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Full Length Research Paper

A Bayesian confirmatory factor analysis of precision agricultural challenges

Maryam Omidi Najafabadi*, Seyed Jamal Farajollah Hosseini and Somayeh Bahramnejad

Department of Agricultural Extension and Education, Science and Research Branch, Islamic Azad University, Tehran, Iran.

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Precision agriculture (PA) is designed to provide data to assist farmers when making site-specific management decisions. By making more informed management decisions, farmers can become more efficient, spend less and make more profit. Such benefits may lead to a sustainable agriculture. In implementation of PA, farmers encountered several challenges; therefore it is necessary to identify such challenges. A survey questionnaire was developed and mailed to a group of 40 experts in Qazvin province. The results showed that the challenges can be classified into nine latent variables namely: educational, economic, operator demographic, technical, data quality, high risk, time, institution-education and incompatibility challenges. The results suggested educational and economic challenges as the two most important challenges in the application of PA. Among the variables which build the educational challenges, lack of local experts and lack of a knowledgeable research and extension personnel provides more impact when compared to others, while lack of allocation funds to performance PA and Initial cost provides more impact in the economic challenges, among other variables.

Key words: Bayesian confirmatory factor analysis, challenges, precision agriculture (PA), sustainable agriculture, Iran.

INTRODUCTION

One of the most important purposes of precision agriculture (PA) is using the variable rate technology (VRT) to reduce agricultural inputs, mainly herbicides. Ministry of agriculture in Iran reported that the mean application rate of herbicides for wheat and corn during 2005 were 0.99 and 4.44 kg/ha, respectively. However, these values for Qazvin province were 2.06 and 5.10 kg/ha, respectively (Iranian Ministry of Agriculture, 2006). This report indicates relatively high application rate of herbicides in Qazvin province compared to the rest of the country.

The PA in Iran can help in managing crop production inputs in an environmentally friendly way. By using site-specific knowledge, PA can target rates of fertilizer, seed and chemicals for soil and other conditions. PA substitutes information and knowledge for physical inputs. A literature review indicates that PA can contribute in many ways to long-term sustainability of production agriculture, confirming the intuitive idea that PA should reduce environmental loading by applying fertilizers and pesticides only where they are needed, and when they are needed. Precision agriculture benefits to the environment come from more targeted use of inputs that reduce losses from excess applications and from reduction of losses due to nutrient imbalances, weed escapes, insect damage, etc. Other benefits include a reduction in pesticide resistance development. So, it seems there is need for an agricultural system to achieve optimizing inputs or maximizing crop yield, more income, environmental benefits and proceeds to sustainable development.

The term "precision agriculture" describes the integration of geographic information system (GIS) and global positioning system (GPS) tools to provide an extensive amount of detailed information on crop growth, crop health, crop yield, water absorption, nutrient levels, topography and soil variability. This information provides mechanisms to manage areas within fields differently,

Corresponding author. E-mail: m.omidi@srbiau.ac.ir.

according to the soil and crop characteristics. The specific objectives of PA are to: (1) Increase profitability and production, (2) reduce costs, erosion and environmental impact of chemicals, (3) track and monitor the use of chemicals and (4) manage large farms (Blackmore et al., 2003).

The development and adoption of precision agriculture in Iran is a slow process. The small size of farms and fields in most Iranian agriculture limits economic gains from currently available precision farming technology, while the population density and public concerns for the environment, food safety and animal welfare means that those potential benefits of precision agriculture are being given more attention.

Certainly, before implementing a PA system, one has to identify challenges of such system. This article explores such challenges in Iran.

PRIOR STUDIES

Challenges of PA application

Simply defined, challenge is a difficult task that tests the ability, capacity and skills of a person, organization or community (Wehmeier, 2002). Thus, the study considers the problems of implementing PA as challenges which indicate the attitudes of the authors and not barriers. The authors' point of view emphasize that each problem has two negative and positive dimensions, and one can transform a negative dimension to a positive one by cognition and understanding the nature of the problem.

Many studies identified important challenges when dealing with PA systems. For instance, Kutter et al. (2009) indicated that PA is applied less frequently than expected. This is mostly attributed to the high investment costs for PA equipments as well as the high learning costs associated with the PA complexity. Hudson and Hite (2001) pointed out to uncertainty about profitability and the producers' belief about the costs of the technology, which outweighs the potential benefits. Reichardt and Jurgens (2009) found an important reason for the hesitant use of PA techniques, and it could be that many farmers have problems with data handling and the right interpretation of data. Data collection, such as soil sampling, interpretation of soil analyses and yield maps can be expensive and time consuming. It is very important to know how this information can benefit crop production and the overall decision-making. Some fields require little information to determine the cause of yield variability while other fields require extensive data collection and even then yield variation may still be unpredictable.

