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A systematic literature review of the factors affecting the precision agriculture adoption process

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Abstract

For agricultural industries to capture many environmental and economic benefits that have been demonstrated for precision agriculture (PA) technologies, an understanding of the factors affecting adoption of these technologies is required to adequately inform the development of PA approaches and the programs used to promote their use. A systematic review of the literature was undertaken to explore the processes of adoption of PA technologies, using an innovation diffusion framework to analyse the complex interactions between different factors in the adoption process. A total of 34 relevant publications were extracted from Scopus database following a systematic search and analysis process. PA technologies adoption research has predominantly been undertaken in the United States and Germany, with industrial crops receiving the most research attention. Relative advantage and motivation were the most frequently mentioned factors affecting PA technologies adoption. However, very few studies have examined multiple components of the complex adoption process, and most were narrowly focussed on assessing the impact of a single aspect. The conclusions drawn from the review are that many of the determinants of innovation diffusion that have been examined in other industry contexts were absent in the PA technologies adoption literature, and that the complexity and multidimensional nature of the adoption process was very poorly represented.

Keywords Precision agriculture · Technology adoption · Adoption process · Diffusion of innovation · Factors · Extension

Introduction

Throughout the history of agriculture, the development and adoption of new technologies has been one of the most important factors shaping agricultural production systems. The introduction, predominantly in the last 200 years, of mechanical power sources for operations such as processing, pumping, transport and tillage, led to productivity gains in most agricultural industries (Binswanger 1986). More recently, the introduction of new

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pesticides, chemical fertilizers and advanced plant and animal breeding technologies have dramatically increased productivity (Fernandez-Cornejo et al. 1998). While the introduction of these new technologies have led to some negative outcomes (Stoate et al. 2001), the intensification of agricultural production that has been made possible by these and other technologies underpin current global food supply capacity. Future agricultural systems will evolve through development and adoption of new technologies that address environmental sustainability issues and support further increase in system productivity.

Precision agriculture is a management strategy that applies a wide range of technologies to collect, process and examine data to guide targeted actions that progress the efficiency, productivity and sustainability of agricultural procedures (International Society of Precision Agriculture 2018). Enabling technologies in PA include the global positioning system (GPS), geographical information systems (GIS) and a multitude of different sensors for assessing site and crop variability, providing information to assist growers in more precise management of agricultural system. Rapid technological advances in computing, information and communications technologies (ICT), robotics and global positioning systems are currently allowing development of a suite of PA technologies that promise to deliver sustainable, high productivity agricultural systems. PA technologies have the potential to drive a new wave of increased agricultural productivity as well as contribute to the environmental sustainability of farming systems. Several PA technologies have been adopted as standard practices in some farming communities. A 2017 PA Dealership Survey in the US showed that 78% of respondents used GPS guidance with auto control on tractors and 55% of the respondents used GPS guidance with manual control (Erickson et al. 2017). Other PA technologies are yet to find widespread adoption. A survey conducted by the Grains Research and Development Corporation (GRDC) in 2014 in Australia found that the national average adoption of variable rate technology and yield mapping were 9.0% and 29% of the cropped area (Umbers et al. 2015). These data reflect a trend of patchy adoption, with some PA technologies adopted quickly while others are not. A greater understanding of the factors and circumstances that lead to adoption are, therefore, required for development of effective strategies to promote widespread adoption of PA technologies.

The literature documenting determinants of adoption of PA practices is relatively broad. A range of studies have examined broad aggregate factors such as farmer age, farm size, subsidy payments, the cost and complexity of technology (Lambert et al. 2015), level of farmer education and access to crop consultants (Robertson et al. 2012) and their influence and relationship with the adoption rate of PA technologies. In contrast, few studies have explicitly presented a conceptual framework with a research objective to better understand and encompass the potential interaction of a range of factors involved in diffusion of innovations.

Tey and Brindal (2012) developed an integrative framework synthesized from interpersonal behaviour and diffusion of innovation theories to show that a set of multidimensional factors influence adoption of sustainable agricultural practices. They found 34 PA technologies adoption factors while reviewing 10 studies and these factors were categorized into 7 groups: (1) Socio-economic factors, (2) Agro-ecological factors, (3) Institution factors, (4) Informational factors, (5) Farmers perception, (6) Behavioural factors, and (7) Technological factors. Operator age, years of farming experience and formal education are examples of socio-economic factors whereas tenure, farm specialization, farm size, farm sales, variable fertilizer rates, livestock sales, debt -to -asset ratio, production value, owned land minus rented land, yield, part-owner farmers, full-owner farmers, farm income/profitability, soil quality, percentage of main crop in total farmland, percentage of farm land as county land area, percentage of cropped land to total farmland, percentage of farmland as large farms and off-farm employment were classified into agro-ecological factors (Tey and Brindal 2012). Likewise, distance from a fertilizer dealer, region, use of forward contract and development were categorized into institution factors, and use of consultant services and perceived usefulness of extension services in implementing precision farming (PF) practices were kept under information factors (Tey and Brindal 2012). Perceived profitability of using PA is classified into farmer perception, willingness to adopt variable-rate technology was kept under behavioural factors and yield mapping, use of computer, farm has irrigation facility and generated own map-based input prescription were classified into technological factors (Tey and Brindal 2012).

Pierpaoli et al. (2013) selected 20 studies and divided them into two groups: ex-post and ex-ante. Both groups incorporated 3 main factors: competitive and contingent, socio-demographic and financial resources. Ex-post studies contained 10 adoption influencing factors whereas ex-ante studies contained 12 adoption influencing factors. Geography, size and soil quality were classified into the competitive and contingent factor, age, computer confidence, information and education were socio-demographic factors, and income, ownership and tenure, full time farmers were classified under financial resources within ex-post studies (Pierpaoli et al. 2013). Likewise, trialability/observability, size, facilitating factors and perceived ease of use were classified into competitive and contingent whereas social factors, age, previous experience and confidence were categorized into socio-demographic and cost, perceived benefit and perceived usefulness were kept under financial resources (Pierpaoli et al. 2013).

