ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES BY FARMERS: A SYSTEMATIC LITERATURE REVIEW AND PROPOSITION OF AN INTEGRATED CONCEPTUAL FRAMEWORK

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Abstract

The adoption of innovations and Precision Agriculture Technologies (PAT) is fundamental for establishing the patterns of agricultural production. However, the dynamics of adoption of PAT by farmers differs by regions. Although there is large number of related researches, there are considerable gaps in the literature: studies on adoption of PAT can be systematically reviewed and integrated in a conceptual model of technology adoption by rural producers, which still lacking in the literature. Thus, the main objective of this paper is to perform a systematic literature review of studies on determinants of adoption of PAT and to build a conceptual framework that consolidates the determinants of adoption of PAT by farmers. We used the method of Knowler and Bradshaw (2007) to analyze 36 empirical studies. The results show that the adoption drivers of major influence are related to socio-economic, agro-ecological, institutional, technological and behavioral factors, in addition to the sources of information and perception of the farmer. We consolidated these drivers in an integrated conceptual model of adoption of PAT by farmers. This model might be tested by future researches, as well as research propositions that we suggest in this work.

Keywords: Adoption of Precision Agriculture Technologies by Farmers; Technology Adoption by Farmers.

1. INTRODUCTION

The use of Precision Agriculture Technologies (PAT) and the adoption of innovations in agriculture are crucial for establishing the production patterns and to mitigate specific risks associated to agriculture. In this sense, the adoption of PAT's affect agronomic, economic and financial results of farm businesses.

In Brazil, although there has been diffusion of technological packages since the 1960's, they did not spread uniformly. Furthermore, the expected performance of the technology (to increase productivity, to reduce labor costs etc.) does not always meet the main needs of farmers, since the adoption of certain technologies often pose risks above the desirable level by the producer, influencing the determinants of adoption of these technologies (Souza Filho et al. 2011).

The modernization of Brazilian agriculture has made even more acute its heterogeneity, considering the use of technology and current work relations, concentrating on the South, Southeast and Midwest regions (Delgado, 2005).

Still, the production and the diffusion of innovations in the Brazilian agriculture have completely changed its dynamics, compared to past decades. Currently, the challenge is considerable, as it highlights several differences between social and economic, rural and non-rural interests. With respect to climate and its changes, the issue is even more extensive, with impacts beyond national borders (Silveira, 2014).

These aspects suggest that the level and the dynamics of adoption of Precision Agriculture Technologies by Brazilian farmers differ among country regions. In addition, some questions arise: Why would a producer adopt certain technology and others do not? How is the process of technology adoption considering different crops and regions? What influences the adoption of certain technology or productive practice?

Sunding and Zilberman (2011) affirm that there is a significant gap between the launch of a technology to the market to its wide use by farmers, therefore its adoption is not immediate. Thus, the use of innovations follows the logic and dynamics of technology adoption and diffusion. Several studies on technology adoption behaviour focus on the determinants that affect the decision of an individual to use or not certain innovations, and when this decision is made. The adoption metrics can indicate both time and intensity of use of new technologies by individuals and can be represented by more than one variable: the adoption can be a discrete choice or a continuous variable. On the other hand, diffusion can be interpreted as aggregated adoption. Studies related to the diffusion describe how innovation enters in a potential market. As well as adoption, there are several indicators of diffusion of a specific technology. For example, a measure of diffusion can be the percentage of the population of farmers adopting certain innovation. Another metric could be the percentage of the total area in which innovations are used.

In this context, farmers seek innovations, such as the Precision Agriculture (PAT) to associate with other technologies to obtain a set of benefits such as: a) cost reduction by decreasing the use of

inputs; b) reduce water pollution c) increase agricultural productivity through more efficient use of inputs (COSTA; GUILHOTO, 2011).

Precision Agriculture (PA) is a broad, systemic and multidisciplinary topic. It composes an integrated handling system of information and technology, based on the concepts that variabilities of space and time influence on crop yields. Precision Agriculture Technologies aim the whole system and the detailed management of the agricultural production, not only of inputs from mapping applications, but of all the processes involved in the production. However, the adoption of PAT in Brazil is happening at a slower rate than initially expected (BERNARDI; FRAGALLE; INAMASU, 2011).

