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Adoption and Use of Precision Agriculture in Brazil: Perception of Growers and Service Dealership

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Abstract

Precision agriculture (PA) is growing considerably in Brazil. However, there is a lack of information regarding to PA adoption and use in the country. This study sought to: (i) investigate the perception of growers and service dealership about PA technologies; (ii) identify constraints to PA adoption; (iii) obtain information that might be useful to motivate producers and agronomists to use PA technologies in the crop production systems. A web-based survey approach method was used to collect data from farmers and services dealership involved with PA in several crop production regions of Brazil. We found that the growth of PA was linked to the agronomic and economic gains observed in the field; however, in some situations, the producers still can not measure the real PA impact in producer system. Economic aspects coupled with the difficulty to use of software and equipment proportioned by the lack of technical training of field teams, may be the main factors limiting the PA expansion in many producing regions of Brazil. Precision agriculture work carried out by dealership in Brazil is quite recent. The most services offered is gridding soil sampling, field mapping for lime and fertilizer application at variable rate. Many producers already have PA equipment loaded on their machines, but little explored, also restricting to fertilizers and lime application. Looking at the currently existing technologies and services offered by dealership, the PA use in Brazil could be better exploited, and therefore, a more rational use of non-renewable resources.

Keywords: soybean, precision agriculture, maize, Brazilian agriculture

1. Introduction

Precision agriculture (PA) involves the development and adoption of some techniques to improve the management of agricultural systems, aiming to optimize inputs applications such as fertilizers, pesticides, seeds and irrigation resources to reduce inputs costs and maximize the crop production (Bora et al., 2012), besides to reduce environmental impacts (Bramley et al., 2008). In several crop production Brazilian regions, PA has been played an important role in crop production systems, mainly due to the technical and economic benefits that PA provides over the years. Costa and Guilhoto (2011) stressed that the benefits of PA adoption, impacts directly on social and economic benefits of Brazilian agricultural economy. However, the benefic effects of PA are more restricted to large cropped areas, usually operated by major companies linked to crop production. Pierpaoli et al. (2013) found that the size of cropped area is the most important parameter to farmers when they have to decide to adopt PA, due to the higher possibility to increase income. Then, properties with large cropped area has more potential to be capable to invest large amount of resources, time and learning in order to use PA technologies compared to properties with small cropped area (Adrian et al., 2005).

Fertilizer optimization has been the major target to use PA in Brazil (Costa & Guilhoto, 2011). However, Bora et al. (2012) showed that in North Dakota, farmers that adopted GPS systems or automatic steering observed

reduction of fuel consumption and machine operation time. Besides the economical aspects, negative environmental impacts arising should be reduced with PA adoption due to a more rational use of inputs in crop production systems (Bramley et al., 2008). Australian farmer's point of view about the low adoption of PA in Australia relays on technology frustration and the lack of technical support in the field. They pointed out that technology costs was not the overriding factor to PA adoption (Mandel et al., 2010). On the other hand, Batte and Arnholt (2003) analyzed six farms in Ohio (US) that recently adopted PA technologies and the profitability was the major factor that motivated farmers to adopt PA, although even not all farmers surveyed have observed the global profitability linked to PA adoption. The farmers surveyed also pointed out that on-farm research, quality information generated by PA to support decision and risk reduction in the environmental contamination were the major concerns to adopt PA. More than a decade ago Swinton and Lowenberg-Deboer (2001) concluded that PA adoption/expansion would increase slowly in area with high population and, in area with less cropland available unless the environmental benefits would be very well reported.

Reichardt and Jürgens (2009) found in German conditions that some major issues related to PA adoption were lack of technical support to PA tools and lack of knowledge to manage correctly the data to apply them correctly in the crop production system. For German farmers, the systems incompatibility among several companies' suppliers stills the major constraint to PA adoption. Batte and Arnhorld (2003) concluded that to increase PA adoption, the development of more simple technologies is the most important contribution to support farmers in the decision making process. In Alabama, farmers PA adoption is related to well establish farmers with large cropped areas and more educated level (Adrian et al., 2005).

Precision agriculture adoption survey has been conducted over the years in United States. In 2011, 85% of the respondents reported that they have been used at least one PA technology in the crop production system (Whipker & Erickson, 2011, 2013). Similar results were found in the previous survey in the same region (Whipker & Akridge, 2009). Although similarity among results was found regarding to PA technology use, Whipker and Erickson (2013) found that the use of GPS guided systems with autocontrol/autosteer was the major used over years. This fact emphasizes that implementation of new PA technologies is more suitable to be embraced for farmers that already use any PA technology available. For instance, PA technology adoption by new users has been increasing annually with 76 and 83% in 2007 and 2008 respectively (Whipker and Akridge 2007; 2008).

There is little information available regarding to PA adoption in Brazil. Silva et al. (2011) demonstrated that PA adoption in sugarcane production increased sugarcane yield and quality, and also increased profitability to farmers. On the point of view of sugarcane industry, the reduction in the environmental impact was the major issue to take attention. The use of PA technologies will be essential to sustainability of Brazilian agribusiness and mainly to achieve higher crop yield while reduce environmental impact (Silva et al., 2011). Precision technology adoption use can affect directly the economy at regional and large scale (Costa & Guilhoto, 2013). A study that evaluated scenarios such as i) increase in crop yield; ii) input reduction; iii) increase in crop yield and reduction in inputs, and; iv) increase in crop yield and increase in inputs, concluded that the major impact was on increase of crop yield, that impact directly in social benefits (employment raised) and economics benefits (increase of income) to Brazilian economy (Costa & Guilhoto, 2013). The benefits of inputs reductions is solely to increase farmers income and it is not reflect in economic benefits to the society; then, the benefits to the society must be analyzed on the point of view of reduction to environmental impact (Costa & Guilhoto, 2013). Silva et al. (2007) attempting to clarifying the costs of PA technology in order to increase the adoption by farmers, carried out a comparative analysis of the costs and economic profitability involved in implementing PA and conventional farming practices in the state of Mato Grosso do Sul. Even though PA presented higher effective operational cost comparing to traditional agriculture due to technical assistance, maintenance of sophisticated equipment, yield and soil mapping, for example, the unitary cost (*i.e.*, the cost per kilogram) in the precision agriculture system was lower than the cost in the tradictional system.