The literature presents several theories and models that explain users' acceptance of new technology and their intention to practice the technology. These include, but are not limited to, the Theory of Diffusion of Innovations (Rogers 1983), the Theory of Planned Behaviour (Ajzen 1991), the Technology Acceptance Model (Davis et al. 1989), and the Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations (Greenhalgh et al. 2004). An examination of these models and theories reveals concepts that have relevance to adoption of PA technologies in the agricultural sector.

Rogers (2003) proposes an adoption process model which is known as the Theory of Diffusion of Innovations, widely used in agricultural extension studies that describes a linear set of diffusion stages: innovators, early adopters, early majority, late majority and laggards. The theory argues that the adoption of innovation does not occur simultaneously in a social system. Some people have a greater tendency to adopt innovation than other people because of their characteristics. Therefore, it is important to understand the features of the target groups while promoting innovation. However, other authors have subsequently argued that this model is simplistic and that innovation processes are not linear and generally include a series of feedback-loops.

The Technology Acceptance Model is built on the theory that the adoption of innovation is influenced by perceived usefulness and perceived ease of use (Davis et al. 1989). Some external factors, such as social, cultural, and political factors, influence perceived usefulness and perceived ease of use. Social factors include skill, language, religion, and family, whereas cultural factors include values, customs, and belief. Likewise, political factors include new legislation, and government contributions to agriculture.

The Theory of Planned Behaviour has the potential to create the conceptual links between beliefs and the behaviour of a prospective adopter of technology. PA is the process of technology adoption in which several steps, such as the formation of a negative or positive attitude towards the technology, intention to accept or reject the technology and, finally, accepting or rejecting the technology are undertaken. Therefore, the Theory of Planned Behaviour could offer an important insight into understanding PA technologies adoption as a potential process whereby attitude and intentional beliefs about technology could underpin behaviour.

Knickel et al. (2009) describe this evolution of innovation perspectives from the linear model to more complex systematic approaches for the agricultural sector. Aubert et al. (2012) used technology acceptance and diffusion of innovation literature to demonstrate that agricultural technology adoption is more complex and multi-facetted than many studies assume. Malerba (2002) presents a systematic view incorporating characteristics of the players involved in the innovation dissemination process, the ways in which they interact, and how these interactions are shaped by external factors. Koschatzky et al. (2009) identify six key elements within this systematic perspective: (1) agents and organizations, (2) mechanisms of interactions and intermediates, (3) knowledge base and human capital, (4) institutions and public policy, (5) technologies and demand, and (6) national and global competition. Given the complexity and multidimensional nature of the adoption process described in these models, it is not surprising that PA technologies adoption studies examining only some of the many interacting factors have tended to produce variable and often conflicting findings. Therefore, another review of the literature is required to synthesize the body of published literature on the process of adoption of PA technologies within a theoretical framework of diffusion of innovation. By exploring these interactions through a systematic review of the literature, this research aims to examine the role of PA technologies and the theoretical and practical components/determinants that impact PA technologies adoption broadly. The objective of this study is to identify key aspects of the innovation adoption process that are affecting the rate of adoption of PA technologies. It seeks to review concepts of innovation diffusion processes as they apply to the adoption of PA technologies.

Conceptual framework

A large body of literature exists on the concept of ‘diffusion of innovations’. From this literature the conceptual model developed by Greenhalgh et al. (2004) in a systematic review of diffusion of innovations in service organizations was selected as the theoretical basis for this systematic review. The model was developed using a meta-narrative review technique that traced the development of the concepts, theories and methods associated with numerous paradigms describing ‘diffusion of innovations’. It provides greater depth of understanding of both adopter and innovation features as well as the adoption sequence.

The model, referred to hereafter as the Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations (MDDDII) differs from the approach used in previous studies of PA adoption. MDDDII covers the multiple factors and interactions between components likely to impact PA technologies adoption. For example, Rogers (2003) covered 5 factors such as relative advantage, compatibility, complexity, trialability and observability in the Theory of Diffusion of Innovations model as the features of innovations. MDDDII adds additional features of the innovation such as technical support, task issues, potential for reinvention, fuzzy boundaries, risk and nature of knowledge required (tacit/explicit) while also covering all the factors from the Theory of Diffusion of Innovations which likely to influence on the adoption of PA technologies.

Given the fact that farms are businesses, many of the PA technologies adoption studies have explicitly or implicitly assumed that adoption of PA technologies would be heavily influenced by profitability, along with risk, resources availability and other economic benefits. Six case studies conducted in the US showed that profit (relative advantage) was the major factor on the adoption of PF (Batte and Arnholt 2003). Likewise, another survey of 30 farmers in the Germany disclosed that economic reasons (relative advantage) was the most important driving force behind the adoption of PA (Kutter et al. 2011). Further, an online survey of 75 farmers in Brazil revealed that increased crop yield, cost reduction, and improvement in management (relative advantages) were the main factors of PA adoption (Anselmi et al. 2014). MDDDII incorporates these factors as drivers of PA technologies adoption.

Technology adoption is a process that occurs over time. The factors that explain one stage in that process, may not explain all stages. While many of the previous PA adoption studies focused on identifying which technologies would be adopted in the long run, MDDDII focuses on the entire adoption process from early stages of adoption to the acceptance and integration in production systems. Because of that long-term adoption focus, many of the early PA adoption studies that concentrated on economic benefits and the track record of those studies from the 1992–2010 period in predicting long run adoption is quite good. They identified the strong potential for GPS guidance, and also the mixed economic benefits from VRT and consequently the relatively low adoption of VRT.