Additionally, PAT are built based on the formal and informal information of the farming systems, where farmers try to balance the costs of data collection, its analysis and implementation of techniques in specific areas. Space management is not a new idea. Farmers around the world try to combine the best practices of growing according to the soil type, microclimate and relief characteristics, but mechanization pushed producers to cultivate larger areas with standard techniques. PAT reduce the cost of data collection, analysis and management, providing detailed economic viability in cultivating larger areas. However, while there are a large number of researches related to agronomic and economic practices of PAT, related researches about the adoption of PAT does not follow the same rhythm (Lowenberg-DeBoer, 1996).

The adoption of PAT technologies is studied in ex-ante and ex-post approaches. Ex-post studies demonstrate the reasons and conditions that influenced and still influence the decisions about adoption of PAT technologies. Now, ex-ante studies allow analyzing the acceptance of a new technology prior to its market introduction.

Souza Filho et al. (2011) conducted a discussion on the determinants of technology adoption in agriculture, focusing on ex-post studies. The authors state that four sets of factors may influence the decision to adopt technological innovations in agriculture: 1) socioeconomic conditions and characteristics of the producer; 2) characteristics of production and land ownership; 3) characteristics of the technology; and 4) systemic factors. Finally, Souza Filho et al. (2011, p. 250) argue that 'the process of adoption and diffusion of technology is complex and social inherently, influenced by other producers, change agents, organizational pressure and social norms.

The vision and the classification of determinants of technology adoption mentioned by Souza Filho et al. (2011) is similar to those presented in the work of Tey and Brindal (2012) and Pierpaolia et al. (2013), although Souza Filho et al (2011) did not focus specifically on the adoption of PAT and these authors have used different method.

Tey and Brindal (2012) performed a systematic review of literature related to the determinants of adoption of PAT, compiling the results of ex-post researches. The authors found that 34 factors grouped under conditions related to 1) socioeconomic factors, 2) agroecological factors, 3) institutional factors, 4) information sources, 5) perceived by the farmer, 6) behavioral factors and 7) technological factors. It is noteworthy that the categorizations of conditions about PAT adoption can be rearranged. A priori, the categorization of Tey and Brindal (2012) will be used, in order to establish a concise overview of these variables.

Pierpaolia et al. (2013) continued the work of Brindal and Tey (2012) and complemented the analysis with more recent ex-post works, including the vision of ex-ante studies. They affirm that the determinants of adoption of PAT studies of ex-ante and ex-post technologies can be grouped into similar categories. The analyzes made by Souza Filho et al. (2011), Tey and Brindal (2012) and Pierpaolia et al. (2013) are useful to understand to adoption of PAT technologies by farmers because they consolidate the main determinants of adoption of technological innovations and PAT and go beyond their findings to explain why farmers adopt or not these technologies.

However, the studies reviewed by Tey and Brindal (2012) and Pierpaolia et al. (2013) did not include studies in Brazil. Also, we did not find literature reviews related to the topic of adoption of PAT technologies in Brazil. Although of the analysis and review of Brazilian studies on the work of Souza Filho et al. (2011), this study does not focus exclusively on identifying determinants about adopting PAT technologies by Brazilian farmers. We may suggest that there is a gap in the literature and an opportunity for systematically review the literature addressing Brazilian and international studies, in order to integrate results found in these studies.

In Brazilian research scenario, the studies related to the adoption of innovations and PAT in Brazil's agricultural activity analyze different crops and regions, such as the studies of Buainain, Souza Filho and Silveira (2002), Silva and Teixeira (2002), Franscisco and Pino (2002), Vicente (2002), Silva and Carvalho (2002), Perz (2003), Segovia (2004), Oliveira, Khan and Lima (2005), Monte and Teixeira (2006) , Melo (2008), Araújo et al (2010), Machado and Nantes (2011), Lanna et al. (2011) and Anselmi (2012). These studies studied the theme by different prisms but generally they identify the role of various technologies and innovations in the value generation process in rural business and its long-term sustainability. However, we identified some theory gaps about adoption of Precision Agriculture Technologies by Brazilian farmers.

- A literature review on the subject can be better organized and systematized, because it has not been crafted in a structured way yet.

- We did not find a broad conceptual model of technology adoption by farmers. Although there are several studies, these studies are not consolidated.

2. RESEARCH QUESTIONS

- What is the influence of socioeconomic factors, agroecological factors, institutional factors, information sources, farmer perception, behavioral and technological factors in the adoption of PAT by farmers?

