Adoption of precision agriculture in subtropical environments[1]

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Abstract – The precision agriculture (PA) aims to increase production and protect the environment, preserving soil and water resources, due to the rational use of agricultural inputs. One of tools of PA is the application of fertilizer at variable rate (VRT). The study aims to analyze the perceptions of farmers on the use VRT, identifying the determining factors for the adoption, its difficulties and the expected and perceived benefits on the use of VRT in subtropical environments. The study was done with farmers that use PA techniques in the soybean crop in the State of Rio Grande do Sul - Brazil. Although this study sampled farmers with a higher education than the average of producers in the region, issues related to knowledge and cost are factors that hinder the adoption of VRT. On the other hand, the benefits perceived by farmers were lower than expected. In sub-tropical environments the perception of the reduction of fertilizer is related to the number of crops on which farmers use VRT. All adopters of VRT had reduced the amount of fertilizer used in the soybean crop, with the greatest reductions been noticeable from the third crop of continue use of VRT.

Keywords: agribusiness, technology, glycine max, Brazil.

Adoção da agricultura de precisão em ambientes subtropicais

Resumo – A agricultura de precisão (AP) visa aumentar a produção e proteger o meio ambiente, preservando os recursos hídricos e do solo pelo uso racional de insumos agrícolas. Uma das ferramentas da AP é a aplicação de fertilizante em taxa variável (ATV). O objetivo deste estudo é analisar as percepções dos agricultores sobre o uso da ATV, para identificar os fatores determinantes da adoção, suas dificuldades e os benefícios esperados e percebidos. O estudo foi feito com agricultores que adotam a ATV na cultura da soja no Rio Grande do Sul, Brasil. Embora o estudo tenha amostrado agricultores de nível superior, questões relacionadas ao conhecimento e ao custo são fatores que dificultam a adoção da ATV. Além disso, os benefícios percebidos pelos agricultores foram inferiores ao esperado. Em ambientes subtropicais, a percepção da redução de fertilizantes está relacionada ao número de safras nas quais os agricultores adotam a tecnologia. Todos os que adotaram a ATV

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reduziram a quantidade de fertilizante usada na safra de soja, com as maiores reduções observadas na terceira safra de uso contínuo da tecnologia.

Palavras-chave: agronegócio, tecnologia, glycine max, Brasil.

Introduction

Soybean is one of the greatest economic importance crops of Brazilian agribusiness, accounting for about 50% of the area planted in grain (Brasil, 2015). This has been attributed to the development and structuring of the international market, the consolidation of soybean as a source of vegetable protein, and the generation of new technologies that made the expansion of exploration in various regions of the world possible (Hirakuri & Lazzarotto, 2014).

In Brazil, soybean was introduced in 1914 in the southern State of Rio Grande do Sul (RS), but it was from the 1960s that soybean acquired economic importance in the country, initially in the southern region, were the cultivars introduced showed better adaptation (Priolli et al., 2004). The area devoted to soybeans in the state currently represents 16% of the total area devoted to soybean in Brazil (Conab, 2014). In these environments, soybeans are sown in spring is preceded by another culture, in winter, such as wheat, barley or oats. The properties are medium to small in size, and soybean is seeded on the same day of the harvest of winter crops; also, all producers use no-till (directly without plowing the soil). The subtropical environments are characterized by the wide variation in the types of soil, soil fertility, and rainfall, with large variations season to season and year to year, higher night temperatures and always high humidity, which is ideal for the growth of fungi, bacteria, insects and weeds (Paterniani, 1990; Gallup & Sachs, 2000).

The management of soil fertility variability and crop conditions to improve agricultural production and minimize the environmental impact are crucial points of the innovative technologies as precision agriculture (PA). The PA has the ability to increase production and protect the environment, preserving soil and water resources, due to the rational use of agricultural inputs. From this premise, Berry et al. (2003) developed the idea of "precision conservation", which was defined as the use of technology and precision procedures by spatial and temporal variability, to achieve conservation goals. Among the PA tools, in tropical environments, emphases have been given to the application of VRT. Some studies have shown that VRT is being adopted in a greater proportion than other precision agriculture tools (Khannaet al., 1999; Batte & Arnholt, 2003). This is a technology that makes it possible to vary the dose of the applied input according to the specific needs of each point within the plot (Tschiedel & Ferreira, 2002). Therefore, taking into account the variability of soil and topography of farms in the state, this favors optimization in the application of fertilizers and the reduction of costs and environmental impacts of agriculture.

The technology has been adopted intensely in European countries, especially in Germany (Reichardt & Jürgens, 2009; Reichardt et al., 2009), Denmark (Pedersen et al., 2003, 2004), and in North America, in the United States (Torbett et al., 2008) and Canada (Aubert et al., 2012). In addition, farmers who plant large areas tend to be more prone to risk than small farmers, as they are the first to adopt new technologies (Walton et al., 2010).