MDDDII consists of nine broad components, each of which incorporates a set of factors and processes that may influence the adoption of innovations such as PA technologies:

1. The innovation (characteristics of the innovation itself);
2. Communication and influence (information availability and communication pathways);
3. The outer context (external socio-economic factors such as the regulatory environment);
4. The adopter (the individual using the innovation);
5. System antecedents for innovation (features of the business in which the individual adopter is based);
6. System readiness for innovation (structure and process feature of the business adopting/not adopting the innovation);
7. Linkage (connections between the business adopting/not adopting the innovation and other parties associated with the innovation);
8. Assimilation (the unit of adoption is the team rather than an individual);
9. Implementation process (nature of the activities and environment in which the assessment, adaption and refinements involved in the adoption of the innovation take place).

The 9 components of the Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations (MDDDII) used by Greenhalgh et al. (2004) incorporate but do not correspond to the seven dimensions presented by Tey and Brindal (2012) and Koschatzky et al. (2009), which are designed to influence the adoption of sustainable agricultural practices. The grouping of additional contextual, social and political motivators within the different components in the MDDDII provide a broader conceptual basis for systematic analysis of the literature. The model was, however, developed for service industries, where the unit of adoption is a team or organization rather than an individual farmer. Therefore, it is acknowledged that not all elements of the model are likely to be identified in the literature dealing with PA technologies adoption.

The model postulates that interactions between components must be considered as adoption is not driven by factors operating independently. For example, the adopter component and system antecedents component interact in that the farmer will have varying degrees of risk aversion (adopter) but the financial structure of the business (system antecedents for innovation) may impose an additional source of risk (financial risk) that may significantly impact the willingness to adopt for farmers with increasing levels of financial leverage. Likewise, components such as the innovation, adopter, linkage, and assimilation interact in that complex technologies (e.g., variable rate application of fertilizer) may require expertise beyond that of the farm team. Many will delegate the VRT decisions and perhaps applications to off-farm service providers or consultants.

In addition to better understanding the adoption process itself, the use of a broad based conceptual model in this systematic review allows analysis of major areas of research focus within the complex processes of PA technologies adoption. Most published studies assess only a subset of the components in the model without considering the interactions and contextual features captured by the model. A systematic analysis may, therefore, identify gaps in the research that prevent a more comprehensive understanding of the adoption processes being reached.

The research questions addressed in the study are the following. Does the MDDDII of Greenhalgh et al. (2004) accurately describe the process of adoption of PA technologies? What components, determinants and interactions appear to have the greatest influence on the adoption process? What gaps within the model framework exist in the research on adoption of PA technologies?

Methodology

The systematic review of the literature followed a defined process of research question formulation, research protocol development, literature search, data extraction, quality assessment, data analysis, and interpreting of results (Wright et al. 2007). The systematic literature search was conducted on 18 July 2018 using the Scopus database. The specific search terms used are illustrated in Tables 1 and 2.

Two broad groups of keywords in the areas of 'Precision agriculture' (Group 1) and 'Practice change' (Group 2) were formed to capture relevant studies for systematic review. The studies within the two groups were then combined to capture all of the studies that dealt with the factors that influence on the adoption of PA.

Table 1 Number of studies identified in the Scopus database for each search term used

Group	Keywords	Number of studies
Precision agriculture (Group 1)	Precision agriculture	7981
	Precision farming	2548
	Site specific agriculture	3839
	Site specific farming	1432
	Variable rate technology	11 578
	GPS guidance	2542
	GPS autosteer	4
	Remote sensing	209 891
	Agricultural robots	1573
Practice change (Group 2)	Adoption	181 980
	Diffusion of innovation	27 210
	Agricultural practice	48 401

Table 2 Search results for keyword combinations

Group	Keywords combinations	Number of studies
Precision agriculture	Precision agriculture or precision farming or site specific agriculture or site specific farming or variable rate technology or GPS guidance or GPS autosteer or remote sensing or agricultural robots	235 860
Practice change	Adoption or diffusion of innovation or agricultural practice	249 179
Combination	Group 1 and Group 2	3650

After combining all individual keywords in group 1, Scopus database produced 235860 publications. Likewise, the combination of all individual keywords in group 2 provided 249179 publications. Then, the combination of keywords in the group 1 and group 2 produced 3650 publications.

Inclusion/exclusion criteria

The abstracts of each of the studies were examined and were either included or excluded from further analysis based on the following criteria: (i) Peer reviewed as well as conference publications were searched in Scopus database confirming that these were in English. (ii) The publications were relevant to PA technologies adoption. (iii) The publications covered PA adoption influencing factors.

Only publications meeting the above criteria were selected for analysis. Therefore, 34 publications were acknowledged to be closely associated to the theme of this review. The selection process was completed independently by two of the authors to ensure validity in the selection process.

Data extraction

As a first task, the background of the 34 selected studies were reviewed. Six parameters of the studies were recorded: publication year, authors, publication bibliographic details, country in which the research was conducted, PA technologies and industries examined in the study.

As a second task, the components and determinants of the MDDDII that were described, mentioned, or captured as research data presented in each publication were identified. Data were extracted manually following review of each full publication and were collated into a spreadsheet designed for this systematic review. Accuracy of the extraction process was verified independently by two of the authors, and where discrepancies were identified they were solved by discussion.

Identification of the components of the model was subjective and, therefore, the components were defined prior to data extraction to ensure repeatability of the process. Defining features of the components and the determinants within components that were found in the publications were as follows.

Component 1: the innovation

The innovation component incorporates the features of the technology that are more likely to influence the adoption of PA. Many aspects of innovations were identified as being able to influence the adoption process, so it was important that all innovation features were considered during the systematic data extraction process. The features can be grouped into the following determinants: relative advantage, compatibility, low complexity, trialability, observability, potential for reinvention, fuzzy boundaries, risk, task issues, nature of knowledge required (tacit/explicit) and technical support (Greenhalgh et al. 2004).

Relative advantage

This determinant describes the advantages of the technology over existing technologies in either effectiveness or cost effectiveness. The effectiveness of the technology may include environmental benefits and also provides important information regarding field variability.