The benefits of PA adoption are widely known and transferred to agricultural systems. Although crop yield is one the major factor that impact PA adoption in some cases, is important to scientist to understand how the perception of farmers and agronomists about PA are in the crop production systems. Research with farmers, agronomists and users about their perceptions of PA technologies are limited in Brazil and there is a gap of information and knowledge that must be filled. Then, our study sought to investigate the perception of growers and service dealership about PA technologies and to identify constraints to PA adoption and also to obtain information that might be useful to motivate producers and agronomists to use PA technologies in the crop production systems.

2. Method

A web-based survey was used to collect data from farmers and services dealership involved with precision agriculture in several crop production regions of Brazil. Survey used was similar found in Silva et al. (2011) to evaluate PA adoption in Sao Paulo State (Brazil) to sugarcane production system.

We previously identified users of PA technologies to obtain their perceptions and support needed and followed the same approach of Diekmann and Batte (2010) adjusted for Brazilian conditions. After this process, we develop a web-based survey to obtain information from two groups: 1) farmers that use AP technology, and; 2) professionals and companies that are technical support providers or farmer consultants. The division in two groups was the same approach used by Reichardt and Jürgens (2009). Web-based survey was developed based on the same approach in Whipker and Akridge (2009) adapted to Brazilian conditions. Both web-based surveyes were accessed by respondents with the follow links: https://sites.google.com/site/agriculturadeprecisaotocantins/ which was developed to farmers to answer it; https://docs.google.com/spreadsheet/viewform?formkey=dG9UUG51WEhtTVZQSXJCR0ZNTVRna3c6MQ to be answered by professionals and companies that are technical support providers or farmer consultants. The sampling frame used to select the respondents was lists of individuals from Precision Agriculture Network coordinated by Embrapa (Brazilian Agricultural Research Corporation) and stakeholders, machinery companies' technical representatives and crop production sales personnel. Similar approach to sampling respondents was used to Larson et al. (2008) and Dieckman and Batte (2010). For each group separately an e-mail was sent them explaining the survey goals and the respective link to the web-survey. Based on prior published data that involved survey (mail or web), we expected about one third of the invited to respond the web-survey (Larson et al., 2008; Dieckman & Batte, 2010).

2.1 Web-Survey to Farmers

The survey included questions about respondent's as follow: year started PA in the farm; total area used with PA considering lime and fertilizers application with variable rate; use PA in the decision making process for crop and soil management; soil sampling using grid or GPS; soil sampling grid size; soil sampling in soil layers; how PA is adopted in the farm (own equipment or contract the service); list of PA equipment's used in the farm; farming operation used as variable rate application (VRA); observations related to PA use (*e.g.* crop production cost reduction); problems found regarding to equipment's maintenance and software support; PA technical support; investments; observations in increase crop yield; constraints to adopt PA at farm and regional scale.

2.2 Web-Survey to Professionals and Companies that Are Technical Support Providers or Farmer Consultants

The survey included the following questions: major company activity; how long the company is on the PA market; average size of the farms assisted; PA market grow since started to work with PA; total area in hectares the service dealership assist; PA area in the farms assisted; service most required by farmers; average soil sampling grid size; percent of PA service in the company income; PA impact on crop production reduction costs to assisted farmers; PA equipment's available to be used in the farmers that are assisted; company grow expectation in the next years; expectations to increase PA adoption at regional scale and the constraints observed and found to consolidate PA as crop and soil management practice to increase nutrient use efficiency.

2.3 Data Analysis

Primary data obtained from the web-survey were analyzed considering percentages of questions answered (Silva et al., 2011). A total of 250 e-mails were sent to farmers and 10% were answered from several states such as Goiás (GO), Rio Grande do Sul (RS), Paraná (PR), Maranhão (MA) and Tocantins (TO). Although returned answers was relatively low, it was similar that was found in similar studies with survey research (Whipker & Akridge, 2009; Holland et al., 2013; Watcharaanantapong et al., 2014; Whipker & Erickson, 2013). The answer from professionals and companies that are technical support providers or farmer consultants reached a large number of crop production region. The respondent companies were from states of São Paulo (SP), Mato Grosso (MT), Bahia (BA), Paraná (PR) and Rio Grande do Sul (RS). Answers from companies were from several regions of Brazil despite the company headquarter was located in one of the listed states above, giving more accurate results.

3. Results and Discussion

3.1 Vision of Farmers that Are PA Users

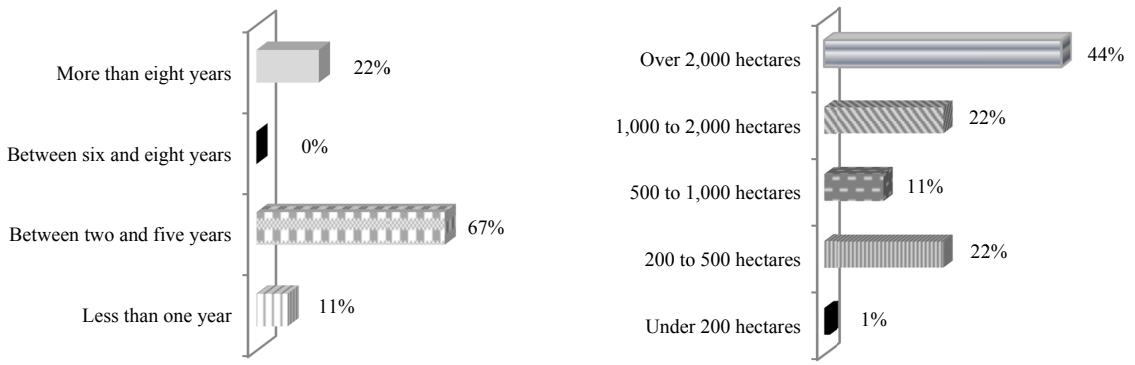
Analyzing farmer respondents we identified that soybean and maize are the most common crops that PA is used (Table 1). Both crops represent the major Brazilian commodities. Silva et al. (2007) already demonstrated that PA technology may guarantee higher production, decreasing the unitary cost and, consequently, making the system more rewarding on a long-term basis for soybean and maize. On the other hand, the adoption of PA

technologies by farmers in area smaller than 200 hectares were found in crops such as cotton, pasture, beans, sugarcane, wheat and coffee (Table 1). It is important to highlight that large producers of cotton or sugarcane, for example, were not contemplated in this study. Silva et al. (2011) investigating the PA adoption from sugar-ethanol companies figured out an area cultivated with sugarcane, using PA technology, much larger than those given for this crop.