Younger farmers have longer planning and therefore have greater incentives to invest in new equipment and technologies compared to older farmers (Isgin et al., 2008; Roberts et al., 2004). Besides, they have a greater understanding of more complex technologies, such as precision agriculture, thereby increasing the probability of adoption (Batte et al., 1990; Roberts et al., 2004).

The adoption of AP technology can be analyzed in two points: before and after the adoption. Analysis after the adoption allows the motives or reasons that encouraged the adoption to be demonstrated; these are possibly the potential factors for the adoption of technology by farmers. Already, the analysis before adoption provides a preliminary analysis of acceptance and introduction of innovative technology.

One of the conditions that determines the time of adoption of a technology is the realization of gains (mainly economic) by farmers (Aubert et al., 2012). Identifying, evaluating and analyzing the determining factors for the adoption of technology, from the perceptions of producers, enables actions to encourage its spread to be created and implemented.

Given the importance of technological innovation in food production and its impact on agriculture and natural resources, the article aims to analyze the perceptions of farmers on the use VRT, identifying the determining factors for the adoption, its difficulties and the expected and perceived benefits on the use of VRT in subtropical environments.

Methodological approach of the study

Description of the study

In this study, the term AP refers to the different techniques of precision agriculture and VRT, exclusively the use of fertilizer application at a variable rate. A survey was conducted with farmers in the State of Rio Grande do Sul - RS. The study involved primary data through a questionnaire. The questionnaire was designed with open and closed questions related to the perceptions of farmers related to the adoption of VRT on the following topics: (a) difficulties in adopting; (b) barriers to expansion; (c) prevention barriers; (d) expected benefits; and (e) perceived benefits.

The pre-test questionnaire was applied to five farmers, in June 2014, who were not part of the final sample analyzed. The collection period of the definitive questionnaire was from June to September 2014. In this period, the preliminary contacts were made and the questionnaire was sent by e-mail to the largest possible number of farmers, with a total of 388 questionnaires sent. The rate of return obtained, measured by the number of returned questionnaires, was 20.9%, i.e. 81 questionnaires were considered valid (those who used VRT in soybean). The questionnaires were made available through a link, using the Google Docs software service. All respondents were aware of the study and agreed to participate.

Description and characterization of the sample

Farmers are located in 30 counties in the northern region of Rio Grande do Sul-RS (Figure 1), which are between longitude 54°39′32,262″W to 51°33′5,297″W and latitude 27°19′13.412″S to 28°52′18,302″S. The high representation of producers from these regions is due to the high availability of machinery and agricultural implement industries and the fact that it is the main grain producing region, mainly soybean (IBGE, 2015b). The sample is typical of local producers, small and medium soybean growing areas, which adopt VRT. The average area planted with soybeans in the last crop study was 192.81 hectares and VRT was used in 164.53 hectares (Table 1). Respondents were owners or those responsible for managing the property.

Regarding the area intended for soybeans and soybean VRT use, the lowest acreage used by adopters was 50 ha in 2009/2010 and the highest was 1100 ha in 2013/2014. In the 2013/2014 season, all of the surveyed properties used VRT (Table 1), agreeing with Bernardi et al. (2011), who claimed that the adoption of VRT occurred in various sectors of agribusiness, but at a slower pace than planned.

Processing and analysis of data

Data regarding perceptions on the use of fertilizers were subjected to analysis of variance, followed by average Scheffe test at 5%

