
Review

Analyzing Precision Agriculture Adoption Across the Globe: A Systematic Review of Scholarship from 1999 – 2020

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Abstract: Precision agriculture (PA) is a holistic, sustainable, innovative systems approach that assists farmers in production management. Adopting PA could improve sustainable food security and community economic sustainability. Developing an understanding of PA adoption attributes is needed to assist extension practitioners to promote adoption and better understand the innovation adoption phenomena. A systematic review of literature was conducted to investigate PA adoption. Thirty-three publications were examined, and four themes were found among the reviewed publications. The results were interpreted using Rogers' diffusion of innovations framework to address the research objectives. Of the reviewed literature, we found relative advantage and compatibility were two dominant attributes to strengthen the adoption of PA, and the complexity attribute was rarely used to promote the adoption of PA. This study shows that change agents do not fully use five attributes of innovation when they promote PA technology to stakeholders to adopt. Thus, we recommend studies from the agricultural extension specialists' perspectives in the future may determine contributions to motivate farmers' adoption of PA, in particular related to complexity.

Keywords: precision agriculture; agricultural extension; profitability; production quality; systematic review

1. Introduction

The 2050 Food Challenge remains a concern of researchers, practitioners, and policy makers around the world. Fitzpatrick et al. [1] identified food security as the extent food access is available for all individuals in all instances to lead a healthy and functional lifestyle. By 2050, the global population is expected to exceed 9 billion, a large portion of which will be in emerging countries, especially in sub-Saharan Africa and South Asia [2]. Wolde et al. [3] recommended the 2050 Food Challenge necessitates global science-based innovations that concentrate on sustainable agricultural practices that support healthful dietary solutions.

Agricultural extension plays an important role in the development [4] and knowledge transfer [5] of innovations that sustain agricultural productivity. There are increased efforts from agricultural extension to promote precision agriculture (PA) in production contexts, such as viticulture to improve sustainability in Italy [6]. In Nigerian drylands, agricultural extension has been promoting precision approaches to teach fertilizer application [7]. Pluralized agricultural extension perpetually is faced with sustainability issues like precision farming due to the cautious nature of farmers toward change [8].

PA technology is a management tool for monitoring the efficiency of resource inputs while reducing chemical use to avoid environmental damage and produce high quality products to satisfy growing demand on food [9-10]. Precision farming is a holistic,

innovative systems approach that assists farmers in managing crop and soil variability to decrease costs, improve yield quality and quantity, and enhance farm income [11]. PA applies traditional farming practices with new technology, practices, and economic drivers to enhance sustainability in a dynamic balance [12]. Studies have reported positive outcomes from PA adoption, including economic savings in productivity factors [13], increasing yield and environmental sustainability [14], and improving food security and community economic vitality in developing regions [15]. Developing an understanding of PA adoption attributes is needed to assist extension practitioners in the promotion and adoption of PA. Empirical evidence is needed for researchers to adopt this innovation [16].

The history of agricultural development showed that the adoption of innovative technologies had been one of the most important factors in the agricultural production systems. However, several studies have shown that the adoption rates of PA are low [17-19]. Decisions by farm managers to adopt new technologies, such as PA technology, are complex. Farmers like the idea of PA but are less convinced of its value even though they believe that PA technologies are useful to farming [20-21].

Diverse factors influence the adoption of PA. Barriers to PA adoption included technical issues with equipment, access to service software, the lack of compatibility of equipment to current farm operations [22], concerns regarding service providers misuse of agricultural data, challenges of managing amount of PA data [23], user-friendly design [10] and the cost [24-25].

For theoretical triangulation, Rogers' [26] diffusion of innovation attributes were used as the framework to consider the rate of adoption. Adoption refers to the decision to make full use of innovation as the best available course of action, while rejection refers to the decision not to adopt innovation. From the perspective of information flow, the diffusion process of agricultural technology innovation involves government units, agricultural research and extension units, agricultural marketing units, media units, and consumers. The agricultural extension system plays an important role in the diffusion process of agricultural innovation. In adopting PA, it is required knowledge and competences in order to acquire and manage data in farms [23] and extension participants' knowledge increased when taught PA innovations through hands-on experience with software coupled with instructor guided and self-directed instruction [27].