Heiniger et al. (2002) implied that there are few researchers and extension personnel who have tested these concepts (for example, DGPS, yield monitors, GIS software and remote sensing) and who have a good handling of the practical field applications.

McBride and Daberkow (2003) opined that PA adopters, when compared with non-adopters, were more likely to be full-time farmers, larger, computer oriented and even own a significant share of the acreage of their farm and cash produce (grains and oilseeds). However, operators who were not aware of PA were generally older, less educated, less likely to be full- time farmers, less familiar with computer, more likely to own most of the acreage of their farm and less likely to use risk management tools than operators who were aware of the PA's system.

The challenges of PA identified in this study, would be brought to the knowledge of the agricultural planners, practitioners, policyholders and extension technology specialists in order to achieve a realistic PA program.

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VARIABLES AND RESEARCH MODEL

Based on previous studies, a questionnaire was developed to study the challenges of PA application. The first section of the questionnaire consisted of some items used to gather data about demographic characteristics, such as age, gender, level of education, etc. The second section included 64 items used to assess challenges. One can categorize the literature results into 8 challenges: time, economic, high risk, incompatibility, data quality, educational, technical and operator demographics challenges.

Time challenges

Time challenges comprise time which is utilize to learn the use of PA's equipments (Wiebold et al., 1998), time which is use to introduce PA's technologies and problems occurring at the beginning (Reichardt and Jurgens, 2009), time which takes to experience any investment return, time which is use to calibrate and setup the PA's equipments and time which in itself is already at a deficit, for example, at harvest or planting times (Wiebold et al., 1998).

Economic challenges

Economic challenges comprise expensive equipments (Reichardt et al., 2009), initial cost (Lavergne, 2004), rental cost of PA tools and consultant fees (Lambert and Lowenberg-DeBoer, 2000), obsolescence potential of hardware and software (kitchen et al., 2002; Adrian, 2006), training and learning costs of using PA equipments (Kutter et al., 2009), higher interest rates (Lowenberg-DeBoer, 1998) and lack of allocation funds to performance PA (Dabarkow et al., 2000).

High risk challenges

High risk challenges comprise unreliable computers and equipments (Reichardt and Jurgens, 2009), uncertainty of the PA's return investment (Adrian, 2006), skepticism about data accuracy (Lavergne, 2004) and skepticism about honesty of the PA tool's function (kitchen et al., 2002).

Incompatibility challenges

Incompatibility challenges comprise incompatibility of software packages (Wiebold et al., 1998), incompatibility between machinery from different manufacturers (Kutter et al., 2009), incompatibility of equipment with older equipments (Lavergne, 2004), lack of integration of PA technologies with current equipments and farming practices (Hudson and Hite, 2001), incompatibility between hardware and software (Fountas et al., 2005).

Data quality challenges

Data quality challenges comprise difficulty in maintaining quality data, difficulty in storing and retrieving data with different formats, difficulty in analyzing data to understand yield limiting factors (Kitchen et al., 2002), difficulty of data transfer to external sources for analysis (Fountas et al., 2005), difficulty of data interpretation (Reichardt and Jurgens, 2009), lack of appropriate measurement and analysis techniques for agronomical important factors (NRC, 1997) , difficulties in managing such a large amount of data and using them efficiently (Reichardt and Jurgens, 2009), problems related to data ownership and data handling (Reichardt and Jurgens, 2009).

Educational challenges

Educational challenges comprise lack of effective advisory services (Reichardt and Jurgens, 2009), low acceptance of PA technologies among the advisors (Reichardt and Jurgens, 2009), lack of local experts (Wiebold et al., 1998), lack of research and extension personnel who have a good handling of the practical field applications (Heiniger et al., 2002), lack of PA awareness of farmers and experts (Reichardt and Jurgens, 2009), ineffective PA education (Kitchen et al., 2002), lack of integrating agronomical knowledge and ecology with PA (Fami et al., 2005), needed skills in the application of PA software and hardware (Adrian, 2006), lack of qualified and experienced operators (Reichardt et al., 2009), lack of technical knowledge and software skills (Fountas et al., n.d.), lack of considering PA topics in universities, lack of considering PA topics in technical and vocational schools, lack of considering PA at education institutions, lack of training courses especially for teachers (Reichardt et al., 2009; Reichardt and Jurgens, 2009), lack of adequate training resources (Wiebold et al., 1998), lack of basic knowledge about PA (Reichardt and Jurgens, 2009) and lack of knowledge about data utilization (Fountas et al., 2005).