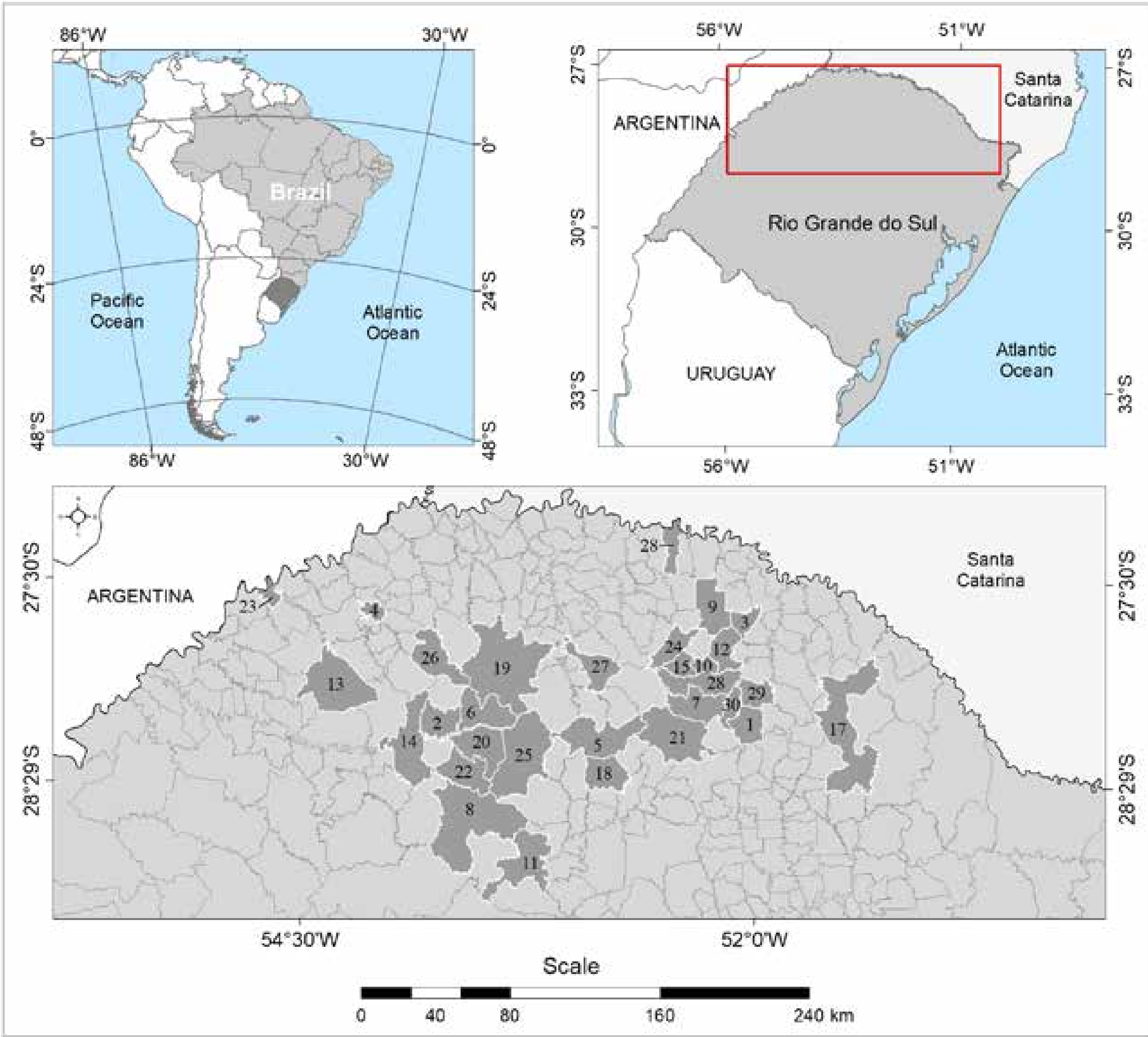

Figure 1. Location of the municipalities where soybean farmers using VRF were shown.

Note: 1 = Água Santa; 2 = Ajuricaba; 3 = Áurea; 4 = Boa Vista do Buricá; 5 = Carazinho; 6 = Condor; 7 = Coxilha; 8 = Cruz Alta; 9 = Erechim; 10 = Estação; 11 = Fortaleza dos Vales; 12 = Getúlio Vargas; 13 = Giruá; 14 = Ijuí; 15 = Ipiranga do Sul; 16 = Itatiba do Sul; 17 = Lagoa Vermelha; 18 = Não-Me-Toque; 19 = Palmeira das Missões; 20 = Panambi; 21 = Passo Fundo; 22 = Pejuçara; 23 = Porto Mauá; 24 = Quatro Irmão; 25 = Santa Bárbara do Sul; 26 = Santo Augusto; 27 = Sarandi; 28 = Sertão; 29 = Tapejara; 30 =Vila Lângaro.

probability. Analysis of variance was performed using the number of crops on which farmers use VRT as the factor and the perceived percentage reduction of fertilizer applied in soybean as a variable. Position measurements and dispersion and correlation were adopted for analysis of the expected benefits and perceived in the adoption of VRT and the difficulties in adopting VRT and the barriers to expansion and/or prevention technology. For data analysis, we used SPSS (Statistical Package for Social Sciences) and Assistat (Statistical Assistance).

Results and discussion

The age of farmers using VRT ranged from 22 to 63 years, with a mean age of 40.2 years (standard deviation 9.95) (Table 2). This age is

Table 1. Number of producers, minimum, maximum, average and standard deviation of soy acreage and soybean VRF in the 2009 to 2014 vintages.

Area for soybeans without the adoption of VRF					
Year	**n[a]**	**Minimum[b]**	**Maximum[b]**	**Mean[b]**	**Standard deviation**
2009/2010	81	50,00	800,00	164,99	105,069
2010/2011	81	63,00	900,00	175,09	112,943
2011/2012	81	68,00	890,00	179,62	112,099
2012/2013	81	68,00	850,00	185,63	109,662
2013/2014	81	70,00	1100,00	192,81	130,219
Area for soybeans with the adoption of VRF					
Year	**n[a]**	**Minimum[b]**	**Maximum[b]**	**Mean[b]**	**Standard deviation**
2009/2010	81	0	382,00	30,99	69,152
2010/2011	81	0	420,00	67,05	87,609
2011/2012	81	0	500,00	106,95	97,068
2012/2013	81	0	454,00	139,84	90,049
2013/2014	81	45,00	600,00	164,53	93,229

[a] Number of respondents. [b] Values hectare.

Table 2. Education (degree) and age of adopters of VRF on soybean in RS state.