Precision agriculture in Brazil is relatively recent were 67% of the respondents stated that are PA users between two and five years (Figure 1a) and about 20% of the farmers respondents are PA users for more than eight years. Maybe for PA is recently widely adopted, farmers do not realize the technology cost-benefit, with more than half of respondents use less than 2,000 ha with PA (Figure 1b). According to Brazilian official statistics, areas up to 2,000 ha represent over 99% of the number of Brazilian farms, which represent about 57.2% of farmland (Incra, 2012). Forty-four percent of the respondents use more than 2,000 ha with precision agriculture technology. These data suggest that technology adoption is mainly with larger producers, similar with reported by Adrian et al. (2005). Among the farmers who already are PA users, about 67 percent of respondents answered they have designed the whole farm area with some PA technology (data not showed).

Table 1. Crops and area used for precision agriculture in both surveyed farms and web-based survey

Crops	Area (ha)				
	Less than 200	200 to 500	500 to 800	800 to 1000	More than 1,000
Soybean	0%	22%	11%	0%	67%
Maize	22%	22%	0%	0%	56%
Cotton	78%	0%	0%	0%	22%
Pasture	56%	0%	11%	0%	33%
Beans	67%	11%	0%	0%	22%
Sugarcane	78%	0%	0%	0%	22%
Wheat	67%	11%	0%	0%	22%
Coffee	78%	0%	0%	0%	22%



(a) (b)

Figure 1. Frequency distribution of (a) years of PA adoption in the farm, and (b) PA area adopted in the farm (b). Data from questionnaires in the crop season 2011/12

All the survey respondents collect soil samples using grid (Figure 2a), representing the major tool used among the PA technologies available, although not all dealership offer this service. The cost related to soil sampling grid and analysis remains relatively high, resulting in soil sampling grid over five hectares and mostly to soil fertility evaluation at 0-20 topsoil layer.

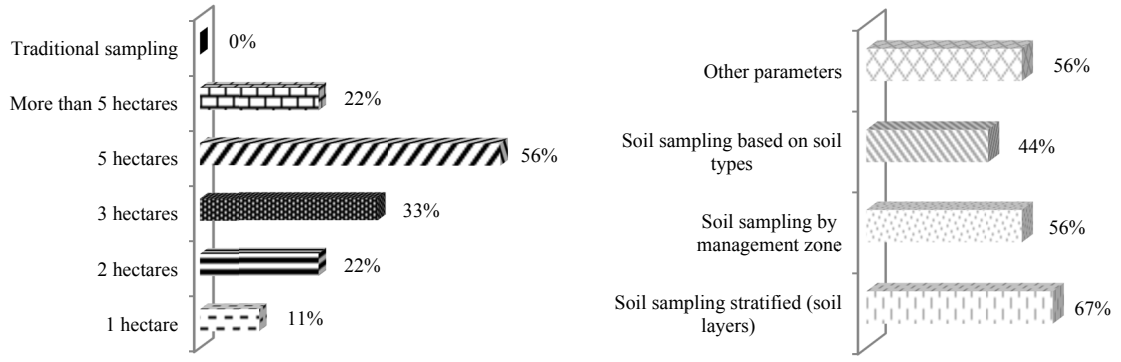


Figure 2. Soil sampling grid size used by farmers (a), and parameters for georeferenced soil sampling in addition to the grid size (b). Data from questionnaires in the crop season 2011/12

Some farmers also carried soil sampling in soil layers (67%); however, management zones and soil type are less used (Figure 2b). Brazilian soils are highly weathering, for which a soil sample in layers below 20 cm are performed mainly by farmers with higher input, with the objective to apply lime or gypsum to achieve better yields and to prevent yield loss due to drought.

Basically PA service has been provided by technical support providers or companies; however, it was observed that farmers are increasing PA. Total answers about this topic, 33% stated that all PA service (soil sampling, field mapping, results interpretation and recommendation) was carried out by dealership; although 45% informed that technical support companies are responsible to soil sampling and field mapping, and the results interpretation and recommendation are organized by farmer's technical team (Figure 3).

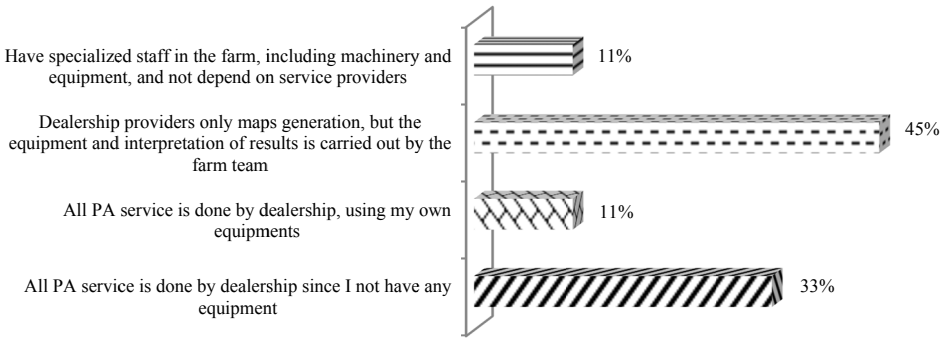


Figure 3. Precision agriculture technical support. Data from questionnaires in the crop season 2011/12

Regarding the use of variable rate application (VRA), without specifying which one (fertilizer, lime, pesticides or seeding), 44% of farmers surveyed used in more than 2,000 hectares for this service (Figure 4a). About 22% of respondents had planned between 1,000 and 2,000 ha and between 200 and 500 ha. These data are similar with those found for the areas designed for PA on farms (Figure 1b). Such information suggests that the incorporation of new areas by the PA users is through the VRA service. Therefore, PA technology of VRA along with soil sampling represents the major services adopted in Brazil.

All PA users adopt controller in soil amendment practices, followed by application of fertilizers (Figure 4b). Variable seeding rates is the least significant service in its category. In order to performing VRA, farmers had been using several equipment's to ancillary them. Manual control systems (light bar) were the most popular type of guidance system (Figure 5). In the USA survey, GPS guidance systems for custom application showed considerable advancements in PA technology. In past surveys, the use of manual control system increased, until the 2009 survey when their popularity reached its peak (Whipker & Akridge, 2009). Automatic control systems (autosteer) showed trending upwards in recent surveys, representing nowadays 47.5% of the guidance system

technology (Holland et al., 2013). In our results, we noticed many farmers employing both systems (likely each machine has different systems), although manual control systems still are more common use (Figure 5).

