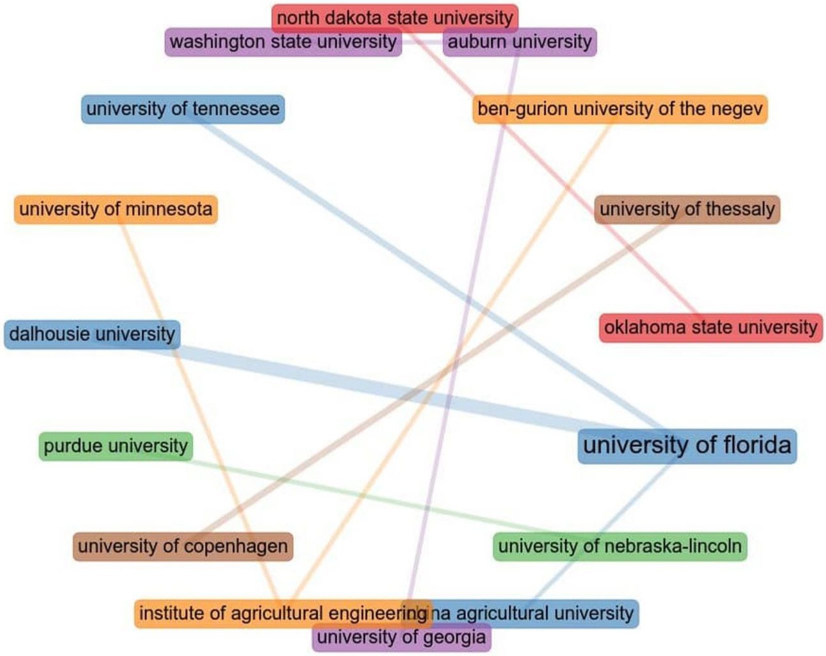

Fig. 7 Co-authorship network of affiliated institutions of authors publishing in PRAG

Summary and conclusion

In 2021, PRAG completed its 21 years of publication. Over the years, PRAG has been established as a recognized body of knowledge in the domain of agricultural and biological sciences. This study offers a bibliometric analysis of the journal. By formulating five research questions, this study aimed to answer the devised research problems by performing the descriptive and network analysis of the journal bibliographies.

The first research question (RQ1) dealt with PRAG's publication and citation trends over the last 22 years. The results show substantial growth in publications and citations, with 955 documents receiving 28 151 citations.

The second research question (RQ2) dealt with the top cited articles of the journal, where the top 20 articles with the maximum number of citations were tabulated.

Research question (RQ3) aimed to introspect the pattern of authorship, affiliations and countries. Table 3 lists the top 20 authors for PRAG. Important indicators like total publication, total citation count, h- index and g-index have been included in the table to identify the top authors. It is interesting to note that most contributing authors are from Europe, followed by North America. For the most productive institutions, the USA leads with the most affiliations. Consequently, most affiliations belong to North America, followed by Europe. The USA, Germany and China occupy the first three positions in terms of the top contributory countries. It is interesting to witness the increasing share of Asian countries. The impressive growth is evidence of the eminence PRAG has achieved.

The fourth research question (RQ4) addressed the various themes and associations for the journal articles through keyword and co-authorship analysis. "Remote sensing",

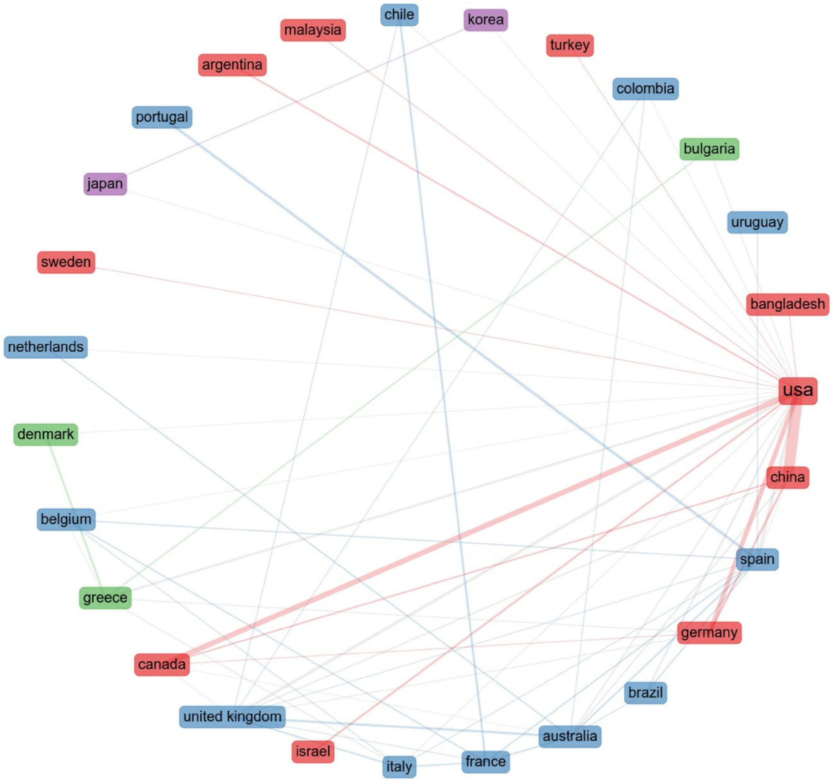

Fig. 8 Co-authorship network of affiliated countries of authors publishing in PRAG

"precision agriculture", "NDVI" and "precision viticulture" are the most used keywords. Co-authorship analysis reveals the most prevalent associations in terms of authors, institutions &countries.

The fifth research question (RQ5) addressed the main themes for the journal using Bibliographic coupling. Eight clusters highlighted common themes. About 81% of the articles, a total of 776 items, were presented with common themes. For example, articles in cluster 1, which happens to be the largest cluster, discussed the topics of soil analysis, precision agriculture and geospatial techniques. The second largest cluster emphasizes on detection, control and monitoring of weeds along with robotic assistance in fields and image processing.

The work aims to contribute in several ways. An attempt to conduct a performance analysis has been made. Based on the results, it is estimated that an increasing number of individuals are likely to recognize the journal in the future. The number of articles and citations is expected to rise, and the journal study topics are likely to become more diverse and in-depth. This will lead to a better understanding of the impact, productivity and the journal reach. PRAG was first published at the turn of the millennium when technology was increasingly applied to agriculture. The journal has positioned itself as a well-reputed source in the diverse field of precision agriculture. The various topics published in the journal are a testament to that effect. PRAG will, without a doubt, act as a platform for the articulation and diffusion of ideas, enhance collaboration among authors, affiliations and countries/regions and create a bridge between academics and industry. The journal has become a leading source of knowledge on advances in precision agriculture and is likely to continue to be a leading publishing source of the varied literature on the topic.

Declarations

Competing interests The authors declare that they have no conflict of interest.

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