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Risk and return of soybeans precision production: a case study in Mato Grosso do Sul state, Brazil[1]

Keywords: risks, returns, precision agriculture, soybeans, Brazil

JEL Code: Q14, Q16

Precision agriculture (PA) has not yet spread in Brazil, despite the benefits stressed in literature. Considering the uncertainty related to PA's results, this study evaluated the tradeoff between risks and returns for precision production of soybeans in Mato Grosso do Sul state, Brazil. A representative farm using PA was compared to a conventional production system through the Earnings-at-Risk metric and a Modified Sharpe Index. PA presented higher expected earnings per hectare while conventional production proved to have a lower risk exposure. The positive difference in expected earnings between precision and conventional systems was insufficient to cover PA's risk exposure, leading to the conclusion that less risk-averse farmers could assume higher risks and prefer precision system.

1. Introduction

Despite the potential benefits related to the use of precision agriculture (PA) – like productivity gains or pollution reduction – and the time elapsed since its development, several studies have shown that this agricultural production system has not effectively spread worldwide (McBride and Daberkow, 2003; Griffin and Lowenberg-DeBoer, 2005; Reichardt and Jürgens, 2009; Mondal and Basu, 2009). Somehow, one could explain this contradiction by the risks associated with PA use or, more directly, by the uncertainty related to agriculture's results under this production system. As far as we know, only Tozer (2009) considered uncertainty in the context of production systems choice, showing that, for his farm case study, the returns from investment in precision agriculture were higher than if investments had been made in conventional system.

This result reinforces the ideas of Plant (2001), that the most risk-averse farmers will only adopt PA when convinced that time and money applied in

[1] The authors gratefully acknowledge the financial support of the Coordination for the Improvement of Higher Education Personnel (CAPES).

DOI: 10.13128/REA-23577
ISSN (print): 0035-6190
ISSN (online): 2281-1559

Published by Firenze University Press
www.fupress.com/rea

the operationalization of this production system are justified by productivity gains or reductions in costs or risks. With this in mind, one could stress the importance of analyzing the possible tradeoff between risks and returns on the utilization of PA tools and concepts. For countries like Brazil, where agricultural production plays a key role in national economy performance (OECD, 2015) and PA has not been widely diffused yet (Bernardi and Inamasu, 2014), this kind of analysis could present significant importance. Seen this, the objective of this research was to explore the risk-return tradeoff related to the utilization of PA in the soybeans production.

Seeking to attain the proposed goal, it was decided to use the case study as research modality. This procedure focuses on the investigation of a well-delimited specific case, in order to perform detailed search of information (Ventura, 2007). Specifically, this study analyzed a Brazilian farm located in the city of Chapadão do Sul, Mato Grosso do Sul state, which applied PA concepts to its soybean plantation. This farm emulates the main characteristics raised by Bernardi and Inamasu (2014) for Mato Grosso do Sul state farms that use PA techniques, considered as a representative farm. Thus, it is believed that the analysis of this case study may reflect, to some extent, the reality of the analyzed region.

In order to enrich the analysis, the results of the precision system were compared with those achieved by the conventional soybean production. According to the Brazilian Institute of Geography and Statistics (IBGE), soybean cultivation represented, in average, approximately half of the agricultural production value for Brazilian Central-West region, Mato Grosso do Sul state and Chapadão do Sul city during the period analyzed in this research (from 2008 to 2015), evidencing the importance of soybean cultivation for the studied region. In addition, soybean is stressed as one of the crops with greater use of PA concepts in Brazil and worldwide (Griffin *et al.*, 2004; Griffin and Lowenberg-DeBoer, 2005; Bernardi and Inamasu, 2014).

Considering the possible impacts of PA on farmers' finances, risk was evaluated as the potential loss of harvest earnings and it was contrasted with the economic results achieved by the agricultural activity. The Earnings-at-Risk metric and a Modified Sharpe Index were the methodological tools applied to the investigation of the risk-return tradeoff. The purpose of this analysis was to provide evidences of the soybean producers' risk exposure when utilizing the PA system in Brazil. Following this, if the gains in productivity and earnings could compensate agricultural risks, this research could provide an empirical basis for the proposition of public policies related to the promotion of PA tools and concepts in Brazilian agriculture.