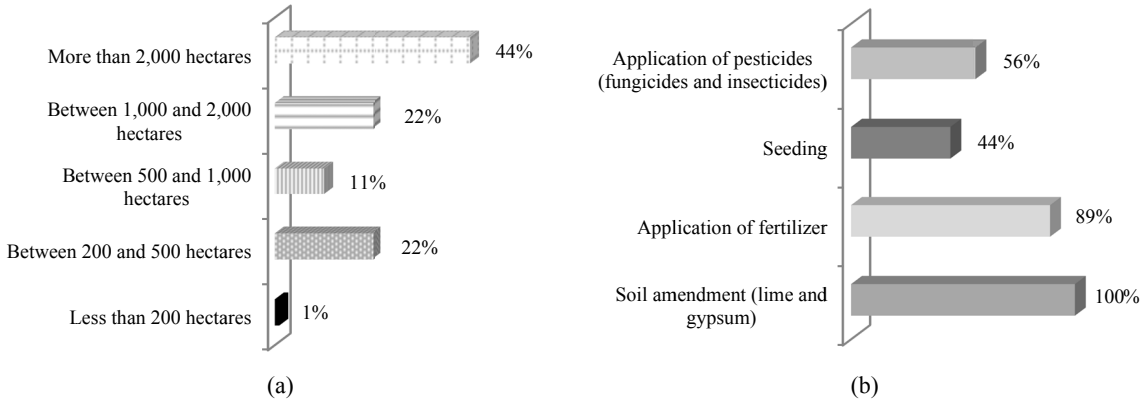


Figure 4. Area designed to variable rate application (a), and type of operation that uses variable rate application in the farm (b). Data from questionnaires answered by farmers in the crop season 2011/12

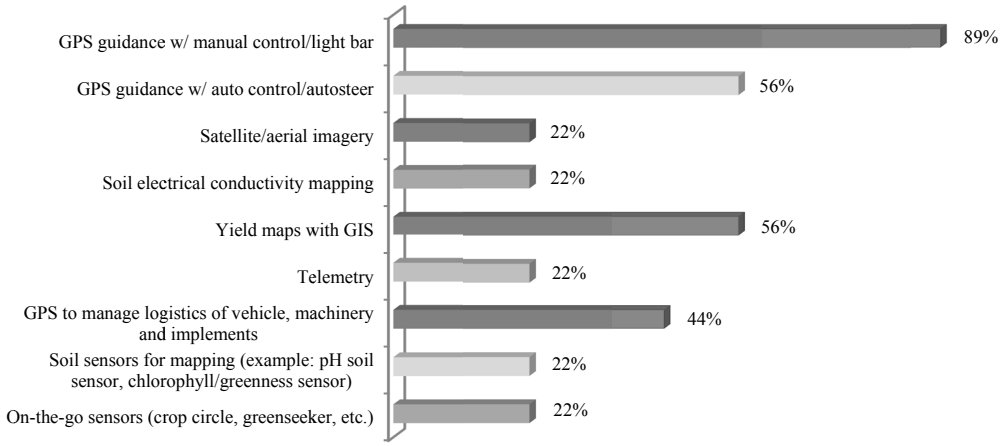
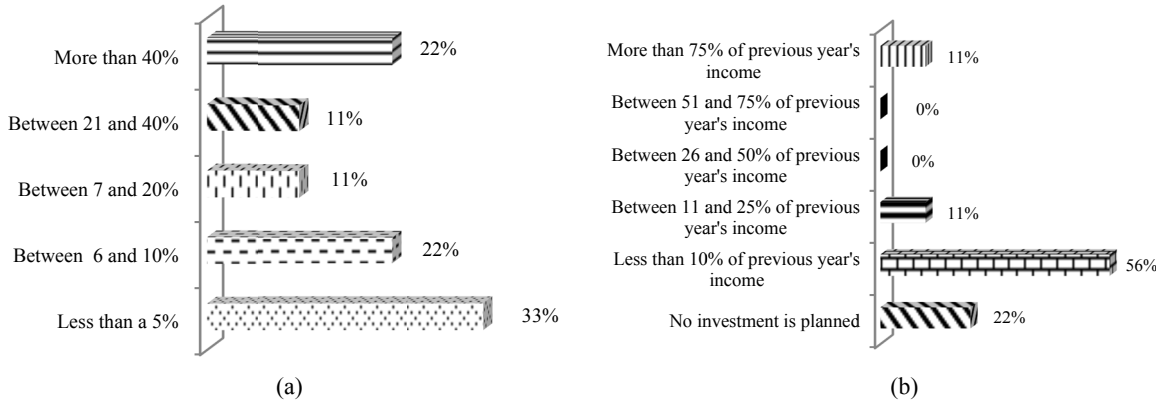


Figure 5. Which precision technology have you been used in the field. Data from questionnaires in the crop season 2011/12

After the control system, yield maps were the most used precision technologies (Figure 5). GPS for logistics also had been used for almost 50% of the PA adopters. Telemetry for field-to-home office communications was one of the biggest increases observed for the USA 2013 survey reaching 15.2% (Holland et al., 2013), which was much less than observed in Brazilian survey. Although farmers observed a cost reduction in the crop production costs due to PA adoption, most of farmers did not know in which situations PA had been impacted in the crop production costs (Table 2). Most of respondents would not be able to determine or measure the real impact in the cost production reduction considering lime, fertilizer and herbicide application or maintenance and consulting with software and equipment (Table 2). This information is corroborated with data showed in Figure 6a, where only one third of respondents informed that observed increase in crop yield was lower than 5% after PA adoption. More than 22% of respondents confirmed that the increase in crop yield ranged from 6 to 10% and in equal proportion the crop yield observed was over 40%. Farmers that did not observed increase on crop yield and do not know the real economic benefits of PA adoption, usually opted to invest in machinery and equipment (Figure 6a).

Table 2. Crop production reduction costs due to precision agriculture adoption. Data from questionnaires in the crop season 2011/12

	Lime application	Fertilizer application	Herbicides application	Maintenance and consulting with software and equipment
Less than 10%	22	34	44	33
10 to 20%	22	22	0	0
20 to 30%	12	0	0	0
More than 30%	0	0	0	0
Do not know	44	44	56	67



(a) (b)

Figure 6. Crop yield observed due to PA adoption (a), and investments in precision technology for the next years (b). Data from questionnaires answered by farmers in the crop season 2011/12

According to investments expectations for the further years, 56% of the farmers answered that they will invest less than 10% of the gross income past year-based in PA. On the other hand, 22% answered that no investments in PA were planned for the next growing season. Results showed PA can increase crop yield from respondent's perspective; however, economic balance needs to be clarified to farmers because it was not clear to respondents if PA adoption in fact is more profitable. Silva et al. (2007) showed that in maize and soybean crops in Brazil the unitary effective cost was lower with use of PA technologies; however, we have to point out that many farmers do not make a detailed description and control in their production costs, making dificult to realize the financial benefits of PA. Based on this scenario, adding cost of production of each growing season into account makes PA adoption very susceptible to commodities market. Then, farmers' decision to adopt PA relayed on costs and economic balance at short term. For most respondent's, to continue or to invest in PA is highly dependent of commodities prices for the next growing season.