A study on PA adoption by Lowerberg-DoBoer and Erickson [21] showed that most research was aimed at understanding the factors of PA adoption at the farm level and many previous studies found that use of PA is associated with higher production and profits [28-29], however, whether the adoption factors related to yield and profit are influenced by the majority of the studies related to the development of agricultural extension systems related to yield and profit. There are few studies on the relationship between agricultural extension systems and PA technology adoption. As a result, in terms of publications in the field of PA research trends, it is necessary to review the literature with a view to incorporating the published literature on the use of PA processes to examine the development of agricultural technology promotion to a system whereby farmers adopt the PA technology.

In order to comprehend the application of PA, this study sought to provide an investigation of adoption by implementing a systematic review in *Precision Agriculture* from 1999 to 2020 to identify PA adoption attributes to assist extension agents to improve the innovation's sustainability among farmers. More specifically, there were three objectives in the study:

1. Examine the adoption attributes of PA;
2. Describe crop varieties produced by PA; and
3. Investigate the number of countries PA adoption scholarship originated.

2. Materials and Methods

A systematic review of literature was used to conduct this research. A systematic review is a method using an exhaustive and comprehensive search based on explicit and

strict protocols to review the existing literature with a synthesis of data focusing on a topic or on related key questions [30]. There were five steps of systematic review used to collect, analyze, and interpret literature in this study. The first step was to identify the critical question of the research. Then, we formulated the search parameters of the data selection procedure. The third step was to implement the systematic search procedure in the database. Data analysis was the fourth step, and the interpretation and summary of the materials were undertaken in the fifth step.

2.1. Data Extraction

A systematic review method was conducted in this study. Systematic reviews offer a scientific and discernable process that is replicable to minimize researcher bias through comprehensive literature examinations by implementing an audit trail of the researchers' conclusions, processes and inferences. An electronic search was conducted in the *Precision Agriculture*, *Journal of Agricultural Education and Extension*, and *Journal of Extension* databases, filtering the results by key terms and publication date from 1999 to 2020 to ensure unbiased samples were collected.

We collected literature whose titles met the following themes on the publication title: 1) Production quality; 2) Improved profitability; 3) Improved the efficiency of resource use; and 4) Environmental sustainability. The research team established a set of code definition and data collecting criteria (see Table 1).

Table 1. Descriptions of Coded Themes Used in the Systematic Review's Data Collection Process.

Coded Theme	Data Collection Process
Production quality	i. Production and quality were used to search as key terms in publication titles in the journal and there were no results. ii. Yield and quality were the titles used to search as key terms in the title of publications in the journal and nine results showed up. iii. Crop and quality were the titles used to search as key terms in the title of publications in the journal to search for articles and there were two articles fitting the search term, but they were the same articles from the first search term.
Improved profitability	i. Profitability was the key term search in the title of publications in the journal and nine results showed up. ii. Profit was utilized as a key term to search for the articles and there were two results fitting the search term. iii. Profit and yield to search for articles and one article which was the same as the previous search in the theme one.
Improved the efficiency of resource use	i. Efficiency and resource to do the key terms search in the title of publications in the journal and there were no results. ii. Efficiency to search for the articles and six results showed up, but there was one article which was the same as the previous search in theme two. iii. Benefit and effectiveness were used as the key terms to search for articles. Three articles indicated precision agriculture benefits and one search result indicated effectiveness. iv. Based on the definition of PA, resource use includes human and material resources; hence, we further used key terms, investments, labor, and worker, to do the title search separately, and there were still no results.
Environmental sustainability	i. Sustainability produced three results as a key term search in published titles. ii. Environment and impact were used to search for articles and zero results existed with the respective terms. iii. Reduce and impact were used to search for articles and zero results existed.

2.2. Data Analysis

After data collection, each of publications was analyzed with the crop varieties, regions, and keyword co-occurrence to provide descriptive statistics with narrative explanations. Three researchers provided interrater reliability in the analysis process. A VOSviewer tool was used to calculate the number of publications in which two keywords appeared together in the title, abstract, or keyword list.