- Based on systematic literature review and the results of this study, is it possible to build a conceptual model that reflects and consolidates the determinants of PAT adoption by farmers?

3. OBJECTIVES

The main objective of this study is to perform a systematic literature review about the determinants of adoption of Precision Agriculture Technologies found in Brazil and other countries.

The specific objectives are characterize the main technologies used by farmers and factors of major influence in the adoption of PAT; Analyze the influence of socioeconomic, agroecological and behavioral factors, sources of information, farmer perception and technological factors in the adoption of PAT; Another objective is also to propose a conceptual model that consolidates the determinants of Precision Agriculutre Technologies adoption.

4. METHODOLOGICAL ASPECTS

There are several operational methods and technologies used in agriculture. Such actions result in a multifaceted decision-making behavior of rural producers, as individuals who take decisions concerning the sustainability of rural businesses. Additionally, the scientific research concerning the theme is extensive and diverse, addressing issues related to fertilizers, pesticides, conservation practices and sustainability, agroforestry innovations, agricultural machinery, new seeds, among other technologies. However, these studies did not provide a clear and unified method for performing such reviews. Then, this task is challenging, especially with regard to the presentation and discussion of the results in a structured and replicable format (TEY; BRINDAL, 2012).

We found many review studies, e.g Pattanayak et al. (2003), Mercer (2004), Knowler and Bradshaw (2007) and Fleming and Vanclay (2010). This paper use the method designed by Knowler and Bradshaw (2007), which perform a revision in a structured form, providing the research stages step by step. Although the method does not involve statistical procedures, such as in a meta-analysis, the outputs of the method mentioned are sufficient for fulfilling the objectives of this paper.

The method of Knowler and Bradshaw (2007) is described by five key components that have captured the most relevant aspects of the studies reviewed: author(s), country, adoption of a specific technology type, method of analysis and significance of the model. Furthermore, Tey and Brindal (2012) complement the method adding two variables: sample size and number of variables used. This adaptation came up considering that different methods of analysis have different requirements to reach statistical significance.

Furthermore, this paper contributes to the method due to the insertion of another variable analysis: crop produced by studied farmers. The analysis of this variable is necessary, once according Daberkow and McBride (2003), crop type may influence the level of adoption of technology by producers. Therefore, eight variables are systematically analyzed in this work: 1- author (s), 2- country, 3- type of cultivation; 4- adoption of a specific type of technology, 5- method analysis, 6- significance of the model, 7- sample size and 8- number of variables used.

According to Tey and Brindal (2012) information on the significant and non-significant variables tested must be taken collectively in detail. Independently of its signals, they are the central concern of the work and will be used in the discussion of results. However, this paper addressing do not exclude the possibility of analyzing the factors influencing adoption of Precision Agriculture Technologies found in qualitative studies, since they are relevant in the construction of a set of determinants.

4.1. DATA

This section summarizes what has been done to identify previous studies. The process required extensive tools for search to identify a set of relevant studies. Were used the following databases:

Scopus, Science Direct Journals, Portal Capes and the University of Sâo Paulo's Library of Thesis and Dissertations

We did a simple search for two combinations of terms like "use / adoption / application" and "agriculture technology / precision agriculture". These combinations were also made in Portuguese.

Science Direct database (2014) provided more than 20,000 results for these search terms. In Scopus (2014) the search resulted over 1,200 results. In "Portal de Períodicos da Capes" (2014) the simple search returned 150 results. The same search in the USP's Digital Library of Theses and Dissertations (2014) returned nearly 10,000 results.

The works were filtered selecting only empirical studies, published in magazines and journals, thesis and dissertations studies, excluding works focused only on politics, energy, environmental issues and economic and agronomic experiments about PAT. Therefore, selected studies were related to the central theme of the review, the use of PAT. On the reading phase, a snowball approach adopted allowed the search of other relevant documents as performed by Pierpaolia et al. (2013).

Thus, 36 empirical studies analyzed at the cutting edge. These studies are presented in Table 1 and ordered according to the country where the study took place, author and publication year, approach used, growing analysis, studied PAT, method of analyzing the results, significance of the model, size of sample and number of variables.