There were limitations to increase PA adoption and respondent's disagreed that PA costs are higher than the benefits observed (Table 3), even they could not measure a reduction in the production cost (Table 2) it was possible to see benefits with PA adoption. Farmer's respondent also disagreed that there are constraints to increase PA use in agriculture such as topography, soil type; they also stressed out that timing from gather information and maps generation is relatively short and acceptable to decision making process in a growing season. Another very important point raised from the results was that the amount of information regarding to new products, technologies and training for field team to use PA technology still need to be improved.

The companies providing PA service have showed good relationships with producers, supplying information such as costs management and benefits with the PA adoption. However, analyzing the limitations (Table 3), the farmers agree that this service generates a security recommendations, although the producers did not know quantify (Figure 6a). Farmers also reported that PA cost is still high, especially in the acquisition of equipment and software, but the amounts charged are not excessive and are consistent with the technology.

For producer's perspective, nowadays equipment and software used in the PA are barriers to growth and investment in technology. The incompatibility between different equipment and hardware device (*e.g.* data formats, information sharing) has limited the use; Reichardt and Jürgens (2009) reported similar obstacles. In addition, the manuals are quite complex and lack of training of field teams, together with the lack of skilled labor

trained to operate machines and equipment with embedded PA systems, contribute for low investment in PA or new users over the years.

Regarding to service provides, farmer's respondents agree that it is too difficult to keep updated with constant new technologies in PA, since dealership provides the PA service or the option to purchase of machinery, but did provide free technology upgrades. Furthermore, respondents also agree that data collection can suffer climatic or operational interference that were not fully corrected by software, thus compromising data accuracy and therefore the recommendation. The lack of PA monitoring for dealerships related in updating and maintenance of software and equipment, training and technical accompaniments, make the field teams remain limited on proper handling of equipment. Pieces for timely replacement are also important obstacles.

Table 3. Limitations that constraint PA adoption to increase responded from farmers from several Brazilian regions in the crop season 2011/2012. Values in percent (%) calculated from answers signed in each specific item

Limitations	**1**	**2**	**3**	**4**	**5**
PA costs to producers are higher than the benefits observed	22	45	0	11	22
Soil type in the field reduce PA profitability	56	11	0	11	22
Field topography limit PA use	67	11	0	11	11
Long time between gathering information and map processing for decision making process	45	11	11	22	11
Confidence on the recommendations based on field division grid-based	12	0	33	33	22
Benefits of PA adoption in the own business	11	0	33	45	11
Values applied in PA are not excessive and are coherent with technology applied	0	22	22	45	11
Constraint to find qualified personnel to handling equipment	11	11	33	33	11
High costs software and equipment acquisition	11	0	33	45	11
Constraint to convince the profitability increase with PA adoption	33	22	0	33	11
High costs with personnel	11	11	11	56	11
PA equipments are very changeable and the costs are high	11	11	11	56	11
Incompatibility between different software's in the market	0	33	11	45	11
Incompatibility between different software's and research-based recommendations	0	33	22	33	11
Equipment and software with very complex manuals to understand	11	11	22	45	11
Constraint to personnel training and support to handling software and equipments	0	22	33	33	11
There are software and equipment's that are not accurate to use in PA	0	11	22	56	11
Data gathering with interferences (climatic, operational, etc.) that makes difficult the results accuracy	11	22	22	33	11
Incompatibility between equipment and technologies constraint the ability to offer new products and services to clients	0	22	22	45	11
Companies do not offer software maintenance	0	33	22	33	11
Companies do not make available software update and/or new free updates via internet	0	33	11	45	11
Little information regarding to new products/technologies in PA	0	45	11	33	11
My team do not receive training about the correct use of software/equipment	11	45	11	22	11
No costumer service response regarding to complaint about use and maintenance product	22	33	11	22	11
Constraint to find replacement parts for my equipment's	11	22	22	33	11
Companies do not give cost management and benefits to market access	11	22	11	22	33
There is none tool available in the market at the same PA level to decision making process and planning for inputs acquisition and use	0	11	22	45	22

Note. 1: Completely disagree; 2: Partially disagree; 3: Fully agree; 4: Partially agree; 5: Not agree/not disagree.

Although more than half want to invest less than 10% of the previous year's income (Figure 6b) in PA tools, hindering great adhesion to PA technologies and still be many limitations to overcome (Table 3), farmers expect improvements in some precision agriculture technologies, or new PA technology options (Figure 7). Farmers have great expectation arising new tools for recommendation and application of fertilizer and lime. In the same scale of expectations (78%), an integrated interpretation considering data analysis in different database is expected. With a lower frequency of responses, but expected still with 67 percent, the variable rate seeding,

increase in technologies of automatic applications, and sensors for application of variable rates, where this technology can perform controlled applications including formulated fertilizers.

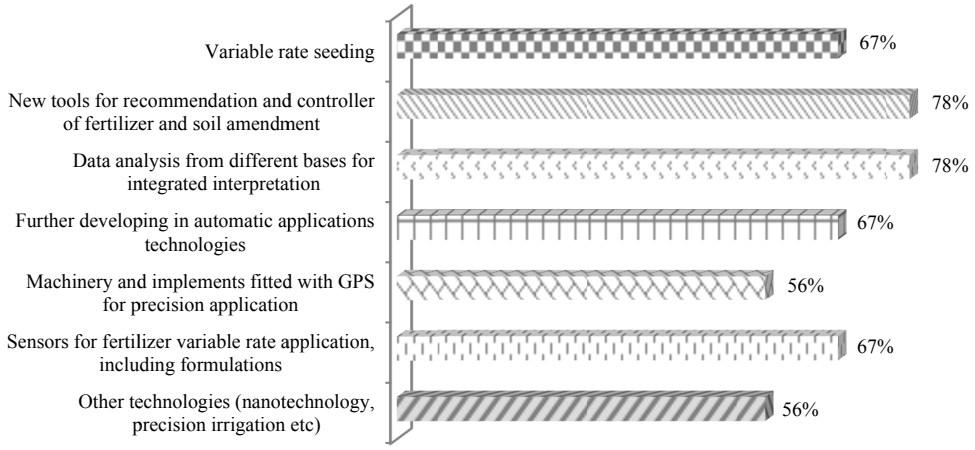


Figure 7. Expectation of new useful precision technologies for your agribusiness. Data from questionnaires answered by farmers in the crop season 2011/12