Compatibility

Technologies that are well-matched with the values, standards and perceived needs of a farmer are considered compatible innovations. A common example is the compatibility of both hardware and software components of new technologies to existing systems used by the farmer.

Low complexity

The ease of use or the farmers' opinion regarding ease of use of the technology is a feature of the innovation that can be defined as low complexity.

Trialability

Technologies that farmers can readily trial on a limited basis before making a firm decision of adoption can be categorized under the trialability feature.

Observability

This determinant describes the feature(s) of a technology that makes the benefits of the technology readily apparent to the farmer. Observability may apply during trialling of the technology or during adoption of the technology by the farmer or by other industry members.

Technical support

Technical support describes access to expert advice and information to assist in the use of the technology by the farmer. For example, manufacturers could manage a help desk to provide technical support for users of their technologies.

Component 2: communication and influence

Communication and influence alter the adopter's propensity for innovation adoption (Wejnert 2002), and this component of the innovation adoption process ranges from the nature of social networks that the adopter engages with to planned dissemination programs such as agricultural extension activities to promote use of the innovation. Determinants of the communication and influence component are the use of channels of communication such as social networks, homophily, peer opinion, marketing, expert opinion, champions, boundary spanners, and change agents (Greenhalgh et al. 2004).

Social networks

This determinant describes the presence and strength of the social network by which farmers make new friends and share their ideas and interests. Social contact using social media such as Twitter, Facebook and Instagram are included under social networks.

Change agents

Change agents are a person or an organization external to the farm who/which supports farmers to bring about improvements and changes in a farm's effectiveness and development. Extension personnel/agency or agents, agricultural exhibitions, and contractors are considered change agents.

Marketing

Marketing is the process of promoting and selling agriculture related products and services to farmers. Thus, the activities of agricultural business companies, private business selling a service, input suppliers, dealers, manufacturers, retailer, media, farm magazines, television, tradeshows, research publications, and the availability of technologies are incorporated under the marketing determinant.

Peer opinion

The beliefs and actions of a farmer can influence decision-making on farms, including adoption of innovations. Thus, the specific networking of farmers with their neighbours and friends can be defined as a determinant under peer opinion.

Expert opinion

Expert opinion is very important to bring about improvements and changes in a farm's effectiveness and development. The opinions or suggestions of crop consultants, agricultural scientists, agricultural engineers, advisory service providers, universities, research centres, agronomists, and veterinarians are considered expert opinion.

Components 3: outer context

The component outer context describes the effect of external factors on the adoption of technologies. The outer context component covers the socio-political climate, incentives and mandates, interorganizational norm-setting and networks, and environmental stability (Greenhalgh et al. 2004).

Component 4: adopter

The process of adoption of an innovation involves decision-making by the adopter and, therefore, the characteristics of the person involved in the decision-making are a component of the model. Needs, motivation, values and goals, skills, learning style, and social networks are the determinants under the adopter component (Greenhalgh et al. 2004).

Skills

The ability of a farmer and farm staff to use technologies necessitates both managerial and technical skills. Factors such as level of education and training, management capacity, and the work experience of a farmer are used as indicators of skills in many studies of agricultural technology adoption.

Motivation

The farmer and farm characteristics that contribute to the motivation to use technologies encompass factors including the age of a farmer, farm size, location, farm condition, layout of the farm, and financial status. An important constraint of motivation is the degree of risk aversion. This often varies with age and level of education. For capital embodied technologies that require a large capital investment, financial risk may be an important element in determining whether to adopt.

Value and goals

Alignment of the likely impact of the technology being considered for adoption with the farmers' lifestyle and business aspirations can be a factor influencing the adoption process. Consideration of the values and goals of the adopter is, therefore, included in the Adopter component.

Component 5: system antecedents for innovation

In addition to the final decision-maker or adopter, many farms operate as businesses with multiple individuals involved in the process of assessing and adopting an innovation. The structural and cultural features of the farming business can influence assimilation of an innovation into the business. Factors such as business size/maturity, formalization, differentiation, decentralization, slack resources, a pre-existing knowledge/skills base, the ability to find, interpret, recodify and integrate new knowledge, enablement of knowledge sharing via internal and external networks, leadership and vision, good managerial relations, a risk-taking climate, clear goals and priorities, and high-quality data capture fit into this component (Greenhalgh et al. 2004).

Component 6: system readiness for innovation

The farming business may not be prepared for or have the desire to assimilate an innovation due to determinants such as tension for change, innovation system fit, power balances, assessment of implications, dedicated time/resources, and monitoring and feedback (Greenhalgh et al. 2004). This component captures the situational aspects of the farming business that relate to preparedness to assess and adopt an innovation.

Component 7: linkage

This component covers the nature and timing of the development of links between the potential adopter and other players involved in the innovation. Shared meanings and mission, effective knowledge transfer, user involvement in specification capture of user-led innovation, communication and information, user orientation, product augmentation and project management support are examples of determinants within the linkage component (Greenhalgh et al. 2004).

Component 8: assimilation

In the service industry, the unit of adoption is the team, department or organisation rather than an individual, and different ways of working are essential while diffusion of innovation is occurring (Greenhalgh et al. 2004). However, the proposed research concerns technology adoption by an individual farmer. Thus, the assimilation component of the model is not relevant.

Component 9: implementation process

Adoption of a new technology within an agricultural business is not a single step process. Indeed, implementation of the innovation is a complex sequence of trialling, adapting and refining until the innovation can be considered to have been adopted as part of the system. Determinants such as decision-making devolved to frontline teams, a hands-on approach by leaders and managers, human resource issues (especially training), dedicated resources, internal communication, external collaboration, reinvention/development and feedback on progress are all included under the implementation process component (Greenhalgh et al. 2004).