3. Results

In this study, 31 publications were identified that met the coding criteria. The analysis was considered based on (a) publications productivity, (b) crop varieties, (c) regions, and (d) keyword frequency. No literature in the *Journal of Agricultural Education and Extension* and *Journal of Extension* databases matched the data extraction criteria. From *Precision Agriculture* volumes 1 through 22, there were 31 articles whose titles met the keywords in four coded themes on the publication title. Two of the 31 articles met the selection criteria in two different coded themes. Figure 1 shows the preferred data selection item for systematic reviews.

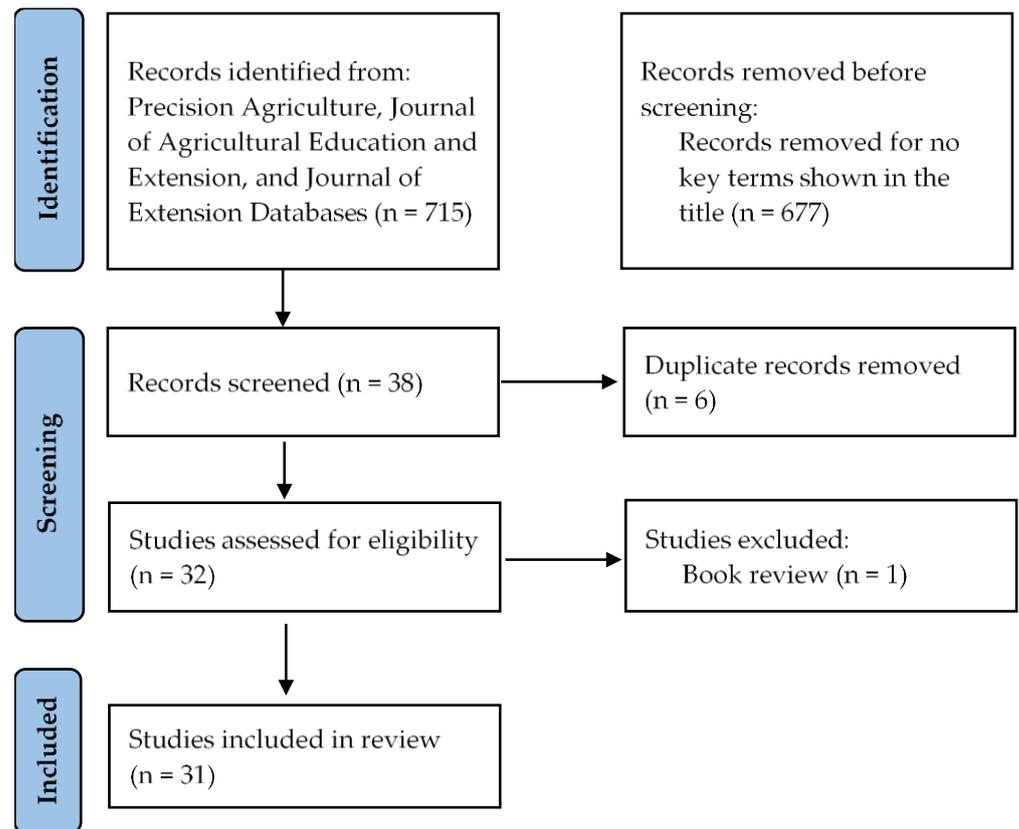


Figure 1. PRISMA flow diagram of data selection procedure.

3.1 Statistic Description of Findings

Among the literature investigated, improved profitability was published the most. Twelve ($n = 12$, 36.4%) of the reviewed literature indicated improved profitability was the deciding characteristic for researchers to promote the adoption of precision agriculture, as shown in Table 2.

Table 2. Literature Analyzed Under the Coded Theme Improved Profitability.