	Frequency	**%**	**% accumulative**
Complete Primary Education Degree	3	3.7	3.7
Incomplete high school	5	6.2	9.9
High school	36	44.4	54.3
Incomplete higher	16	19.8	74.1
Graduated	20	24.7	98.8
Master and / or Ph.D.	1	1.2	100.0
Total	81	100.0	

	n	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Age	81	22	63	40.20	9.96

similar to Danish and American adopters, with average ages of 43 and 46 years, respectively (Fountas et al., 2005). In 90.1% of cases, the VRT adopters have an education above the state average, with most having finished high school. According to the IBGE (2015a), the level of education for the RS population aged 25 years or more is 7.5 years of education, while the national average is 7.1; this is equivalent to "completing elementary school."

AP differs from other technologies introduced in agricultural production because it consists of a complex set of tools, each with a specific purpose (Khanna et al., 1999; Khanna, 2001) and require more educated farmers. In this sense, the farmers of this study have more years of formal education than most farmers, which would be likely to adopt an innovation more quickly, unlike those with a lower education level, which corroborates the the findings of Rogers (2003), Roberts et al. (2004) and Isgin et al. (2008).

Difficulties in adopting and the barriers for expansion of VRT

The adoption of technological innovations in agriculture is of fundamental importance for the economic and environmental sustainability of agricultural production, especially in subtropical environments.

For the RS soybean producers, the main difficulties for the adoption of VRT and with equal importance are: a) lack of information on VRT technology; b) lack of qualified personnel; c) VRT technology costs and d) high cost of service providers. These can be divided into two main items: related to knowledge (a and b) and related to costs (c and d). The least important factors are: a) lack of service providers; b) lack of funding; c) operational difficulty and d) VRT not always generating profit. (Table 3). The complexity of VRT technology could point to operational difficulties being a problem for adoption of the technology, which did not materialize, probably due to the presence of service providers and also the education of farmers sampled in this study (Table 3).

Farmers ranked the possible barriers to adoption of VRT in their properties. As can be seen in Table 4, the main barriers to the adoption of the VRT were: (i) difficulties in training employees for programs and equipment handling; (k) acquisition costs of equipment and software being high; (m) difficulties in hiring skilled labor; (j) amounts charged by technology companies being excessive. Again they can be grouped into two main factors: a) labor and b) technology costs. On the other hand, farmers realize (l) the benefits of adopting VRT and (j) do not consider the costs to outweigh the benefits generated. Despite producing crops in highly variable environments, producers think that the topography is not a barrier to expansion of the area with VRT (c) or the climatic variations that are characteristic of tropical environments interfere with the collection of reliable data (b) (Table 4).

Even if the cost of the technology is a barrier which inhibits its diffusion, the benefits generated by the VRT are considered higher than the cost. This fact was also reported for German farmers, stating that the adoption of technology could impact on financial benefits (Reichardt &

Table 3. Potential problems, number of respondents, mode, mean and standard deviation of the adoption of VRF by RS soybean producers.

Difficulties for the adoption of VRF	RN[a]					n[b]	M[c]	Me[d]	SD[e]
	1	2	3	4	5				
a) Cost of VRF technology	0	0	16	41	24	81	4	4.10	0.70
b) Lack of funding	10	51	13	7	0	81	2	2.21	0.77
c) Lack of qualified personnel	0	0	3	42	36	81	4	4.41	0.56
d) Lack of information on VRF technology	0	0	0	39	42	81	5	4.52	0.50
e) Lack of service providers	24	48	9	0	0	81	2	1.81	0.61
f) High Cost of service providers	0	5	9	45	22	81	4	4.04	0.79
g) Operational difficulty	0	68	0	13	0	81	2	2.32	0.73
h) Not always the system generates profit	6	57	3	15	0	81	2	2.33	0.86

[a] Respondent number by scale, Scale of 1 to 5, where 1 = strongly disagree and 5 = strongly agree

[b] Total number of respondents

[c] Mode

[d] Mean

[e] Standard Deviation

Table 4. Mean and standard deviation as possible barriers to the spread of the VRF by the RS soybean producers.

Barriers to the spread of VRF	RN[a]					n[b]	M[c]	Me[d]	SD[e]
	1	2	3	4	5				
a) VRF costs are greater than the benefits generated by technology.	47	32	2	0	0	81	1	1.44	0.548
b) Data collection on interference (climate, operational etc.) that hinder its implementation	42	35	3	1	0	81	1	1.54	0.633
c) Topography of soil prevents use	41	32	6	2	0	81	1	1.61	0.734
d) The AP service providers require a minimum of ha to meet the producer.	27	49	5	0	0	81	2	1.72	0.570
e) Precision equipment change rapidly and increase costs	25	50	6	0	0	81	2	1.76	0.576
f) It is difficult to assess the gain in production with the use of AP	22	47	5	7	0	81	2	1.96	0.828
g) Delay between the collection of soil samples to the generation of maps	20	48	2	4	7	81	2	2.13	1.602
h) Soil quality in the area limits the profitability of AP	18	46	4	13	0	81	2	2.14	0.950
i) Difficulties in training employee for programs handling and equipment	0	1	4	44	32	81	4	4.32	0.629
j) Amounts charged for the technology are not excessive	0	8	5	41	27	81	4	4.07	1.140
k) Acquisition costs of equipment and software are high	0	0	10	48	23	81	4	4.16	0.622
l) I can observe the benefits of VRF in my business	0	9	0	40	32	81	4	4.17	0.905
m) Difficulty of hiring skilled labor	2	2	12	38	27	81	4	4.06	0.899

[a] Respondent number by scale, Scale of 1 to 5, where 1 = strongly disagree and 5 = very agree.