Data analysis and results

Characteristics of the studies

A total of 34 publications were analysed in this systematic review. The number of publications relevant to the systematic review topic varied with publication year (Table 3). No

Table 3 Number of publications published per year

Year	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2005	2004	2003
Number of publication	2	1	3	1	6	1	3	4	1	2	4	2	1	1	2

relevant publications were identified in 2006 and before 2003, and between 2018 and 2015 only 1–3 publications per year were relevant in the review. This number increased to a maximum value of 6 publications in 2014 followed by 4 publications in each of the years 2011 and 2008.

Classification of technologies

Many technologies are identified within selected publications; therefore, these technologies have been divided into two groups in this research study: 1. Information technologies; and 2. Management technologies.

Information technologies

Information technologies support farmers by providing information about soil, crop, weeds, insect, diseases and much more. These technologies are further divided into 5 subgroups.

(i) Yield mapping such as yield monitoring
(ii) Soil monitoring technologies such as grid soil sampling, GPS based soil sampling
(iii) Remote sensing such as aerial photos and satellite imagery
(iv) Geographical information system
(v) Bundle technologies such as the combination of grid soil sampling and yield monitoring

Soil monitoring technologies such as geo-referenced soil testing was mostly studied in 2014 and 2008. Both of the technologies, yield monitor and remote sensing were mostly studied in 2008. The first study focussed on bundles of information technologies was published in 2015. Some of the publications (Bagheri and Bordbar 2014; Daberkow and McBride 2003; Paustian and Theuvsen 2017; Paxton et al. 2011) did not mentioned any specific tools of PA technologies (Table 4).

Table 4 Number of publications corresponding to year discussing information technologies

Year	‘18	‘17	‘16	‘15	‘14	‘13	‘12	‘11	‘10	‘09	‘08	‘07	‘05	‘04	‘03
YM	0	0	1	0	1	0	1	0	0	0	2	1	1	1	1
YMP	0	0	1	0	1	1	1	1	0	2	0	0	0	0	1
SMT	0	0	1	0	3	0	0	2	1	2	3	0	1	0	0
RS	1	0	1	0	1	1	1	0	0	0	2	0	1	0	0
GIS	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0
BT				1	0	0	0	0	0	0	0	0	0	0	0
SI					1	0	0	0	0	0	0	0	0	0	0
AP								1	0	0	0	1	0	0	0

‘=20 such as ‘18 = 2018

YM yield monitor, *YMP* yield mapping, *SMT* soil monitoring technologies, *RS* remote sensing, *GIS* geographical information system, *BT* bundle of technologies, *SI* satellite imagery, *AP* aerial photos

Management technologies

Management technologies involve systems for precision control of production inputs in farming systems. These systems often use outputs of information management technologies to guide precise input utilisation. The management technologies are further divided into 2 subgroups for this analysis.

(i) Variable rate technologies (variable rate fertilizer application, variable rate lime application, variable rate irrigation)
(ii) Automation technologies (auto steer vehicles, automated insect traps, automated irrigation controllers)

Variable rate technologies were mostly studied in 2008. Likewise, automation technologies were mostly studies in 2011. The types of management technologies examined in the selected publications changed over the study period. Each of these technologies may differ with regard to components MDDDII. VRT is among the most complex and often is delegated to a consultant or service provider. Automation technologies may be much easier for an adopter to understand and be willing to adopt without external expert guidance (Table 5).

Study location

The major location where studies were conducted was the US, with 47.1% of all selected publications describing technology adoption in the US agricultural industries. Germany was the country with the next largest representation, with 11.8% of publications, followed by Australia with 8.8% of the studies. Further, 11.8% of the publications involved studies conducted in multiple countries. Countries where a single study was published were Denmark, Turkey, Hungary, Nigeria, Canada, Brazil and Iran. The data on location of studies is consistent with research being conducted predominantly in developed countries where the investment in development of technologies applicable to precision agriculture is highest and promotion of those technologies has led to interest in understanding the adoption process.

Classification of agricultural industry

There are a broad range of agricultural industries mentioned in the literature and in the analysis and these were grouped as industrial crops (cotton and sugarcane), grains (rice, wheat, barley) and mix multiple crops (Grain, vegetable, industrial, fruit, oleaginous).

Table 5 Number of publications corresponding to year discussing management technologies

Year	‘18	‘17	‘16	‘15	‘14	‘13	‘12	‘11	‘10	‘09	‘08	‘07	‘05	‘04	‘03
VRT	1	0	2	0	1	0	1	0	1	1	3	1	0	1	1
AMT	1	0	0	0	1	0	1	3	0	0	0	1	0	0	0

‘=20 such as ‘18 = 2018

VRT variable rate technologies, *AMT* automation technologies

Industrial crops were most heavily represented in the selected publications. 26.5% of the publications did not mentioned any type of agricultural industries.

The largest percentage of publications (8.8%) was covered by industrial crops in 2014 and in 2008. However, no publications mentioned other agricultural industries in the same years. In addition, 2.9% of publications discussing mix multiple crops appeared in several years such as 2018, 2017, 2016 etc. Similarly, no publications have reached more than 2.9% of publications in grain industries in an individual year. The data reflected that industrial crops producers used more PA tools than other crops producers (Table 6).

Components and determinants of PA adoption

The frequency of inclusion of components and determinants of MDDDII in the studies of adoption of PA technologies was also quantified. The adopter component (94.1% of the publications) and the innovation component (88.2% of the publication) were included in the majority of publications. Communication and influence component was discussed in 82.4% of the publications, while outer context was discussed in 38.2% of the publications. Further, linkage component was discussed in 8.8% of the publication whereas other components such as system antecedents for innovation, system readiness for innovation, assimilation and implementation process were not discussed in any of the selected publication.

Within each component, several specific determinants were the most prevalent in the selected studies. Relative advantage was analysed, inferred, or discussed in most of the publications and was the dominant determinant in the innovation component. Compatibility and complexity were also frequently included in the selected publications. Motivation and skills were the most commonly covered determinants in the adopter component. The determinants such as needs, values and goals, social networks and learning style within adopter component were not analysed, inferred, or discussed in any of the publications, representing a major omission from the study of PA technologies adoption.