Literature	Title	Crop	Country
Karatay & Meyer-Aurich [31]	Profitability and downside risk implications of site-specific nitrogen management with respect to wheat grain quality	wheat	Germany
Mills et al. [32]	The profitability of variable rate lime in wheat	wheat	USA
Stamatiadis et al. [33]	Variable-rate application of high spatial resolution can improve cotton N-use efficiency and profitability	cotton	Greece
Yost et al. [34]	A long-term precision agriculture system sustains grain profitability	corn; soybean	USA
Stefanini et al. [35]*	Effects of optical sensing based variable rate nitrogen management on yields, nitrogen use and profitability for cotton	cotton	USA
Tona et al. [36]	The profitability of precision spraying on specialty crops: a technical-economic analysis of protection equipment at increasing technological levels	grapevine; apple	Central-Southern Europe

Larson et al. [37]	Effect of field geometry on profitability of automatic section control for chemical application equipment	cotton	USA
Boyer et al. [38]	Profitability of variable rate nitrogen application in wheat production	wheat	USA
Maine et al. [39]	Impact of variable-rate application of nitrogen on yield and profit: a case study from South Africa	N/A	South Africa
O'Neal et al. [40]	Profitability of On-Farm Precipitation Data for Nitrogen Management Based on Crop Simulation	corn; soybean	USA
Young et al. [41]	Site-Specific Herbicide Decision Model to Maximize Profit in Winter Wheat	wheat; peas	USA
Reyns et al. [42]	Site-Specific Relationship Between Grain Quality and Yield	wheat	Belgium

The theme of improving the efficiency of resource use was published the second most as shown in Table 3, with ten articles ($n = 10$, 30.3%).

Table 3. Literature Analyzed Under the Coded Theme Improved the Efficiency of Resource Use.

Literature	Title	Crop	Country
Stamatiadis et al. [33]*	Variable-rate application of high spatial resolution can improve cotton N-use efficiency and profitability	cotton	Greece
Martinez et al. [43]	A cost-effective canopy temperature measurement system for precision agriculture: a case study on sugar beet	sugar beets	Spain
Pavuluri et al. [44]	Canopy spectral reflectance can predict grain nitrogen use efficiency in soft red winter wheat	wheat	USA
Ampatzidis et al. [45]	Portable weighing system for monitoring picker efficiency during manual harvest of sweet cherry	cherry tree	USA
Ortiz et al. [46]	Evaluation of agronomic and economic benefits of using RTK-GPS-based auto-steer guidance systems for peanut digging operations	peanut	USA
Go'mez-Cando'n et al. [47]	Sectioning remote imagery for characterization of Avena sterilis infestations. Part B: Efficiency and economics of control	wheat	Spain
Rascher & Pieruschka [48]	Spatio-temporal variations of photosynthesis: the potential of optical remote sensing to better understand and scale light use efficiency and stresses of plant ecosystems	soybean; avocado	USA
Torbett et al. [49]	Perceived importance of precision farming technologies in improving phosphorus and potassium efficiency in cotton production	cotton	USA
Biermacher et al. [50]	Maximum benefit of a precise nitrogen application system for wheat	wheat	USA

Krell & Pedigo [51] Comparison of Estimated Costs and Benefits of Site-Specific Versus Uniform Management for the Bean Leaf Beetle in Soybean soybean-corn rotation USA

*Duplicate record

Furthermore, nine ($n = 9$, 27.3%) articles have been published as production quality as shown in Table 4.

Table 4. Literature Analyzed Under the Production Quality Coded Theme.

Literature	Title	Crop	Country
Holland et al. [52]	Proximal fluorescence sensing of potassium responsive crops to develop improved predictions of biomass, yield and grain quality of wheat and barley	wheat; barley	Australia
Uribeetxebarria et al. [53]	Stratified sampling in fruit orchards using cluster-based ancillary information maps: a comparative analysis to improve yield and quality estimates	peach	Spain
Arno et al. [54]	Spatial variability in grape yield and quality influenced by soil and crop nutrition characteristics	grape	Spain
Aggelopoulou et al. [55]	Spatial variation in yield and quality in a small apple orchard	apple	Greece
Link et al. [56]	Evaluation of current and model-based site-specific nitrogen applications on wheat (<i>Triticum aestivum</i> L.) yield and environmental quality	wheat	Germany
Jørgensen & Jørgensen [57]	Uniformity of wheat yield and quality using sensor assisted application of nitrogen	wheat	Denmark
Miao et al. [58]	Spatial variability of soil properties, corn quality and yield in two Illinois, USA fields: implications for precision corn management	corn	USA
Miao et al. [59]	Identifying important factors influencing corn yield and grain quality variability using artificial neural networks	corn	USA
Reyns et al. [42]*	Site-Specific Relationship Between Grain Quality and Yield	wheat	Belgium

*Duplicate record

Environmental sustainability was the least published ($n = 2$, 6%) adoption construct from the systematic review analysis (see Table 5).