Operator demographics challenges

Operator demographics challenges comprise older farmers (Torbet et al., 2007; Larson et al., 2008), farmer's low educational level (Khanna et al., 1999; Robert, 2002), lack of computer knowledge (McBride and Daberkow, 2003), low farming experience (Dizaji and Nikbakht, 2009), type of production (Fountas et al., 2005), negative attitude towards new technologies (Reichardt and Jurgens, 2009), producer resistance to change (Lavergne, 2004), risk averse (Torbet et al., 2007), subsistence farmers with low income (Cook et al., 2003), part-time and multiple job farmers (Hudson and Hite, 2001).

Technical challenges

Technical challenges comprise complexity of PA technologies (Bongiovanni and Lowenberg-Deboer, 2004), difficulty of quantifying PA profitability because of its complexity with other benefits such as environmental benefits and food safety (Reichardt and Jurgens, 2009), missing computer equipments (Reichardt and Jurgens, 2009), unchangeable machines (Reichardt and Jurgens, 2009), lack of PA research (Mcbratney et al., 2005), low mechanization level on the farms (Cook et al., 2003) and small farms (Zarei, 2007).

RESEARCH DESIGN

The questionnaire items were developed based on the previous literature. The questionnaire was revised with the help of experts who had significant experience in PA to examine the validity of the research model. A 5–point likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) was used for the measurement. A pretest for the reliability of the instrument was conducted with 15 experts randomly chosen from the target population. The computed Cronbach's alpha is 80.3%, which indicated the high reliability of the questionnaire.

The province of Qazvin is one of the 30 provinces of Iran. It is situated in the north-west of the country, and its center is the city of Qazvin. About 13,000 km² are under cultivation in the province, covering 12% of the cultivable lands of the country (Iran). The agricultural produce of the land is grape, hazelnut, pistachio, almond, walnut, olive, apple, wheat, barely, sugar beet, pomegranate and cereals. The research population included all the experts in Qazvin province (N = 40). They include some experts who work in either an agricultural research center or an agricultural educational center. Moreover, they are familiar with the PA's concepts and equipments, such as GPS and GIS, and as such, they can answer the questionnaire more properly. However, the small population (N = 400) encouraged the authors to conduct a census study. The initial and follow-up mailing generated 40 useable responses from experts resulting in a response rate of 100%.

This research used an open source statistical package, known as Win BUGS 14. Win BUGS is a statistical software for Bayesian analysis and it uses Markov chain Monte Carlo methods. It is based on the BUGS project that began in 1989 and it is run under Microsoft Windows. It was developed by the BUGS project, a team of UK researchers at the MRC Biostatistics Unit, Cambridge, and the Imperial College School of Medicine, London.

Bayesian confirmatory factor analysis

The usual confirmatory factor analysis (CFA) employs the maximum likelihood (ML) method to estimate unknown parameters. It is well known that the statistical properties of the ML approach are asymptotic (Lehmann and Casella, 1998). Therefore, many properties of the ML estimators have been oscillated for a small sample size. In the context of some basic CFAs, many studies have been devoted to study the behaviors of the ML asymptotic properties with small sample sizes (Lee, 2007) for an excellent review. It was concluded by such researches that the properties of the statistics are not robust for small sample sizes, even for the multivariate normal distribution. The Bayesian approach to the CFA has the ability to:

1. Work properly for the small sample size. Still, the small sample size, the posterior distributions of parameters and the latent variables can be estimated by using a sufficiently large number of observations that are simulated from the posterior distribution of the unknown parameters through efficient tools in statistical computing such as the various Markov chain Monte Carlo (MCMC) methods (Lee, 2007).
2. To utilize the useful and prior information about the problem (which is translated to a prior distribution) to achieve better results. For situations without accurate prior information, some type of non-informative prior distributions can be used. In these cases, the accuracy of the Bayesian estimates is close to that obtained from the classical CFA (Robert, 2001).

Figure 1. Qazvin province.

3. Treat the discrete variables (such as the Likert and rating scales) as the hidden continuous normal distribution with a specified threshold (or cut point). Clearly, such approach provide a powerful tool to analyze the discrete variables rather than using special, but less powerful, statistical technique to do so (Lee, 2009).