[b] Total number of respondents.

[c] Mode.

[d] Mean.

[e] Standard Deviation.

Jürgens, 2009). Another important factor which hinders the diffusion of technology is skilled labor. This factor tends to be related to the technical knowledge of VRT, which corroborates the reports of Pedersen et al. (2004) and Fountas et al. (2005). Thus, it is important that the benefits generated by technology are measured and used as an information base for other producer's non-adopters.

Expected and perceived benefits in the adoption of VRT

When comparing the expected benefits and perceived by farmers after the adoption of VRT, the greatest expectation was with: (d) increased yield of soybean (100% of producers) followed by (b) rapid decision-making (82.7%), (f) rational use of fertilizers (79.0%) and (a) reduction of production cost (69.1%). The smaller expectations were: (g) to improve the quality of soil (16.0%) and (h) prioritization of investments in areas where the yield potential is higher (16.0%). On the other hand, the perceived benefits were: (d) the increased yield of the crop (86.6% of the producers), (f) rational use of fertilizers (70.4%) and (b) rapid decision-making (62.3%). Therefore, the farmers realized lower benefits than expected. The lower perceived benefits were: (e) the improvement of the environment (17.3%) and (h) prioritization of investments in areas where the yield potential is higher (24.7%) (Table 5).

Table 5. Perception of the expected and perceived benefits of VRF (%) of soybean producers in RS – Brazil, 2014 (n = 81).

Benefits	Expected		Perceived	
	No	Yes	No	Yes
a) Reduction in production costs	30.9	69.1	59.3	40.7
b) Rapid decision-making	17.3	82.7	37.7	62.3
c) Control of the property by the use of information	71.6	28.4	61.7	38.3
d) Increased yield of the crop	-	100	13.6	86.4
e) Environmental improvement	58.0	42.0	82.7	17.3
f) Rational use of fertilizers	21.0	79.0	29.6	70.4
g) Improvement of soil quality	84.0	16.0	60.5	39.5
h) Prioritization of investments in areas where the yield potential is higher	84.0	16.0	75.3	24.7

The results of the empirical study show that the difference between the expected and observed may be related to the number of crops (years) that the farmer uses the technology (Table 6). There is a positive correlation between all of the variables that express the expected use of the VRT and the number of crops that farmers adopt the technology. Thus, farmers tend to visualize the benefits of VRT, but to do this, they need to continue to adopt the technology.

The variation of soil type and rainfall patterns in subtropical environments directly and indirectly influence agricultural production (Zhang et al., 2002). Allied to this, the lack of technical knowledge regarding VRT tends to hinder the realization of the benefits in the early adoption of crops. Reports and studies in Denmark and the USA (Sørensen et al., 2002; Fountas et al., 2005) found that farmers had difficulties using the data collected for decision making in the application of the variable rate fertilizer, which could not generate benefits perceived by farmers. This may be occurring in RS, due to a lack of technical knowledge on VRT (Table 3) and the lack of skilled labor (Table 4), which would impact on the efficient use of technology and, consequently, its results. Thus, while farmers are continuing the use of VRT, they acquire knowledge about the technology and how to use it efficiently in their properties, increasing the benefits generated by technology.

Table 6. Correlation of variables that express the expectation of the use of VRF with the number of crops (years) that adopters use technology in soybean RS – Brazil, in 2014.

Variables that express the expectation of use of VRF	CCP[a] harvests
Reducing the cost of production	0.573*
Rapid decision-making	0.541*
Control of the property by the use of information	0.616*
Increased productivity of the crop	0.571*
Environmental improvement	0.582*
Rational use of fertilizers	0.655*
Soil quality improvement	0.638*
Prioritization of investments in areas where the yield potential is higher	0.536*

[a] Pearson's correlation coefficient, significant at $p < 0.01$.

Perceptions of farmers: optimizing the use of fertilizers with the adoption of VRT

The rational use of fertilizers is one of the major benefits provided by the adoption of VRT; thus, an important question is: What are the results perceived by farmers regarding the impact on the use of fertilizers from the adoption of the VRT?

In this sense, Table 7 shows the number of farmers who obtained a reduction in the use of fertilizers in the number of crops by adopting VRT. All farmers who adopt the VRT to four or more crops, realized a reduction in the use of fertilizer on soybean at a rate of 11 to 20%. This result differs from the study by Dellamea (2008), which found an average reduction of fertilizers by 33.1%. This difference may be related to the experimental data used by Dellamea (2008) and the number of crops where farmers adopt the technology and the previous history of the area.