Table 5. Literature Analyzed Under the Coded Theme Environmental Sustainability.

Literature	Title	Crop	Country
Kountios et al. [60]	Educational needs and perceptions of the sustainability of precision agriculture: survey evidence from Greece	cotton; vegetable; cereal	Greece
Bongiovanni et al. [61]	Precision agriculture and sustainability	corn	Argentina

Wheat ($n = 11$, 28.2%) was the most PA produced crop, followed by corn ($n = 6$, 15.4%) and soybean ($n = 4$, 10.3%) the fourth, indicating that PA was more relatively adopted in food crops (see Figure 2).

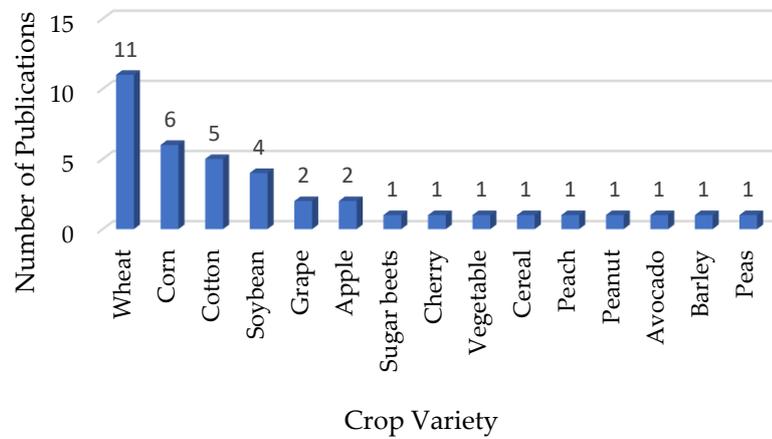


Figure 2. Distribution by crop variety.

The majority of the 31 PA studies ($n = 16$, 51.6%) were conducted in the United States (see Figure 3).

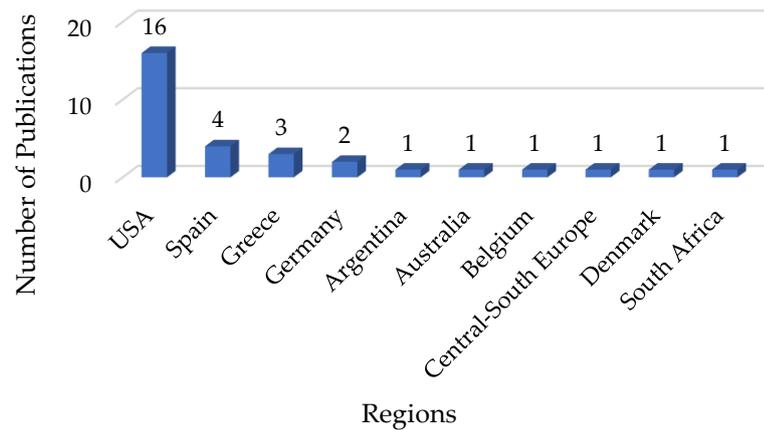


Figure 3. Distribution by Regions.

The VOSviewer tool was utilized to understand the variety of keywords used by researchers frequently in *Precision Agriculture*. The results indicated the number of publications in which 12 major keywords occurred together more than five times in the title, abstract, or keyword list producing a total strength co-occurrence linkage of 110. The results indicated the majority of publications had used these keywords as depicted in Figure 4.