To illustrate the Bayesian CFA of the supposed three observed variables (X_1, X_2 , and X_3), the study will be summarized into a factor F_1 (Figure 1). In Bayesian CFA, one of the factor loadings is fixed to be 1 and others are estimated using sufficiently large iterations of a MCMC code.

Now using the MCMC code, one can estimate mean, variance and $100(1-\alpha)\%$ credible interval for mean of each factor loadings.

All ordinal and observed variables in this research are considered as normally distributed latent variables. Using such an approach for the ordinal and observed variables along with the Invert Gamma and Invert Wishart prior information, which were commonly used with normal distribution (whenever prior information is not available), one can employ the Win BUGS software to test the theoretical framework given by the variables and research model.

The analysis described in the study's results was run in WinBUGS for a total of 100,000 iterations, which was mostly burn in about 10,000 iterations. All model validation criteria, such as MC-error (which should be considerably lower than the variance for each estimated parameters), autocorrelation functions (which should be approached to zero exponentially for each estimated parameters) and kernel density (all estimated parameters have to be normally distributed) have been met by the final models. When considering briefness, such validity criteria should be removed from the article.

RESULTS

Descriptive statistics

Table 1 summarizes the demographic profile and descriptive statistics of experts.

Bayesian confirmatory factor analysis

Since the sample size of the study is relatively small (the study will need about 200 observation for the usual CFA when n = 40) and all variables follow the Likert scale, therefore, the Bayesian CFA is an appropriate statistical technique used to analyze the data.

The final conceptual framework of challenges arrived after: (i) removing "higher interest rates", and "lack of compatibility between hardware and software", respectively, from the economic and incompatibility challenges; (ii) adding a new factor, named "education-institution", which obtained four variables namely: "lack of considering PA topics in universities", "lack of considering PA topics in technical and vocational schools", "lack of considering PA at education institutions" and "lack of effective advisory service" from educational challenges.
However, Figure 3 represents the conceptual framework of challenges.

Variables C_1 , , C_{62} in Figure 3, respectively, represent: the time consumed to learn how to use the equipment and derive the greatest benefit from it for producers (C1), the time consumed to introduce the PF technologies and problems occurring at the beginning (C2), the length of time it takes to experience any return on the producer's investment (C3), the length of time it takes to calibrate and set up equipment (C4), the time consumed when time is already at a deficit [for example, at harvest or planting times (C5)], equipment cost (C6), initial cost (C7), rental cost of PA tools (C8) and consultant fees (C9), obsolescence potential of hardware and software (C10), training and learning costs of using equipments and the PA's system (C11), lack of allocation funds to performance PA (C12), unreliable computer and equipment (C13), uncertainty of return investment on PA (C14), skepticism about accuracy of data (C15), skepticism about honesty of the PA tool's function (C16), lack of compatibility of software packages (C17), lack of compatibility between machinery from different manufacturers (C18), incompatibility of equipment with older equipment (C19), lack of integration of SSM technologies with current equipment and farming practices (C20), difficulty in maintaining quality data (C21), difficulty in storing and retrieving data with different formats (C22), difficulty of the yield data analysis methods to help understand yield limiting factors (C23), difficulty of data transfer to external sources for analysis (C24), difficulty of data interpretation (C25), lack of appropriate measurement and analysis techniques for agronomical important factors (C26), difficulties in managing such a large amount of data and in using them efficiently (C27), problems related to data ownership and data handling (C28), lack of effective advisory service (C29), lack of considering PA topics in universities (C30), lack of considering PA topics in technical and vocational schools (C31), lack of considering PA at education institutions (C32), low acceptance of PF technologies among the advisors (C33), lack of local experts (C34), lack of research and extension personnel who have tested PA concepts and have a good handling of the practical field applications (C35), lack of awareness of farmers and experts about PA technologies (C36), insufficient or ineffective education about PA (C37), lack of integrating agronomical knowledge and ecology with

Table 1. Demographic profile and descriptive statistics of experts.

Work experience	Mean = 12.6	S.D=4.2
Gender	Female = 2 (5%)	Male = 38 (95%)
Age/year	Mean = 36.5	S.D=4.2
Major	Agricultural mechanics (43%) and agronomy (27%)	Other majors (30%)
Level of education	Master (45%) and Bachelor (40%)	Ph. D (15%)

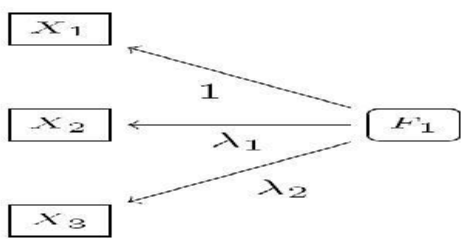

Figure 2. An example of CFA.