5. SYSTEMATIC LITERATURE REVIEW

Table 1 – Studies analyzed by authors

Country	Authors and Publicatioin Year	Approach	Crops	Studied Technology	Analysis Method	Sig.	Sample	Variables
Germany	Reichardt e Jurgens (2009)	Ex-Post	N/A	Various practices and PAT	Cross Tab	sig.	6.183	5
Australia	Robertson et al. (2012)	Ex-Post	Grains	Floating Rate, Maps and Productivity	Logit	sig.	1.170	8
Brazil	Anselmi (2012)	Ex-Post	Grains	Various practices and PAT	Factor Analysis	sig.	75	5
Brazil	Lanna et al. (2011)	Ex-Post	Coffee	Pulping Technology	Logit	sig.	59	7
Brazil	Machado e Nantes (2011)	Ex-Post	Livestock	Internet	Case Study	N/C	10	N/A
Brazil	Araújo et al (2010)	Ex-Post	Papaya	Various practices and PAT	Multiple Regression	sig.	113	5
Brazil	Melo (2008)	Ex-Post	Garlic	Virus Free Garlic Seeds	Descriptive Statistics	N/C	33	N/A
Brazil	Monte e Teixeira (2006)	Ex-Post	Coffee	Pulping Technology	Logit	sig.	56	7
Brazil	Oliveira, Khan e Lima (2005)	Ex-Post	Banana	Various practices and PAT	Probit	sig.	N/C	9
Brazil	Segovia (2004)	Ex-Post	Sugar Cane	Agroforestry Systems	Descriptive Statistics	N/C	25	35
Brazil	Perz (2003)	Ex-Post	Several	Various practices and PAT	Logit	sig.	261	6
Brazil	Silva e Carvalho (2002)	Ex-Post	N/A	Various practices and PAT	Counting	N/C	120	5
Brazil	Vicente (2002)	Ex-Post	Several	Herbicides and Fertilizers	Probit	sig.	~7000	4
Brazil	Franscisco e Pino (2002)	Ex-Post	Several	I.T	Logit	sig.	3.204	28
Congo	Lambrecht et al. (2014)	Ex-Post	Several	Mineral Fertilizer	Probit	sig.	412	20
Ethiopia	Abebe et al (2013)	Ex-Post	Potato	Improved Varieties Of Potato	Probit	sig.	334	25
USA	D'Antoni et al. (2012)	Ex-Post	Cotton	Auto-Steering Technology	Logit	sig.	1.692	13
USA	Walton et al. (2008)	Ex-Post	Cotton	Sampling of Soils	Probit	sig.	827	12
USA	Larson et al. (2008)	Ex-Post	Cotton	Remote Sensing	Logit	sig.	1.125	11
USA	Isgin et al. (2008)	Ex-Post	N/A	Various practices and PAT	Logit	sig.	491	10
USA	Torbett et al. (2007)	Ex-Post	Grains	Improved Efficiency of Mineral	Logit	sig.	1.131	22
USA	Roberts et al. (2004)	Ex-Post	Cotton	Various practices and PAT	Probit	sig.	1.131	10
USA	Daberkow e McBride (2003)	Ex-Post	Several	Various practices and PAT	Logit	sig.	8.429	11
USA	Fernandez-Cornejo et al (2002)	Ex-Post	Several	Various practices and PAT	Tobit	sig.	4.040	7
USA	Roberts et al. (2002)	Ex-Post	Cotton	Various practices and PAT	Logit	sig.	284	10
USA	Khanna (2001)	Ex-Post	Grains	Soil Sampling and Variable Rate	Logit	sig.	650	10
USA	Daberkow e McBride (1998)	Ex-Post	Grains	Various practices and PAT	Logit	sig.	950	11
Philippines	Mariano et al. (2012)	Ex-Post	Rice	Technologies and Best Practices	Logit	sig.	3.164	6
Canada	Aubert, Schoroeder e Grimaudo (2012)	Ex-Ante	Grains	Various practices and PAT	Minimum Square Regression	sig.	438	15
USA	Marra et al (2010)	Ex-Ante	Cotton	Yield Monitor	Probit/Logit	sig.	743	7
USA	Adrian et al. (2005)	Ex-Ante	N/A	Various practices and PAT	Technology Acception Model TAM)	sig.	85	7
USA	Hudson e Hite (2003)	Ex-Ante	N/A	Variable Rate Application	Factor Analysis	sig.	423	14
USA	Hite et al. (2002)	Ex-Ante	Grains	Various practices and PAT	Probit	sig.	762	15
Iran	Rezaei-Moghaddam e Salehi (2010)	Ex-Ante	N/A	Various practices and PAT	Technology Acception Model(TAM)	sig.	249	7
Nigeria	Folorunso e Ogunseye (2008)	Ex-Ante	Several	Extension Services	Technology Acception Model (TAM)	sig.	370	7
India	Krishna e Qaim (2006)	Ex-Ante	Eggplant	Hybrid Seed	Contigency Analysis	sig.	360	19