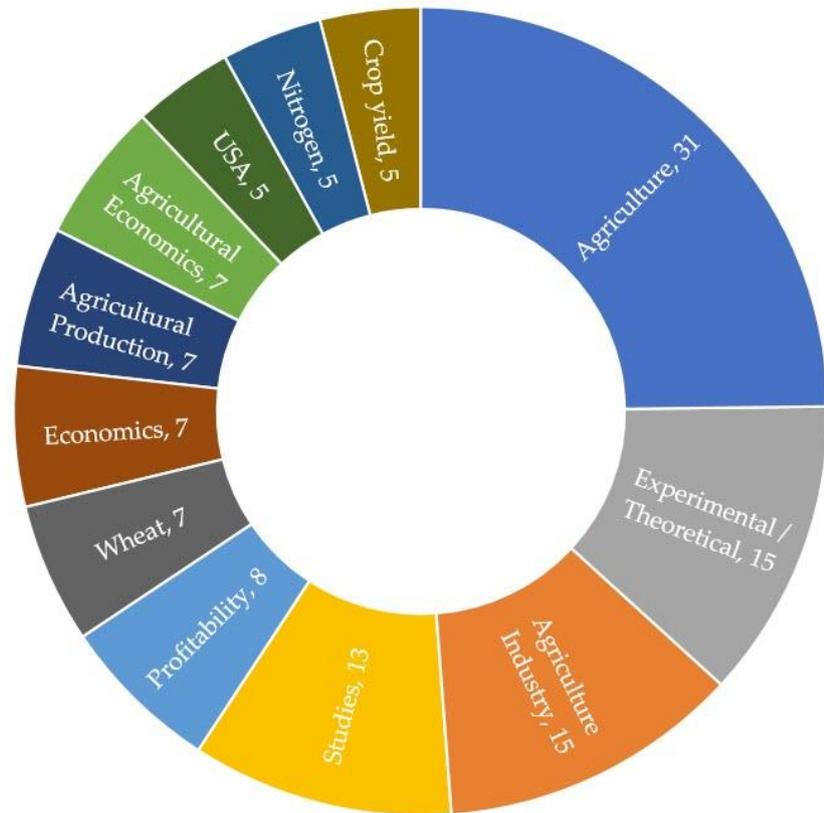


Figure 4. Number of publications keywords are presented.

Figure 5 illustrates a keyword map that had three clusters with the majority of research related to agriculture, profitability, and crop. These three main clustered sections (green, red, and blue) are primarily the themes researchers found promoted PA adoption.

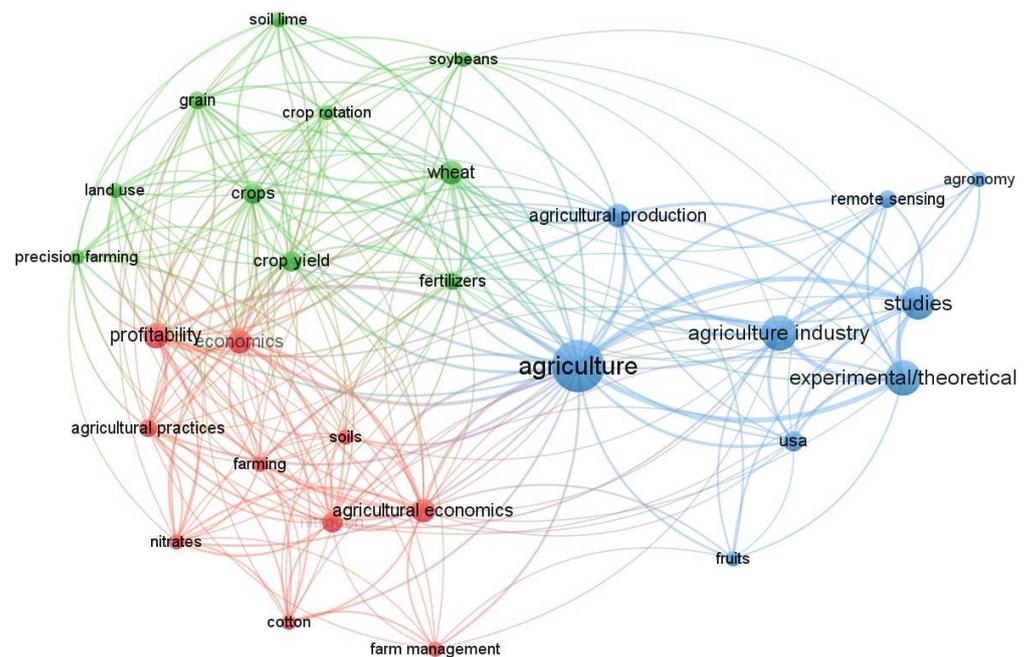


Figure 5. VOSviewer Analysis of Precision Agriculture (PA) Keyword Networks.