PA (C38), needed skills used in the application of PA software and hardware (C39), lack of expertise and qualified and experienced operators (C40), lack of technical knowledge and software skill (C41), lack of training courses especially for teachers (C42), lack of adequate training resources (C43), lack of basic knowledge about PA (C44), lack of knowledge about the utilization of data (C45), older farmers (C46), farmer's low educational level (C47), lack of computer knowledge for the farmers (C48), low farming experience (C49), type of production including grain crops, root crops, fruits and livestock (C50), negative attitude toward new technologies (C51), producer resistance to change (C52), risk averse (C53), existing subsistence farmers with low income (C54), existence of part-time (off-farm) farmers and occupation of farmers in more than one occupation (C55), complexity of precision agriculture technologies (C56), difficulty of quantifying PA profitability due to its complexity with other benefits such as environmental benefits and food safety (C57), missing computer equipment (C58), the machines are unchangeable (C59), lack of research about PA (C60), low mechanization level on the farms (C61) and the small farm size (C62).

From the factor loadings of the aforementioned conceptual framework, one may observe that: (1) lack of local experts and lack of research and extension personnel who have tested PA concepts and who have a good handling of the practical field applications provide more impact on the educational challenges, (2) lack of allocating funds to performance PA and initial cost provide more impact on the economic challenges, (3) producer resistance to change and Risk averse provide more impact on the operator demographic challenges, (4) Difficulty of the yield data analysis methods to help understand yield limiting factors and difficulty of data interpretation provide more impact on the data quality challenges and (5) Low mechanization level on the farms and small farm size provide more impact on the technical challenges.

Table 2 represents the common variance which is explained by each P.A. challenges.

From Table 2, one can order the challenges based on their impact on the system as: educational, economic, operator demographic, data quality, technical, high risk, incompatibility, time and institution-education challenges. These factors, in total, explain 81.5% of the total variance.

DISCUSSION AND CONCLUSION

The Bayesian CFA suggested 'educational challenges' (to include low acceptance of PF technologies among the advisors, lack of local experts, lack of research and extension personnel who have tested PA concepts and have a good handling of the practical field applications, lack of awareness of farmers and experts about PA technologies, insufficient or ineffective education about PA, lack of integrating agronomical knowledge and ecology with PA, needed skills in the application of PA software and hardware, lack of expertise and qualified and experienced operators, lack of technical knowledge and software skill, lack of training courses especially for teachers, lack of adequate training resources, lack of basic knowledge about PA and lack of knowledge about the utilization of data) and 'economic challenges' (to include: equipment costs which are expensive, initial cost, rental cost of PA tools and consultant fees, obsolescence potential of hardware and software, training and learning costs of using equipments and PA system and lack of allocating funds to performance PA) as the two most important challenges of application of the precision agriculture. Among variables which build the 'educational challenges', lack of local experts and lack of research and extension personnel who have tested PA concepts and have a good handling of the practical field applications provides more impact when compared to others, while lack of allocating funds to performance PA and initial cost provide more impact in the economic challenges, among other variables.

The observation about the 'educational challenges' can be interpreted by the facts that most of the advisors did not recognize the advantages of PA technology because most of them have only little knowledge about it. Special