Table 7. Number of producers who have reduced the use of fertilizer as the number of crops with VRF increases. RS – Brazil, in 2014.

Number of Crops	Number of producers by% reduction in fertilizer use			Total
	Less than 10%	11 to 20%	do not know	
1	0	0	6	6
2	5	1	8	14
3	8	11	1	20
4	0	23	0	23
5	0	10	0	10
6	0	5	0	5
7	0	3	0	3
Total	**13**	**53**	**15**	**81**

Variable	Pearson correlation coefficient
	Number of Crops
Fertilizers	0,745*

*Significant at $p < 0.01$.

The perception of the reduction of fertilizer is related to the number of crops on which farmers use VRT. With the increased number of crop-adopting technology, farmers tend to perceive a reduction in fertilizer use. This fact is explained by the better distribution of fertilizers in the management in the application of inputs (Reyes et al., 2015). With succeeding crops, there is a more efficient use of fertilizer.

The analysis of variance for the reduced amount of fertilizer, and as a factor the number of crops on which farmers use VRT, was significant, demonstrating that there is a difference between farmers, depending on the number of harvests using VRT. The farmers were classified in two homogeneous groups. The first group is formed of farmers who adopted VRT in one or two crops. The second group is formed by farmers who adopted the VRT for three or more crops. Thus, from the third crop adoption, the reduced amount of fertilizer remains constant, with minor variations which do not differ significantly, in all producers who adopt the technology for more than three harvests realize the same percentage of fertilizer reduction (10 to 15%) when compared with traditional systems (Table 8).

Table 8. Mean values of the reduced use of fertilizers (%), number of VRF crops and number of producers of each crop.

Number of crops	Number of producers	Group of farmers[a]	
		1	2
1	6	0[b]	-
2	14	2.86	-
3	20	-	10.25
4	23	-	15.00
5	10	-	15.00
6	5	-	15.00
7	3	-	15.00
Sig.		0.84	0.29

[a] Groups formed by Scheffe test ($p < 0.05$).

[b] The reduction of average values for fertilizer use / number of crops.

These results are important globally, given that one of the key challenges for humanity in the coming years is to offer food without harming the integrity of the environment (Foley et al., 2011). Therefore, technologies aimed at reducing and/or rationality in the application of agricultural inputs should be intensified. In this sense, the use of VRT technology to reduce the excessive application of agricultural fertilizers is highlighted on both the national and international scene.

Conclusion

Even in subtropical environments, large variations in soil and climate, and farmers with small and medium areas of cultivation, precision agriculture can bring benefits to farmers and improve grain production. Although this study sampled farmers with a higher education than the average of producers in the region, issues related to knowledge and cost are factors that hinder the adoption of VRT. In addition, the main barriers are a lack of qualified personnel and technology costs. On the other hand, the benefits perceived by farmers were lower than expected. All adopters of VRT had reduced the amount of fertilizer used, with the greatest reductions seen from the third VRT use.

The difficulty in adopting VRT is related to knowledge and technology cost. Spread measures of the knowledge of precision tools, either through public or private agencies, become important in view of the benefits of technology, especially in environmental aspects. Moreover, the cost of technology is an initial barrier to the adoption of VRT. After this phase, the benefits generated become visible to farmers, and are higher than the cost of its implementation. Thus, credit line mechanism for investment in early adoption tends to benefit its dissemination.

Expectations regarding the benefits of VRT are not always implemented in the first year of adoption. The trend is to adopt the technology by a sequence of crops; the farmer can realize its benefits. Some become visible in the first harvests, while others only become apparent after a sequence. In this regard, the reduction in fertilizer use is noticeable to farmers after the third year of VRT adoption.

Therefore, the adoption of VRT can be disseminated as an alternative in optimizing natural resources and reducing the environmental impact (caused by overestimated use of agricultural fertilizers). Therefore, it is necessary to create mechanisms that encourage the adoption and dissemination by farmers based on the factors “cost” and “knowledge.”

References

AUBERT, B.A.; SCHROEDER, A.; GRIMAUDO, J. IT as enabler of sustainable farming: an empirical analysis of farmers’ adoption decision of precision agriculture technology. **Decision Support Systems**, v.54, p.510-520, 2012. DOI: https://doi.org/10.1016/j.dss.2012.07.002.

BATTE, M.T.; ARNHOLT, M.W. Precision farming adoption and use in Ohio: case studies of six leading-edge adopters. **Computers and Electronics in Agriculture**, v.38, p.125-139, 2003. DOI: https://doi.org/10.1016/S0168-1699(02)00143-6.

BATTE, M.T.; JONES, E.; SCHNITKEY, G.D. Computer use by Ohio commercial farmers. **American Journal of Agricultural Economics**, v.72, p.935-945, 1990. DOI: https://doi.org/10.2307/1242625.