Many of the possible determinants within system antecedents for innovation, system readiness for innovation, assimilation and implementation process were not detected in any of the PA literature examined. The potential for these determinants, for example, the business structure and maturity within the system antecedents for innovation component to

Table 6 Number of publications based on agricultural industries

Year of publication	Mix multiple crops	Industrial crops	Grains
2018	1	0	0
2017	1	0	0
2016	1	1	1
2015	0	1	0
2014	0	3	0
2013	1	0	0
2012	1	1	1
2011	1	2	1
2010	0	1	0
2008	0	3	0
2007	1	0	0
2004	1	0	0
2003	1	0	1

influence the innovation diffusion process of PA technologies is a significant gap in the literature. The paucity of studies covering the full suite of determinants in all but the adopter, the innovation, communication, and influence components suggest that a full appreciation of the innovation diffusion process is yet to be achieved for PA technologies (Table 7).

In addition to gaps in the literature on specific determinants, the lack of appreciation of the complex interactions between components that is implicit in the MDDDII is evident within the published PA technologies adoption literature. Of the 34 selected publications, none covered all 9 of the model components. Two studies (Bagheri and Bordbar 2014; Busse et al. 2014) included analysis and/or discussion of 5 components, while 10 publications (Adekunle 2013; Aubert et al. 2012; Kountios et al. 2018; Lambert et al. 2015; Markley and Hughes 2014) included 4 components. Nearly all publications covered 2 or more components, with only two publications (Boyer et al. 2016; Daberkow and McBride 2003) covering a single component (Table 8).

The low number and, in many cases, the absence of analysis of some determinants in the literature, as well as the low frequency of coverage of multiple components suggests that the innovation diffusion process for this group of technologies is yet to be fully understood. The low frequency of coverage of some components and determinants may either reflect the lack of importance of these components/determinants to PA technologies adoption or result from a focus of most studies on only part of the awareness-assessment-uptake-sustained use-widespread diffusion continuum of technology adoption. This is identified as major gap in the literature relating to what may be important factors influencing adoption of PA technologies. This knowledge gap may have contributed to the relatively slow rate of adoption in many areas, as strategies to promote use of PA technologies are based on incomplete understanding of the innovation diffusion process.

Evidence of component combinations influencing PA technologies adoption rate

Consistent with the complexity and multi-dimensional nature of the adoption process described in the models of Greenhalgh et al. (2004), Koschatzky et al. (2009), Tey and Brindal (2012), and Malerba (2002), several of the studies from the systematic review that incorporated multiple component combinations acknowledge the complexity of the adoption process and the influence of interactions between multiple factors. Busse et al. (2014) note that by presenting explanations of the complex interactions of important factors in the innovation process chain, they were able to increase understanding of PF adoption. Aubert et al. (2012) highlight several key interactions, hypothesizing that compatibility, farm owner and staff knowledge, and quality of support influence the perception of the ease of use of PA technologies, while compatibility, relative advantage, information use and ease of use impact on the perceived usefulness of PA technologies and, finally, that communicability, trialability and voluntariness impact on the PA technologies adoption decision. The key determinants knowledge gap identified through the systematic review process can be extended to include interactions between components and their determinants, as very few of the publications acknowledged, let alone examined, this topic.

Many of the publications selected in the review documented studies aimed at identifying key factors promoting or barriers to adoption of PA technologies. As the majority of publications examined 3 components from the MDDDII (and often only a subset of the determinants within each of the components examined), the significance of their findings is questionable. As a framework describing the components of the innovation dissemination process, the model is intended to highlight the set of parameters and their complex interactions that can

Table 7 Number of components and determinants in the publications

The innovation	Communication and influence	Outer context	System antecedents for innovation	System readiness for innovation	Linkage	Adopter	Assimilation	Implementation process
Relative advantage (30)	Social network (1)	Socio-political climate (0)	Size/maturity (0)	Tension for change (0)	Shared meanings and mission (0)	Needs (0)	Complex, non-linear process (0)	Decision making devolved to frontline teams (0)
Compatibility (7)	Homophily (0)	Incentives and mandates (13)	Formalization, Decentralization (0)	Innovation-system fit (0)	Effective knowledge transfer (0)	Motivation (29)	Soft periphery elements (0)	Hands-on approach by leaders and managers (0)
Low complexity (4)	Peer opinion (3)	Interorganizational norm-setting and networks (0)	Slack resources (0)	Power balances (Supporters vs. opponents) (0)	User involvement in specification (0)	Values and goals (0)		Human resource issues, especially training (0)
Trialability (2)	Marketing (16)	Environmental stability (0)	Clear goals and priorities (0)	Assessment of implications (0)	Capture of user-led innovation (0)	Skills (24)		Dedicated resources (0)
Observability (2)	Expert opinion (17)		High quality data capture (0)	Dedicated time/resources (0)	Communication and information (3)	Learning styles (0)		Internal communication (0)
Potential for reinvention (0)	Champions (0)		Pre-existing knowledge/skill base (0)	Monitoring and feedback (0)	User orientation (0)	Social networks (0)		External collaboration (0)
Fuzzy boundaries (0)	Boundary spanners (0)		Ability to find, interpret, recodify and integrate new knowledge (0)		Product augmentation (0)			Reinvention/development (0)

Table 7 (continued)

The innovation	Communication and influence	Outer context	System antecedents for innovation	System readiness for innovation	Linkage	Adopter	Assimilation	Implementation process
Risk (0)	Change agents (15)		Enablement of knowledge sharing via internal and external networks (0)		Project management support (0)			Feedback on progress (0)
Task issue (0)			Leadership and vision (0)					
Nature of knowledge required (0)			Risk-taking climate (0)					
Technical support (1)			Good managerial relations (0)					

Table 8 Number of components and publications

Number of components	Number of publications
The innovation, communication and influence, outer context, adopter and linkage (5 components)	2
The innovation, communication and influence, outer context and adopter (4 components)	10
The innovation, communication and influence and adopter (3 components)	14
Any two components	6
Only one component	2

influence the technology adoption process. Where multiple components are not considered in an analysis, an incomplete picture of the complex processes emerges. Further insights can be gained through appraisal of the studies, particularly those that include analysis or discussion of 4 or more components, and by using the MDDDII as the lens through which the study data and discussion are viewed.