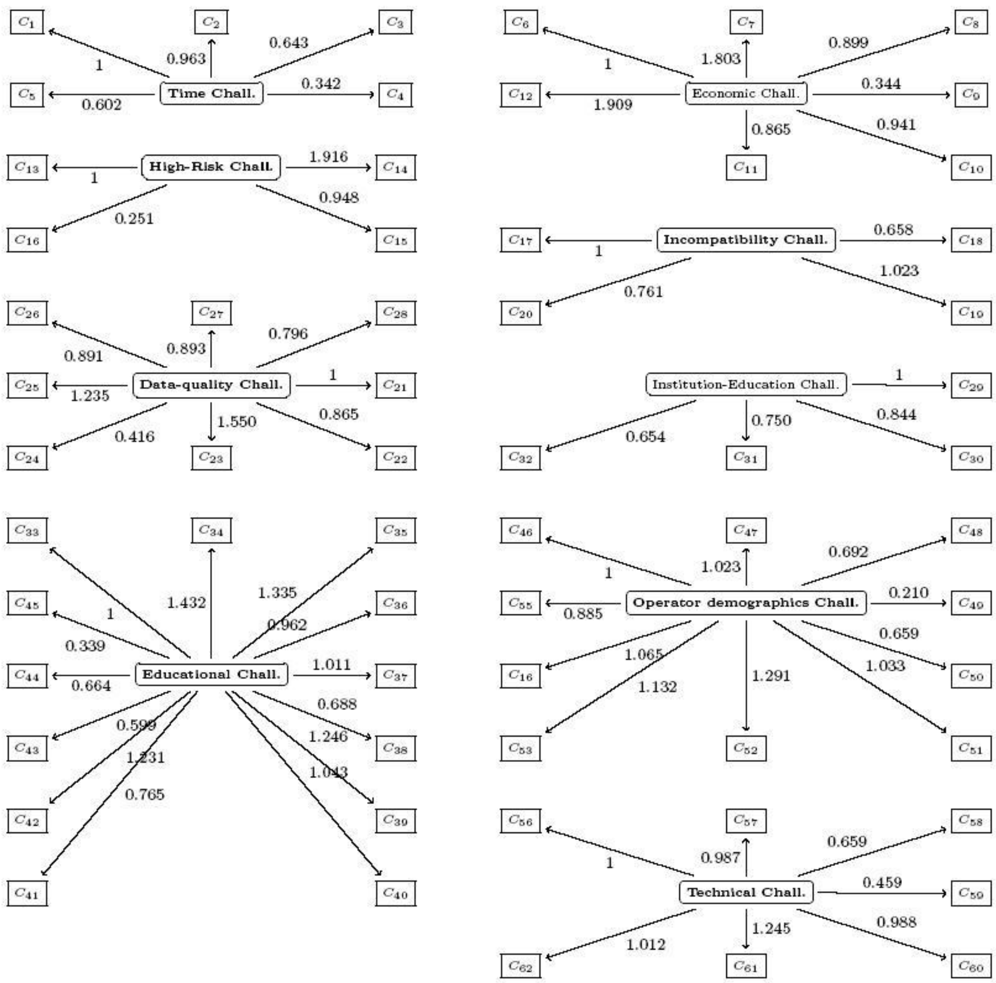

Figure 3. Conceptual framework of the challenges of precision agriculture.

Table 2. The common variance explained by each challenge factors.

Factor	Explained common variance by factor (%)
Educational challenges	17.3
Economic challenges	14.02
Data quality challenges	10.88
Operator demographic challenges	11.98
Technical challenges	8.27
High risk challenges	7.55
Time challenges	3.78
Institution- education challenges	3.62
Incompatibility challenges	4.10
Total	81.5

training courses for such local advisors in the PA field could improve this situation (Reichardt and Jurgens, 2009). The preferred model for developed countries would be consultants that are highly trained in PA who can interpret PA data, make agronomic recommendations and design and analyze on-going experiments in conjunction with soil and weather monitoring networks to optimize production (Mcbratney et al., 2005). To achieve a comprehensive use of PA technologies, it is necessary to offer an advisory service, which provides technical support and agronomic knowledge (Reichardt et al., 2009). Awareness is the first critical stage in diffusing an agricultural technology (Daberkow and McBride, 2003). Existence of PA information sources and their quality directly affect the adoption of a PA system (Daberkow and McBride, 2003). Awareness of PA technologies can be raised through schools, community groups, field days, local media, outlets (Mcbratney et al., 2005), trade publications and extension services (Hudson and Hite, 2001). However, instructors and advisors play a critical role in such raising processes.

The finding about 'educational challenges' was verified by several authors, such as, Reichardt and Jurgens (2009), Robert (2002) and Wiebold et al. (1998) among others.

The observation about 'economical challenges' can be interpreted by the facts that PA is a new technology which requires some new advanced and expensive equipments such as yield monitoring sensors, GPS receiver, etc. Such facilities are very costly for PA farmers. Therefore, many of them try to avoid the PA's system, especially in situations where their productions have low commodity prices (Robert, 2002). Moreover, Swinton et al. (1997) and Lavergne (2004) identified that initial costs of PA technologies are the most important financial requirements for PA farmers, which make them overwhelmed, since such technologies change rapidly. So, the main pre-requisite for PA application is reducing PA technologies costs and providing some financial supports for farmers in PA initial stages (Reichardt and Jurgens, 2009). Nonetheless, the finding about 'economic challenges' was verified by several authors, such as Lavergne (2004) and Dabarkow et al. (2000) among others.

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