6. RESULTS

The literature review shows that published research focus different countries, crops, types of PAT and methods of analysis. There is a predominance of ex-post approach in these studies and Logit and Probit methods. In addition, the dependent variable is Precision Agriculture Adoption or set of technologies. The determinants of innovations adoption and consolidated PAT studies are present in Table 1.

Table 1 – Determinants of PAT adoption – Adapted de Souza Filho et al. (2011), Tey e Brindal (2012) e Pierpaolia et al. (2013), based on Table 1.

Categories	Variables
Socioeconomic Factors	Age, Education, Family Size, Activity Experience, Ability to obtain and process information, network, credit, risk aversion, producer organization level, farm management
Agro-Ecological factors	Land domination, farm specialization, total area, revenue, variable rate fertilizer application, livestock sales, asset / liability ratio, value of production, yield, corporate structure, income, and farm profitability, quality of soil,% of primary crop of the total area, % of the total area harvested area, % of the farm area divided y municipal area, activity / non-agricultural employment and others.
Institutional Factors	Distance from the fertilizer distributors, Region, using of future contracts, development pressure and distance to the main market.
Information Sources	Access to information sources, use of consultants, perceived extension services in the implementation of agricultural practices and other.
Farmer Perception	Perceived profitability with the increased use of technology and importance of PAT (current and future).
Behavioral Factors	Producer behavioral profile; Intention to adopt variable rates technology for input application
Technological Factors	Type of adopted technology, computer use, farm irrigation structure, prescription use of inputs made on the farm.

6.1. SOCIOECONOMIC FACTORS

Socioeconomic factors refer to personal context of the primary decision maker of the farm. Once some technologies demand high level of information and knowledge, the skills and abilities of farmers clearly influence their decision to adopt PAT (DABERKOW; MCBRIDE, 1998).

Socioeconomic factors influencing the adoption of PAT found in analyzed papers are: gender, age, education, family size, residence place, influence in decision making, experience in agriculture, experience with PAT, ability to obtain and process information, networking, membership in associations and cooperatives, financing and credit sources, risk aversion and organization level of producers in the region.

Studies conducted in different countries and cultures are similar, differing only on level of depth and number of variables studied.

6.2. AGROECOLOGICAL FACTOR

The agroecological factors are known as the biophysical factors of the farm. As naming suggests, this factor influences both the exploitation of natural resources and the operational factors to explain the adoption of PAT. Among the natural factors, quality is one of the only influential determinants in the adoption of PAT. However, operational factors which affect the operating model include land ownership and financial situation (TEY; BRINDAL, 2012)

It has noticed that farmers are more likely to manage their own land in a more favorable way than rent lands. With land ownership, they have more chances to enjoy the advantages

that their own farm management provides and increase the PAT adoption. Although this factor was insignificant in some cases, its impact on the adoption has been generally consistent, as in Roberts et al. (2002) and Isgin et al. (2008).

The farm size refers to the total amount of land available to a farmer perform its agricultural production (TEY; BRINDAL, 2012)

Major determinants are: dominion over farm area, farm specialization, total area, revenue, variable rate technologies in application of inputs, livestock sales, assets and liabilities ratio, value of production, productivity, corporate structure, income, farm profitability, soil quality, percentage of main culture over the total area, percentage of harvested area over total area, percentage of the farm area in the municipal area and performing of non-agricultural activities.

6.3. INSTITUTIONAL FACTORS

Institutional factors are indicators that influence the behavioral change of the farmer. The main determinants: distance to fertilizer distributor, region, use futures contracts, development pressure and distance to the main market.

6.4. INFORMATION SOURCES

Information is the key to the diffusion of innovations (Rogers, 2003). Given the difficulty of quantifying information, it can be characterized by access to information from a particular source, or how often it receives the information within a period. The major determinants found were: use of consultants, perceived usefulness in extension services, presence and access to technical companies, agencies and government extension utility. It is assumed that producers that have more access to sources of information about PAT are more likely to adopt new technologies because they increase awareness about the impact of PAT adoption in farm businesses.