BERNARDI, A.C. de C.; FRAGALLE, E.P.; INAMASU, R.Y. Inovação tecnológica em Agricultura de precisão. In: INAMASU, R.Y.; NAIME, J. de M.; RESENDE, A.V. de; BASSOI, L.H.; BERNARDI, A.C. de C. (Ed.). **Agricultura de precisão**: um novo olhar. São Carlos: Embrapa Instrumentação, 2011. p.297-302. Available at: <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1002959/agricultura-de-precisao-resultados-de-um-novo-olhar>. Accessed on: Dec. 17 2015.

BERRY, J.K.; DELGADO, J.A.; KHOSLA, R.; PIERCE, F.J. Precision conservation for environmental sustainability. **Journal of Soil and Water Conservation**, v.58, p.332-339, 2003. Available at: <https://www.jswconline.org/content/58/6/332>. Accessed on: Dec. 17 2015.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Vegetal**: cultura da soja. 2015. Available at: <http://www.agricultura.gov.br/vegetal/culturas/soja>. Accessed on: Dec. 17 2015.

CONAB. Companhia Nacional de Abastecimento. **Safras**: culturas de verão: série histórica. 2014. Available at: <http://www.conab.gov.br/conteudos.php?t=2&a=1252&filtrar=1&f=1&p=115&e=0&d=0&m=0&s=0&ac=0&tps=0&lvs=0&l=0&ed=0&i=>. Accessed on: Dec. 28 2015.

DELLAMEA, R.B.C. **Eficiência da adubação a taxa variável em áreas manejadas com agricultura de precisão no Rio Grande do Sul**. 2008. 161p. Dissertação (Mestrado) - Universidade Federal de Santa Maria, Santa Maria.

FOLEY, J.A.; RAMANKUTTY, N.; BRAUMAN, K.A.; CASSIDY, E.S.; GERBER, J.S.; JOHNSTON, M.; MUELLER, N.D.; O’CONNELL, C.; RAY, D.K.; WEST, P.C.; BALZER, C.; BENNETT, E.M.; CARPENTER, S.R.; HILL, J.; MONFREDA, C.; POLASKY, S.; ROCKSTRÖM, J.; SHEEHAN, J.; SIEBERT, S.; TILMAN, D.; ZAKS, D.P.M. Solutions for a cultivated planet. **Nature**, v.478, p.337-342, 2011. DOI: https://doi.org/10.1038/nature10452.

FOUNTAS, S.; BLACKMORE, S.; ESS, D.; HAWKINS, S.; BLUMHOFF, G.; LOWENBERG-DEBOER, J.; SORENSEN, C.G. Farmer experience with precision agriculture in Denmark and the US Eastern Corn Belt. **Precision Agriculture**, v.6, p.121-141, 2005. DOI: https://doi.org/10.1007/s11119-004-1030-z.

FOUNTAS, S.; PEDERSEN, S.M.; BLACKMORE, S. ICT in Precision Agriculture –diffusion of technology. In: GELB, E.; OFFER, A. (Ed.). **ICT in agriculture**: perspective of technological innovation. Jerusalem: The Hebrew University of Jerusalem, 2005. Available at: <http://departments.agri.huji.ac.il/economics/gelb-table.html>. Accessed on: Mar. 22 2016.

GALLUP, J.L.; SACHS, J.D. Agriculture, climate, and technology: why are the tropics falling behind? **American Journal of Agricultural Economics**, v.82, p.731-737, 2000. DOI: https://www.jstor.org/stable/1244634.

HIRAKURI, M.H.; LAZZAROTTO, J.J. **O agronegócio da soja nos contextos mundial e brasileiro**. Londrina: Embrapa Soja, 2014. (Embrapa Soja. Documentos, 349). Available at: <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/990000/o-agronegocio-da-soja-nos-contextos-mundial-e-brasileiro>. Accessed on: Dec. 17 2015.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Cidades**: Rio Grande do Sul. 2015a. Available at: <http://cidades.ibge.gov.br/xtras/temas.php?lang=&codmun=430020&idtema=123&search=rio-grande-do-sul|ajuricaba|producao-agricola-municipal-lavoura-temporaria-2012>. Accessed on: Mar. 22 2016.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Estatística da Produção Agrícola**. 2015b. Available at: <http://www.ibge.gov.br/home/estatistica/populacao/trabalhoerendimento/pnad2013/default_reponderadas.shtm>. Accessed on: Dec. 28 2015.

ISGIN, T.; BILGIC, A.; FORSTER, D.L.; BATTE, M.T. Using count data models to determine the factors affecting farmers' quantity decisions of precision farming technology adoption. **Computers and Electronics in Agriculture**, v.62, p.231-242, 2008. DOI: https://doi.org/10.1016/j.compag.2008.01.004.

KHANNA, M.; EPOUHE, O.F.; HORNBAKER, R. Site-specific crop management: adoption patterns and incentives. **Review of Agricultural Economics**, v.21, p.455-472, 1999. DOI: https://doi.org/10.2307/1349891.