3.2 Vision of Professionals and Companies that Provides Technical Support

Before of twenty-first century, the difficulty in access to knowledge about PA technology and especially, the cost of purchase new equipment or tools has contributed to prevent the growth of PA. The advent of dealerships, particularly in mechanization and agricultural automation segments, offering the technology already available embedded in machinery and outsourcing of PA sector by technicality companies provided great leap in the use and dissemination of the benefits of PA in Brazilian agriculture. This statement is corroborated with Figure 8a, which shows the PA use in the regions served by the dealerships. 50 percent of respondents reported that the total area of properties that employ PA is between 1,000 and 2,000 hectares. On the other hand, 25% of companies assist farmers with area smaller than 200 hectares.

All dealership answered that the time operation in the PA market only from two to five year. This information suggest the PA work carried out by service providers companies is relatively recent in Brazil. Regarding to services offered, all companies mentioned performing georeferenced soil sampling and prepare maps for lime and fertilizer variable rate applications (Figure 8b). Holland et al. (2013) reported soil sampling with GPS was the most popular use in the USA 2013 survey. Besides the above-mentioned service, half of responding dealership also offering agronomic consulting services, and only a quarter offers product for buying or technical assistance for PA equipment (Figure 8b).

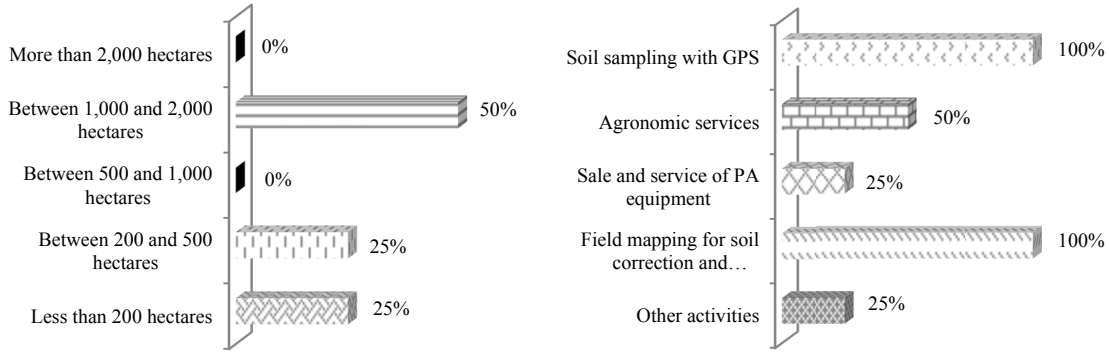


Figure 8. Property size assisted by dealership (a) and; company main activities, more than one answer (b). Data from questionnaires answered by dealership in the crop season 2011/12

Costumers have dedicated between 20-40% of the total cropland to use with PA (Figure 9). The other half of the costumers is divided among those who use less than 20% of the area and between 40-60% of the area. Even among the producers who adopt the PA, the dealerships reported that none answered that in the farm is used more than 60% of the area with this technology. As reported by producers (Table 2), this fact may be related to the difficulty of skilled labor, employee training, cost to purchase equipment and software, incompatibility among others. Thus, it can be noted that there is still great scope for PA expansion, considering that the area increase with technology occurs mainly among the producers who already employ some PA technology (Whipker and Erickson 2013).

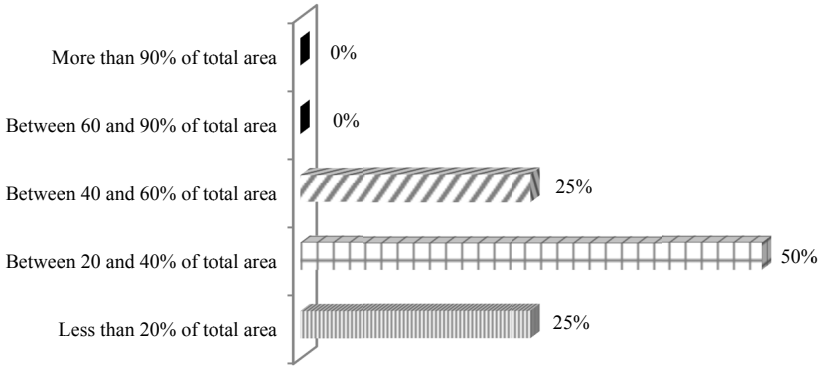


Figure 9. Percentage of area that customers intended to PA. Data from questionnaires answered by dealership in the crop season 2011/12

Both for producers and for dealerships, the use of PA is restricted to the use of some technologies, far below the potential that the PA can offer. The most service sought by customers is the controller to lime and fertilizer application. Dealership reported that all its customers have sought the PA service for lime VRA and 75% of farmers still sought companies to fertilizer VRA. Such percentage is higher that reported by Holland et al. (2013) for American farmers.

Grid size of soil sampling was quite varied; however, 50% of the dealership responded that their customers choose to grids of 5 hectares (Figure 10a), corroborating with producers response (Figure 2a). For the recent America PA survey, the most common was the grid sample between 1 and 2 hectares in size (Holland et al., 2013). The smallest grid requested by producers to the companies was to 2 hectares (25% of respondents), although the dealership also offer grid size of 1 hectare. Due to high cost to denser sampling, map generation and variable rate application, producers opt for larger grid sizes in order to minimize costs, even though there is a direct relationship between the grid size and the cropland variability, which may affect the amount and accuracy of the fertilizers application.