The studies that include 5 components were conducted in Germany (Busse et al. 2014) and Iran (Bagheri and Bordbar 2014), and all present survey data gathered from interviews with agricultural experts. In each study factors relevant to the innovation, Adopter, Communications, Influence, and Outer Context components are identified as factors influencing or barriers to the PA technologies dissemination process. Statistical analyses used to rank the barriers to adoption of PA produced widely varying lists in each of the studies, suggesting that the importance of determinants within the components varies according to the specific circumstances of the PA technologies adoption being studied. Busse et al. (2014) acknowledges directly in stating that an examination of social and organizational innovations in the PF innovation field would provide a broader understanding of innovation mechanisms. The Iranian study (Bagheri and Bordbar 2014) emphasize the need to decrease the cost of technology and improve knowledge of the technology.

Of the studies that incorporated 4 components of the MDDDII, several acknowledged that PA adoption research had largely focused on assessing the importance of individual farm and owner characteristics, ignoring the diverse components and complex interactions that characterize an adoption decision. Aubert et al. (2012) suggest that a sound understanding of the complexity of PA adoption is necessary in order to develop adequate policies and initiatives which support the adoption of PA technologies. Kutter et al. (2011) conclude that research on PF relates the adoption of PF primarily to economic incentives as well as farm attributes, whereas social factors are commonly ignored. While the complexity of the PA technologies adoption process is highlighted in these studies, none present an extensive examination of component interactions. Advances in understanding the adoption of PA technologies is likely to come from research examining these complex interactions, and this knowledge will be critical to the development of effective strategies to promote adoption of PA technologies.

Conclusions

This systematic review found that 5 of the 9 key components from the MDDDII were covered in the literature pertaining to the process of adoption of PA technologies. Consistent with the conceptual basis of the model, the complexity of the innovation diffusion process is highlighted by the range of determinants of PA adoption presented in the reviewed publications. Few publications have addressed more than a few of the components of MDDDII. The relative advantage was the most commonly identified innovation diffusion determinant, followed by the motivation. The low frequency of coverage of some model components and determinants was identified as major gap in the literature and this knowledge gap may have contributed to the relatively slow rate of adoption of PA technologies. In addition, very few studies examined multiple components of the adoption process, and most were narrowly focussed on assessing the impact of a single aspect. The conclusions drawn from this review are that many of the determinants of innovation diffusion that have been examined in other industry contexts were absent in the PA technologies adoption literature, and that the complexity and multidimensional nature of the adoption process was very poorly represented.

Appendix: details of selected publications

Year	Authors	Publication	Country	PA technologies	Industry
2018	Kountios, G. Ragkos, A. Bournaris, T. Papadavid, G. Michailidis, A.	Precision Agriculture, vol. 19: 537–554	Greece	Variable rate technology Remote sensing Geographical information systems	Multiple (Cotton, cereal, vegetables, arboriculture)
2018	Tamirat, T. W. Pedersen, S. M. Lind, K. M.	Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, vol. 68: 349–357	Denmark Germany	Auto guidance	Not mentioned
2017	Paustian, M. Theuvsen, L.	Precision agriculture, vol. 18: 701–716	Germany	Not mentioned	Multiple (Wheat, barley, rye, oilseed, corn, feeding crops)
2016	Keskin, M. Sekerli, Y. E.	Agronomy Research, vol. 14: 1307–1320	Turkey	Geographic information systems Remote sensing	Multiple (Grain, vegetable, industrial crop, fruit)
2016	Boyer, C. N. Lambert, D. M. Velandia, M. English, B. C. Roberts, R. K. Larson, J. A. Larkin, S. L. Paudel, K. P. Reeves, J. M	Journal of Agricultural and Resource Economics, vol. 41: 81–96	US	Variable rate technology Geo-referenced precision soil sampling	Cotton
2016	Schimmelpfennig, D. Ebel, R.	Journal of Agricultural and Resource Economics, vol. 41: 97–115	US	Yield monitor Yield map Variable rate technology	Grain

Year	Authors	Publication	Country	PA technologies	Industry
2015	Lambert, D. M. Paudel, K. P. Larson, J. A.	Journal of Agricultural and Resource Economics, vol. 40: 325–345	US	Bundled of Yield monitors and grid soil sampling Bundle of aerial, satellite imagery, hand-held devices with GPS and soil survey maps	Cotton
2014	Lambert, D. M. English, B. C. Harper, D. C. Larkin, S. L. Larson, J. A. Mooney, D. F. Roberts, R. K. Velandia, M. Reeves, J. M.	Journal of Agricultural and Resource Economics, vol. 39: 106–123	US	Geo-referenced soil testing	Cotton
2014	Bagheri, N. Bordbar, M.	Agricultural Engineering International: CIGR Journal, vol. 16: 119–123	Iran	Not mentioned	Not mentioned
2014	Lencses, E. Takacs, I. Takacs-Gyorgy, K.	Sustainability, vol. 6: 8452–8465	Hungary	Auto-guidance	Not mentioned
2014	Busse, M. Doernberg, A. Siebert, R. Kuntosch, A. Schwerdtner, W. Konig, B. Bokelmann, W.	Precision Agriculture, vol. 15: 403–426	Germany	Yield mapping GPS based soil sampling	Not mentioned
2014	Watcharaanantapong, P. Roberts, R. K. Lambert, D. M. Larson, J. A. Velandia, M. English, B. C. Rejesus, R. M. Wang, C.	Precision Agriculture, vol. 15: 427–446	US	Remote sensing Yield monitor Grid soil sampling	Cotton
2014	Markley, J. Hughes, J.	International Sugar Journal, vol. 116: 278–285	Australia	Variable rate technology Satellite imagery	Sugarcane
2013	Adekunle, I. O.	Middle East Journal of Scientific Research, vol. 13: 1230–1237	Nigeria	Yield mapping Remote sensing	Multiple (Grain, vegetable, industrial crop, fruit, grape, oleaginous)