6.5. FARMER PERCEPTION AND BEHAVIOR

Farmer's perception refers to a subjective assessment of attributes and personal innovation. Among the perceived attributes suggested by Rogers (2003), perceived relative advantage is used to evaluate the perception of relative benefits of adopting new technologies and the gain that it brings to overcome other technologies. Among other advantages, profitability is a major concern when considering increase in any capital intensity of agricultural technology, including PAT technologies. Realistically and perceptibly, farmers do not want to get losses in their investments. Therefore, the probability of PAT adoption will be higher if the results of this adoption can be seen. These assumptions are supported by the results of the work of Walton (2008) and Anselmi (2012).

The relative perception of the producer on the technological attributes such as relative advantage of certain technology, visibility of results, compatibility with existing technologies in the farm and the opportunity to experiment PAT are also factors that can influence this decision (ANSELMI, 2012).

Collectively, the expression of most likely or willing to adopt PAT indicates that farmers have actual control over his behavior and therefore, they are more likely to notice it. As such, the decisions of adopters emerge from intentionality. This factor has a positive impact on the adoption of PAT, especially when the cost of acquiring them is being subsidized (Khanna, 2001).

The main determinants found were profitability with increased use of technology, perceived importance of PAT (current and future) and disposition of adopt variable rate application of inputs and behavioral profile of producer.

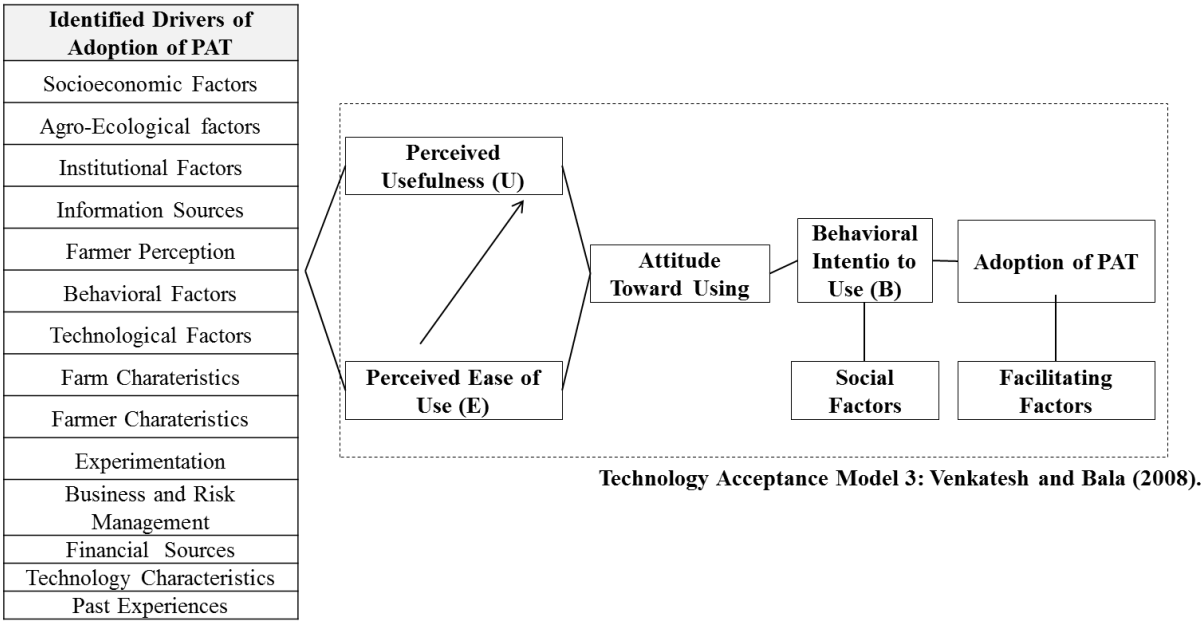
6.6. TECHNOLOGICS FACTORS

Technological factors incorporate a number of indicators in the use of technologies, including irrigation facilities, the PAT and computers. The adoption of I.T as part of the farm management shows that farmers have some knowledge of the technological operation, regardless if the computer is used for registration or other purposes. As such, the computer is an integral part of PAT (Roberts et al., 2004). The main technological factors were type of technology adopted, computer use, farm structure with irrigation and prescription of use of inputs made on the farm. Based on the studies analyzed, it is assumed that producers that have high level of mechanization technology and adoption of various technologies are more likely to adopt PAT.