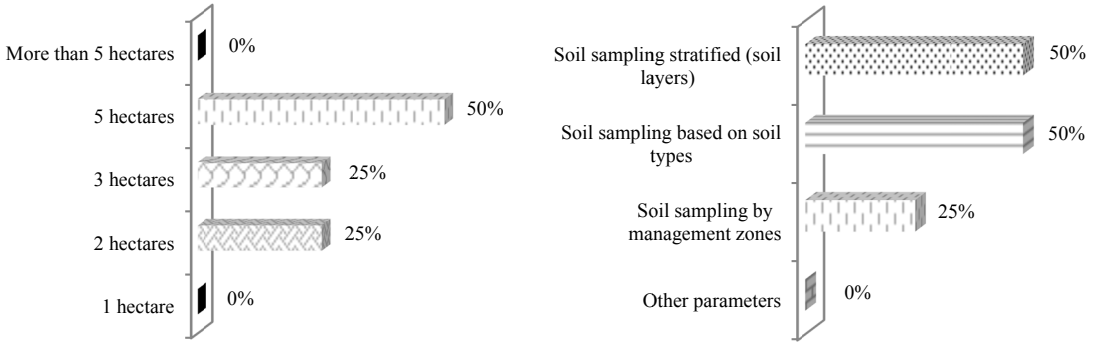


Figure 10. Soil sample grid size (a) and; other parameters for perform georeferenced soil sampling (b). Data from questionnaires answered by dealership in the crop season 2011/12

In addition to the sampling grid, dealerships often offer soil sampling georeferenced taking into account other parameters (Figure 10b). In this analysis, 50 percent of survey respondents reported that perform soil samples by layer (0-20 and 20-40 cm) considering the different types of soils on properties. Only 25% of dealership reported that they perform georeferenced soil sampling taking into consideration of management zones. Holland et al. (2013) reported 54% of dealership offered sampling following a grid pattern and 35% offered sampling by management zone. By the currently existing technologies in Brazilian producing regions, the use of management zones for decision making process is still little explored by both dealership and producers, showing great potential for improvement of management more aware of the soil and inputs.

Survey showed farmers already have in their PA machines coupled equipment such as GPS, light bar, harvest monitors etc.; however, they perform some PA work with dealership. Companies reported that the vast majority of producers also have GPS with manual control/light bar guidance system for fertilizer and lime application (75%). To a lesser extent (25%), survey respondents reported that, in addition to GPS, they also found in the producer's machines equipment like harvest monitor with GIS and autopilot in order to guide the operations of mechanized land preparation and cultivation in the fields. Even using some PA tool many producers do not yet have any PA equipment (25%), although already perform soil sampling and lime and fertilizers at variable rates application.

Farmers who already have equipment in their machines perform basically the lime and fertilizers VRA. Only a small proportion of dealership customers perform application of pesticides using the equipment available in machinery (25%). For these answers, it appears that the PA service offered by the dealership on these customers is restricted to soil sampling and field mapping for lime and fertilizers at variable rates application.

Although the producers did not know how to inform the actual reduction in production costs (Table 1), the service providers reported that three-quarters of its customers achieved a reduction in production costs between 11 and 20% (Figure 11a) and for the rest of this reduction was less than 10%. This view by dealership may be related to its marketing strategy to convince new users to acquire some service offered by companies (Table 3). Concerning to growth of the PA market (Figure 11b) the wide majority of companies reported an increase between 6 and 10%.

Most companies already have, since before 2010, in their service list the fertilizers and lime application (Table 4), having GPS navigation to perform this operation. However, many producers make this application with its own machinery and employees (Figure 3). Within this topic application technology, the pesticide application service at a variable rate is still very incipient and is a place where businesses can grow, bringing enormous environmental benefits.

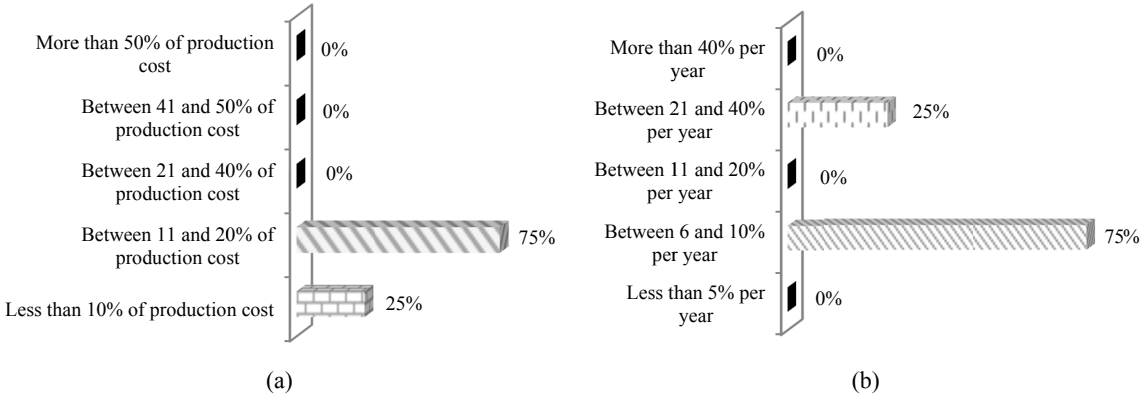


Figure 11. Average reduction of precision technology that dealership observed in their customers (a) and, growing of PA market (b). Data from questionnaires answered by dealership in the crop season 2011/12

Table 4. Products/services offered by companies that providing services and trends. Values in percentages calculated from the responses marked on each item. Data from questionnaires answered by dealership in the crop season 2011/12

Products/Services	Since 2010	Offer by 2011	Intend to offer	Don't know
Soil samppling with GPS	78	0	0	22
Soil samppling for layer with GPS	33	11	11	45
Variable rate application				
Fertilizers	56	0	11	33
Lime	56	0	11	33
Pesticides	12	0	44	44
Controller-driven (GPS) for application				
Fertilizers	45	0	22	33
Lime	45	0	22	33
Pesticides	12	0	44	44
Yield maps	45	11	11	33
Sales / technical support / rental				
Yield monitor without GPS	11	11	33	45
Yield monitor with GPS	0	0	33	67
Softwares and equipments	11	11	22	56
Field maps: fertility, yield, monitoring of pests, diseases, weeds etc.	22	0	33	45
Recommendation of fertilizers, lime and pesticides through field maps	78	0	0	22
Sale / technical support for aerial images/satellite	22	0	33	45
Controller for variable rate application, single nutrient	45	0	22	33
Controller for variable rate application, multiple nutrients	12	0	44	44

We can also notice that the PA branch companies focus their efforts on providing services rather than the sale or rental of PA products. This may be related to the fact that large companies of machinery and equipment now offer this technology at the moment of the machinery sale. This information can be a big opportunity for companies offer a rental service to small farmers who plan to take PA technologies on their property, since they do not need to purchase new machines with load technology. This is another option for service providers expand its operations.

Dealership also responded one series of questions about the limitations for increasing the adhesion to PA technologies. Although a small portion of farmers reported that they agreed that the producer cost was higher than the benefits (Table 3), the vast majority of companies and service providers reported that totally disagree that the costs are higher than the benefits (Table 5). This lower perception of farmers can be due to many of them do not have a detailed control of the cost with and without application of PA tools.