3.2 Findings of Innovation Attributes

Profitability and cost saving, yield and quality enhancement, and sustainability were three major benefits frequently discussed in the reviewed studies. We used Rogers' [26] five perceived attributes of innovation to interpret the findings of technologies used in the 31 investigated publications. Within each innovation attribute, several factors were the most prevalent in the investigated studies.

Relative advantage was illustrated, analyzed, inferred, and discussed in 29 of 31 publications. Twelve among 29 publications showed the potential for PA adoption to reduce the amount of fertilizer usage and improve fertilizer efficiency. Stefanini et al. [35] used real-time on-the-go optical sensing measurements (OPM) to evaluate the profitability and nitrogen efficiency. Torbett et al. [49] model also showed precision farmers found PA technologies were important to improve fertilizer efficiency. 15 of 29 publications concluded that adoption of PA applications could maintain profitability while reducing resource usage in the conventional practice, and improving yield and quality. Boyer et al. [38] used plant sensing to determine the amount of nitrogen to apply in the field and found that the technology had the potential to reduce nitrogen costs or increase grain yield and production profit. Also, Young et al. [41] applied a computerised site-specific herbicide decision model in the field and showed that a reduction on the herbicide dose could continue to increase profits.

Compatibility was frequently included in the examined publications. Fourteen of 31 studies indicated that researchers applied the technologies based upon what farmers had been used in the field. Both Stefanini et al. [35] and Boyer et al. [38] studies indicated that they designed the research for variable-rate nitrogen management currently used by farmers. Reynolds et al. [42] used the previously developed sensors to obtain the grain yield data to do the study. Eight of 31 studies revealed that PA enhanced environmental protection by reducing fertilizer usage in which researchers applied the PA technologies based not just on what farmers had been used in the field but also match the existing values that PA may lead to more sustainable cropping systems. Yost et al. [34] stated that even no profit gains with PA system but should invest in PA to help environmental protection without forgoing profit. Kountios et al. [60] concluded that farmers who had a better knowledge of PA would have a better acknowledgment of the environmental, economic, and social sustainability of PA.

There was one study explicitly addressing the complexity within 31 examined publications. Young et al. [41] stated the computerized site-specific herbicide decision model proved easy to use. In addition, Karatay and Meyer-Aurich [31] noted that one of the reasons their study did not take into account farmers' adoption of PA was to simplify complex production management.

Trialability and observability were not explicitly addressed among studies, but 30 of 31 publications were conducted in the on-farm trial or with computerized models to get the results and the methods in studies provided methods to replicate the PA application. Figure 6 depicted the innovation attribute distribution addressed among 31 examined studies.

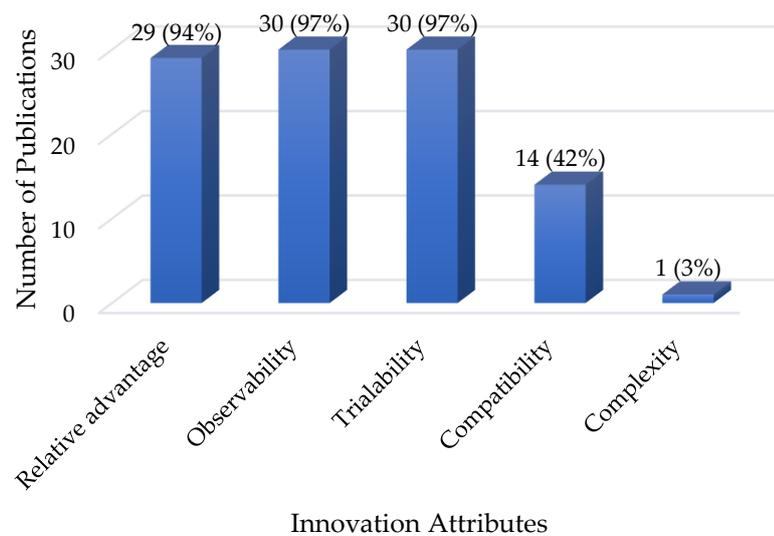


Figure 6. Descriptive Statistics of Innovation Attributes.