6.7. PROPOSITION OF AN INTEGRATED FRAMEWORK OF ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES BY FARMERS

Based on the conditions identified in the systematic literature review, we built a conceptual model of adoptions of innovation and PAT by farmers. The model consolidates Socioeconomic Factors, Agro-Ecological, Institutional Factors, Behavioral Factors, Technological Factors, Information Sources and Farmer Perception, integrating various dimensions into Figure 1. We use the Technology Acceptance Model (TAM) of Venkatesh and Bala (2008) to enhance the scope of this framework, covering also the influence of external factors, perceived usefulness and ease of use, facilitating factors, which may affect attitudes toward the adoption of PAT by farmers. We assume that the framework is not static and increments should be made by new researches

Figure 1 - Integrated Model of Adoption of Precision Agriculture Technologies by Farmers. Elaborated by the authors based on existing literature



7. CONCLUSIONS

This paper performed a systematic literature review of studies of the drivers of adoption of Precision Agriculture Technologies (PAT), featuring the main technologies used and the factors of major influence in the adoption of PAT. Furthermore, we analyzed the influence over factors as socioeconomic, agroecological, behavioral, information sources, perception by the farmer and technological in the adoption of PAT. We also proposed a conceptual framework consolidating the determinants of adoption by farmers PAT in one figure.

We found gaps in the literature and the paper in question contributes to the literature identifying opportunities for future studies. There are opportunities in the study of adoption of PAT in grain production in Brazil, as tough sugarcane, for example.

The framework built is purely conceptual and it can be tested through application of field research with farmers. It is not clear in the literature, what are the influence of different types of crops, permanent or temporary, in the Adoption of Precision Agriculture.

For example, what is the difference between the adoption of PAT in cotton, highly intensive crop, and the PAT adoption in coffee production?

Based on the studies analyzed we were able to build up some propositions relating the determinants identified in the studies analyzed with the probability of farmers adopt or not PAT, which may indicate pathways for development of future studies. The assumptions are as below:

- A1) Producers that have larger farms are more likely to adopt PAT, since the adoption can generate economies of scale.

- A2) Producers with higher level of education are more likely to adopt PAT, since they have more knowledge about best production practices.

- A3) The age of the producers can be a limiting factor in the PAT adoption: as older farmers are more resistant there are in adopting new technologies.

- A4) Farmers who have other sources of income besides agriculture are more likely to adopt PAT, because the risk of failure of adoption is less impactful in income than those who rely exclusively on agriculture.

- A5) Producers with greater availability of financing sources for funding the production and financing of machinery are more likely to adopt PAT, since the access to these sources can encourage the purchase of new machinery and modern inputs.

- A6) Farmers who participate in associations and cooperatives have more experience changes with other producers and this aspect influence the adoption of PAT

- A7) Producers who have more access to sources of information about PAT are more likely to adopt new technologies because they get awareness about the impact of adoption on the farm business.

- A8) Producers who have better management of rural business are more likely to adopt PAT because the this vision creates more chances of identifying opportunities for investment in PAT, affecting profitability in the long term.

- A9) Producers who have a positive perception regarding the use of PAT are more likely to adopt these technologies because they are more willing to experiment and innovate.

- A10) The opportunity to experiment the technology on a smaller scale before its adoption in the entire area provides a greater chance of adoption of PAT, because producers can evaluate the results and impacts of the adoption in their business before exposing themselves to the risk of adopting in the full area.

- A11) Negative past experiences and difficulties in adopting certain technology negatively influence the adoption of PAT by the producer, because the negative history of adoption can create barriers in adopting new technologies.

- A12) The type of technology to be adopted influences adoption of new technologies. PAT perceived as simpler are more likely to be adopted than technologies that are more complex.

- A13) The crop type influences the Adoption of Precision Agriculture. Producers of row crops (soybeans, corn, cotton) are more likely to adopt the PAT that crops such as vegetables, fruits and minor crops.

- A14) More sensitive and risky crops require more technology to operationalize the production, which demands greater adoption of precision agriculture by producers.

We expect that this work contributed to the construction of future studies relating the adoption of Precision Agriculture worldwide

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