Comparing the results from Table 3 and Table 5, we obserced similarity between the answers given by producers and service providers. However, some points should be highlighted. For example, around 45% of farmers respondent figured out benefits of PA adoption in the own business (Table 3). This percentage could be higher according to the service providers' vision, or even among those who realized this benefit it could be more significant. Once the companies responded that 75% completely disagree that their customers who could have benefits from PA technologies are already users. While 25 percent fully agree (Table 5).

Table 5. Limitations that constraint PA adoption to increase responded from dealerships from several Brazilian regions in the crop season 2011/2012. Values in percent (%) calculated from answers signed in each specific item.

Limitations	1	2	3	4	5
PA costs to producers are higher than the benefits observed	75	25	0	0	0
Soil type in the field reduce PA profitability	50	50	0	0	0
Field topography limit PA use	75	25	0	0	0
Long time between gathering information and map processing for decision making process	0	50	0	25	25
Confidence on the recommendations based on field division grid-based	0	0	25	75	0
All customers who could have benefits with PA already are PA users	75	0	25	0	0
Values applied in PA are not excessive and are coherent with technology applied	0	50	50	0	0
Constraint to find qualified personnel to handling equipment	0	0	75	25	0
High costs software and equipment acquisition	0	25	50	25	0
Constraint to convince the profitability increase with PA adoption	25	25	25	25	0
High costs with personnel	0	25	50	25	0
PA equipments are very changeable and the costs are high	0	0	25	75	0
Incompatibility between different software's in the market	0	25	50	25	0
Incompatibility between different software's and research-based recommendations	0	50	25	25	0
Equipment and software with very complex manuals to understand	0	50	25	25	0
Constraint to personnel training and support to handling software and equipments	0	0	75	25	0
There are software and equipment's that are not accurate to use in PA	0	50	25	25	0
Data gathering with interferences (climatic, operational, etc.) that makes difficult the results accuracy	25	25	0	50	0
Incompatibility between equipment and technologies constraint the ability to offer new products and services to clients	0	50	25	0	25
Companies do not offer software maintenance	25	25	25	25	0
Companies do not make available software update and/or new free updates via internet	25	50	25	0	0
New companies have difficult to introduce new PA products	0	25	50	25	0
Software companies offer training about the correct use of software/equipment	0	50	25	25	0
Software companies offer service response regarding to complaint about use and maintenance product	25	25	0	50	0
Constraint to keep replacement parts for customers equipment's	50	50	0	0	0
With PA tools the companies can plan inputs acquisition and use	0	25	75	0	0
There is negotiation on the costs of services provided to farmers	0	0	75	25	0

Note. 1: Completely disagree; 2: Partially disagree; 3: Fully agree; 4: Partially agree; 5: Not agree/not disagree.

A point that is worth emphasized is that according to the producers, one limitation is finding replacement spare parts (Table 3). However, the service providers as a whole disagree with this statement, reporting not having trouble keeping replacement parts in stock (Table 5).

Services providers companies were also surveyed about expectation of new PA technologies (Figure 12). In general they showed lower expectations when compared with producers. However, it is noteworthy that a higher expectation regarding to technologies for implementing the variable rate seeding. Such service also have been reported in the last USA survey, being among the services that more is expected to grow by 2018 (Widmar & Erickson, 2015).

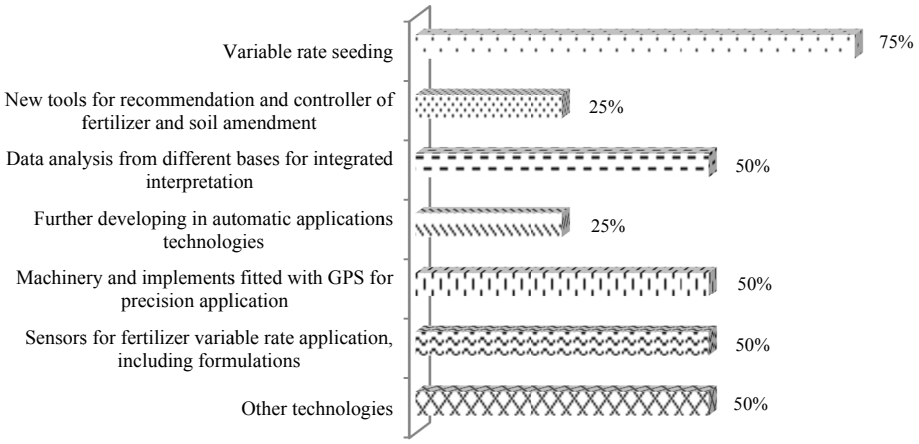


Figure 12. Expectation of new useful precision technologies for future. Data from questionnaires answered by farmers in the crop season 2011/12

While most farmers expect to invest less than 10% of previous year's income (Figure 6b), 50% of service provides respondents expect to reinvest between 11 and 25% of its profit. The other half are divided equally between those wishing to reinvest less than 10%, and the more daring, those how expected to reinvest their profit in the range of 26-50%. This information suggests that service providers are more hopeful about the growth of PA activity in Brazil, likely managing to reach new users.

Results showed the complexity of how PA has been used in Brazil. Since farmers and consultants answered questionnaire from a wide range Brazil region, it was noted that PA is still recent in Brazil, which means that are many opportunities to grow. Based on our results we observed that PA adoption is a quite restrictive and PA needs some adjustments to increase its adoption in Brazil, even with knowledge and benefits that PA brings to crop production system. Precision agriculture adoption could be increased if the environmental benefits due to PA adoption would be better explained to user, besides the economic benefits (Swinton and Lowenberg-Deboer 2001).

4. Conclusion

The growth of precision agriculture is due to the agronomic and economic gains already known in the field; however, in some situations, the producers continue not able to measure the real PA impact in its agribusiness. The information obtained, the economic aspect, coupled with the difficulty in the use of software and equipment proportioned by the lack of technical training of field teams, may be the main factors limiting the PA expansion in many producing regions of Brazil.

Precision agriculture work carried out by dealership in Brazil is quite recent. The most services offered is soil sampling with grids between 2-5 hectares in size, field mapping for lime and fertilizer application at variable rate. Many producers already have PA equipment loaded on their machines, but little explored, also restricting to fertilizers and lime application. Looking at the currently existing technologies and services offered by dealership, the PA use in Brazil could be better exploited, and therefore, a more rational use of non-renewable resources.

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