Year	Authors	Publication	Country	PA technologies	Industry
2012	Robertson, M. J. Llewellyn, R. S. Mandel, R. Lawes, R. Bramley, R. G. V. Swift, L. Metz, N. O'Callaghan, C.	Precision Agriculture, vol. 13: 181–199	Australia	Variable rate technology Yield mapping	Grain
2012	D'Antoni, J. M. Mishra, A. K. Joo, H.	Computers and Electronics in Agriculture, vol. 87: 121–128	US	Autosteer	Cotton
2012	Aubert, B. A. Schroeder, A. Grimaudo, J.	Decision Support Systems, vol. 54: 510–520	Canada	Yield monitor Geographic information systems Remote sensing	Multiple (Cereal and oleaginous)
2011	Silva, C. B. De Moraes, M. A. F. D. Molin, J. P.	Precision Agriculture, vol. 12: 67–81	Brazil	Satellite imagery Aerial photography Auto-guidance	Sugarcane
2011	Kutter, T. Tiemann, S. Siebert, R. Fountas, S.	Precision Agriculture, vol. 12: 2–17	Multiple locations (Czech Republic, Denmark and Greece)	Yield mapping Auto-guidance Soil sampling	Grain
2011	Paxton, K. W. Mishra, A. K. Chintawar, S. Roberts, R. K. Larson, J. A. English, B. C. Lambert, D. M. Marra, M. C. Larkin, S. L. Reeves, J. M. Martin, S. W.	Agricultural and Resource Economics Review, vol. 40: 133–144	US	Not mentioned	Cotton
2011	Lawson, L. G. Pedersen, S. M. Sorensen, C. G. Pesonen, L. Fountas, S. Werner, A. Oudshoorn, F. W. Herold, L. Chatzinikos, T. Kirketerp, I. M. Blackmore, S.	Computers and Electronics in Agriculture, vol. 77: 7–20	Multiple locations (Denmark, Finland, Germany and Greece)	Auto-guidance Grid soil sampling	Multiple (Vegetable, industrial crop, cereal, livestock)

Year	Authors	Publication	Country	PA technologies	Industry
2010	Walton, J. C. Roberts, R. K. Lambert, D. M. Larson, J. A. English, B. C. Larkin, S. L. Martin, S. W. Marra, M. C. Paxton, K. W. Reeves, J. M.	Precision Agriculture, vol. 11: 135–147	US	Grid soil sampling Variable rate technology	Cotton
2009	Reichardt, M. Jurgens, C.	Precision Agriculture, vol. 10: 73–94	Germany	GPS based soil sampling Yield mapping Variable rate technology	Not mentioned
2009	Reichardt, M. Jurgens, C. Kloble, U. Hüter, J. Moser, K.	Precision Agriculture, vol. 10: 525–545	Germany	GPS based soil sampling Yield mapping	Not mentioned
2008	Torbett, J. C. Roberts, R. K. Larson, J. A. English, B. C.	Computers and Electronics in Agriculture, vol. 64: 140–148	US	Grid soil sampling Yield monitor Remote sensing	Cotton
2008	Larson, J. A. Roberts, R. K. English, B. C. Larkin, S. L., Marra, M. C. Martin, S. W. Paxton, K. W. Reeves, J. M.	Precision Agriculture, vol. 9: 195–208	US	Remote sensing Variable rate technology	Cotton
2008	Isgin, T. Bilgic, A. Forster, D. L. Batte, M. T.	Computers and Electronics in Agriculture, vol. 62: 231–242	US	Yield monitor Variable rate technology Grid soil sampling	Not mentioned
2008	Walton, J. C. Lambert, D. M. Roberts, R. K. Larson, J. A. English, B. C. Larkin, S. L. Martin, S. W. Marra, M. C. Paxton, K. W. Reeves, J. M.	Journal of Agricultural and Resource Economics, vol. 33: 428–448	US	Variable rate technology Soil sampling	Cotton
2007	Jochinke, D. C. Noonon, B. J. Wachsmann, N. G. Norton, R. M.	Field Crops Research, vol. 104: 68–76	Australia	Yield monitor Autosteer Aerial photography	Not mentioned

Year	Authors	Publication	Country	PA technologies	Industry
2007	Nganje, W. E. Friedrichsen, M. S. Gustafson, C. R. McKee, G.	Agricultural finance review, vol. 67: 295–310	US	Variable rate technology	Multiple (Grain, vegetable, oleaginous)
2005	Adrin, A. M. Norwood, S. H. Mask, P. L.	Computers and Electronics in Agriculture, vol. 48: 256–271	US	Yield monitor Remote sensing Grid soil sampling	Not mentioned
2004	Pedersen, S. M. Fountas, S. Blackmore, B. S. Gylling, M. Pedersen, J. L.	Acta Agriculturae Scandinavica Section B: Soil and Plant Science, vol. 54: 2–8	Denmark	Yield mapping Variable rate technology	Multiple (Grain and oleaginous)
2003	Daberkow, S. G. McBride, W. D.	Precision Agriculture, vol. 4: 163–177	US	Not mentioned	Grain and oilseed
2003	Batte, M. T. Arnholt, M. W.	Computers and Electronics in Agriculture, vol. 38: 125–139	US	Yield monitor Variable rate technology Grid soil sampling	Grain

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