4. Discussion

The data presented here informs international agricultural extension agents to promote the adoption of PA to improve profitability and efficiency of resource use, production quality, and environmental sustainability as the innovation attributes. Agricultural commodities produced from PA technology ranged from wheat to peas and the majority of PA inquiries were conducted in the United States over the last twenty years. The systematic review and the VOSviewer analysis underscored the extent adoption barriers may exist for change agents [26] that do not target the adoption characteristics identified in this study.

Rogers' [26] five perceived attributes of innovation was used to explain the factors that most PA technologies commonly used to increase the adoption of PA. We concluded that relative advantage and compatibility were two major factors that researchers considered to promote their innovation. If something is perceived as better than the innovation proceeding and compatible with farmers current situation, the rate of adoption will increase.

In this study, there were more publications targeted on improving profitability to promote PA adoption. And the results of the keyword frequency showed that *profitability* and *economics* are highly used by researchers in the publication. Profitability motivates producers to adopt PA because it meets their economic needs also contributing a relative advantage.

Compatibility was another important reason that encouraged producers who adopt PA. The number of articles published with the "Improved the efficiency of resource use" theme was the second highest, which equates to Rogers' [26] compatibility that innovations align with the farmers' norm of belief and perspectives. Because farmers' norm is looking for producing products in an efficient way, such as reducing the fertilizer usage amount, and in matching the existing value that PA led to a more environmentally friendly production system, or helping manual harvesting work, PA is more likely to be adopted by farmers.

The keyword frequency results showed that keywords of *experimental* and *crop yield* were highly used in the publication that refers to Rogers' [26] trialability and observability attributes of the innovation. There were 30 of 31 articles analyzed in this study that described crop items in the experimental field which demonstrate the innovation to farmers.

Improved profitability was the dominant theme that impacted sustainability of PA to improve farmers' income [62]. Producers could estimate and predict the yield and increase profit with PA application.

The second dominant theme was improved efficiency of resource use related to farmers' concern about whether the PA technology was beneficial for producers to efficiently manage their manual labor and production materials [63-64]. Farmers who adopted PA were more efficient.

Theme three "production quality" indicated that farmers could use PA to improve the crop quality more precisely, such as by using the right amount of fertilizers based on the data, to have better market value on the production.

All reviewed studies, except one, did not mention the complexity of the innovation. To enhance sustainability, the technology complexity can be a factor slowing the rate of adoption. Through trialability and observability in trial plots it would be imperative to demonstrate the ease of operation and cost of PA in comparison to increased efficiencies (cost-benefit analysis). However, if PA is too complex, farmers may reject the adoption of PA. So in essence, the attribute of complexity is about the adoption of technologies that are perceived as simple, or less complex. It is interesting that "ease of use" was not a prevalent theme.

5. Conclusions

From the perspective of information flow, the diffusion process of agricultural technology innovation involves government units, agricultural research and extension units, agricultural marketing units, media units, and consumers. The agricultural extension system plays an important role in the diffusion process of agricultural innovation. The adoption of agricultural technologies in the agricultural extension transfer process is facilitated from the agricultural extension system to farmers to assist in the adoption of PA innovations to advance agricultural development and provide solutions to agricultural issues [65].

The results of this study showed that researchers did not fully use five attributes of innovation when they promoted PA technology to stakeholders to adopt. Of the reviewed literature, we found researchers used relative advantage and compatibility as two dominant attributes to strengthen the adoption of PA. Improved profitability and efficiency were the driving factors of adoption. However, international extension agents can act as translation scientists to increase communication channels for PA adoption primarily in trialability and observability. As a part of farmer field schools or extension workshops the issue of "complexity" can be addressed by showing farmers the ease of use of these technologies. This would strengthen the "production quality" theme and provide more sustainable farm systems.

There was a gap in the literature regarding agricultural extension specialists promoting PA. Considering the limitations of systematic reviews discovered through the data analysis of the current study, we suggest there continues to be a vital requirement for consistency of systematic reviews regarding precision agriculture's sustainability. We concur that the PRISMA procedure is principally intended at systematic reviews in medicine, and thus, we recommend the items adopted and adjusted from the PRISMA model for future social science researchers conducting sustainability systematic reviews. PRISMA will reduce researchers' biases, and enable comprehensibility, reliability and validity to assessments of precision agriculture's sustainability.

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