KHANNA, M. Sequential adoption of site-specific technologies and its implications for nitrogen productivity: a double selectivity model. **American Journal of Agricultural Economics**, v.83, p.35-51, 2001. DOI: https://doi.org/10.1111/0002-9092.00135.

PATERNIANI, E. Maize breeding in the tropics. **Critical Reviews in Plant Sciences**, v.9, p.125-154, 1990. DOI: https://doi.org/10.1080/07352689009382285.

PEDERSEN, S.M.; FOUNTAS, S.; BLACKMORE, B.S.; GYLLING, M.; PEDERSEN, J.L. Adoption and perspectives of precision farming in Denmark. **Acta Agriculturae Scandinavica, Section B-Soil & Plant Science**, v.54, p.2-8, 2004. DOI: https://doi.org/10.1080/09064710310019757.

PEDERSEN, S.M.; FOUNTAS, S.; BLACKMORE, S.; PEDERSEN, J.L.; PEDERSEN, H.H. Adoption of precision farming in Denmark. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 4., 2003, Berlim. **Precision agriculture**: proceedings. Wageningen: Wageningen Academic Publishers, 2003. p.533-538. Editors J. Stafford and A. Werner.

PRIOLLI, R.H.G.; MENDES-JUNIOR, C.T.; SOUSA, S.M.B.; SOUSA, N.E.A.; CONTEL, E.P.B. Diversidade genética da soja entre períodos e entre programas de melhoramento no Brasil. **Pesquisa Agropecuária Brasileira**, v.39, p.967-975, 2004. DOI: https://doi.org/10.1590/S0100-204X2004001000004.

REICHARDT, M.; JÜRGENS, C. Adoption and future perspective of precision farming in Germany: results of several surveys among different agricultural target groups. **Precision Agriculture**, v.10, p.73-94, 2009. DOI: https://doi.org/10.1007/s11119-008-9101-1.

REICHARDT, M.; JÜRGENS, C.; KLÖBLE, U.; HÜTER, J.; MOSER, K. Dissemination of precision farming in Germany: acceptance, adoption, obstacles, knowledge transfer and training activities. **Precision Agriculture**, v.10, art.525, 2009. DOI: https://doi.org/10.1007/s11119-009-9112-6.

REYES, J.F.; ESQUIVEL, W.; CIFUENTES, D.; ORTEGA, R. Field testing of an automatic control system for variable rate fertilizer application. **Computers and Electronics in Agriculture**, v.113, p.260-265, 2015. DOI: https://doi.org/10.1016/j.compag.2015.03.003.

ROBERTS, R.K.; ENGLISH, B.C.; LARSON, J.A.; COCHRAN, R.L.; GOODMAN, W.R.; LARKIN, S.L.; MARRA, M.C.; MARTIN, S.W.; SHURLEY, W.D.; REEVES, J.M. Adoption of site-specific information and variable-rate technologies in cotton precision farming. **Journal of Agricultural and Applied Economics**, v.36, p.143-158, 2004. DOI: https://doi.org/10.1017/S107407080002191X.

ROGERS, E.M. Elements of diffusion. **Diffusion of innovations**. 5th ed. New York: Simon & Schuster, 2003.

SØRENSEN, C.G.; FOUNTAS, S.; BLACKMORE, S.; PEDERSEN, H.H.; ROBERT, P.C. Information sources and decision making on precision farming. In: INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE AND OTHER PRECISION RESOURCES MANAGEMENT, 6., 2002, Minneapolis. P**roceedings**. St. Paul: University of Minnesota, 2002. p.1683-1695.

TORBETT, J.C.; ROBERTS, R.K.; LARSON, J.A.; ENGLISH, B.C. Perceived improvements in nitrogen fertilizer efficiency from cotton precision farming. **Computers and Electronics in Agriculture**, v.64, p.140-148, 2008. DOI: https://doi.org/10.1016/j.compag.2008.04.003.

TSCHIEDEL, M.; FERREIRA, M.F. Introdução à agricultura de precisão: conceitos e vantagens. **Ciência Rural**, v.32, p.159-163, 2002. DOI: https://doi.org/10.1590/S0103-84782002000100027.

WALTON, J.C.; LARSON, J.A.; ROBERTS, R.K.; LAMBERT, D.M.; ENGLISH, B.C.; LARKIN, S.L.; MARRA, M.C.; MARTIN, S.W.; PAXTON, K.W.; REEVES, J.M. Factors influencing farmer adoption of portable computers for site-specific management: a case study for cotton production. **Journal of Agricultural and Applied Economics**, v.42, p.193-209, 2010. DOI: https://doi.org/10.1017/S1074070800003400.

ZHANG, F.-S.; YAMASAKI, S.; NANZYO, M. Waste ashes for use in agricultural production: I. Liming effect, contents of plant nutrients and chemical characteristics of some metals. **Science of the total Environment**, v.284, p.215-225, 2002. DOI: https://doi.org/10.1016/S0048-9697(01)00887-7.