This article aims to fill a gap in the literature by the explicit analysis of the risk-return tradeoff related to the PA utilization. Specifically, we performed an economic evaluation of the risks involved in the use of PA on a real farm and the returns associated to this production system. It is argued that, despite being based on a case study of a representative farm, this analysis is capable of presenting initial evidence about the risk exposure and the economic returns observed by a farmer who uses PA concepts and tools. Going further, comparing PA results with those of conventional agriculture can help in understanding the current level of PA adoption in Brazil.

The analysis shows that, for the considered case, soybean production under precision system generates higher earnings in comparison to the conventional production. In contrast, Earnings-at-Risk estimations showed that PA is relatively riskier than conventional system. In other words, there is evidence that the use of precision techniques gives rise to greater returns in exchange for greater exposure to risk, highlighting the tradeoff between risk and return. The tradeoff analysis showed that, for most of the considered years, the positive difference between precision and conventional earnings could not suppress the risk related to the soybean production under the precision system.

The paper is organized in three more sections, besides this Introduction. Section 2 details the materials and methods used in the empirical analysis, while Section 3 presents the results achieved. Finally, some conclusions are drawn in Section 4, highlighting the possible policy implications of the results found.

2. Materials and methods

Yin (2003) presents a set of five major rationales that ensure the single-case study as an appropriate research design. Among them is the revelatory case in which the single-case study can serve as a revealing tool. It occurs when the researcher is able to observe and analyze a situation that few or no other researchers had prior access to, although this may be a relatively common phenomenon. In spite of not been widely used in Brazil, PA is present in several Brazilian states (Bernardi and Inamasu, 2014). In this sense, we conducted an exploratory case study on a specific case of PA utilization in order to provide initial evidence about an important phenomenon that can (and should) later be investigated further by other researchers.

As stated by Gerring (2007), a single-case study research design, by definition, relies on a single, relatively bounded unit. As previously expressed, the main object of study is the precision system applied to a soybean farm in the Mato Grosso do Sul state, Brazil. This farm was chosen because it is considered one of the pioneers in the use of precision techniques in Brazil. The transition from conventional to precision production started in the early 2000s.

However, for the time interval considered in this study, the whole area cultivated with soybeans used PA concepts. The farm is equipped with crop yield monitor installed on GPS-equipped combine harvesters and variable-rate input applicator (VRT). Fertilizers are the only inputs applied using VRT, while seeds, pesticides, and lime are applied by uniform-rate. In fact, Bernardi and Inamasu (2014) show that two-thirds of Mato Grosso do Sul farmers who adopt PA techniques on their farms use these tools in crop fertilization.

Seeking to enrich the analysis, this study also analyzed the economic results of the so-called conventional system. In order to make a direct comparison, both systems are located in the same Brazilian municipality, Chapadão do Sul, Mato Grosso do Sul state. The conventional system refers to the direct plantation system most used in the studied region. The data for this system were gathered from the National Supply Company (Conab), which manages Brazilian farm inventories, providing regional spreadsheets with average productivity and production costs measured in a one-hectare basis. As Conab uses the mode of the technological package applied in the municipality's agricultural activity to calculate the spreadsheets and anecdotal information points to a low use of PA in the analyzed location, it is argued that a comparison of the results is possible.

Since it is expected that PA has direct impact on the utilization of productive inputs, it was opted to consider only the operational costs of the agricultural activity. The calculation of revenue, total operational costs (TOCs) and earnings series were based on the averaged productivities and operational costs by hectare early gathered. Revenue for both production systems was obtained by multiplying the selling price obtained from the manager of the farm and the respective productivity. TOCs are the sum of the crop cost expenses[2]. Differences in the initial investment required for each productive system are implicitly considered in the value of the depreciation. Earnings are given by the simple difference between revenue and TOCs. All monetary values are presented in 2015 value basis.

The risk analysis of the soybean production systems was carried out by the utilization of the Earnings-at-Risk (EAR) metric (RiskMetrics, 1999). This tool, based on the primary concepts developed for the Value-at-Risk (VAR) metric, corresponds to the calculation of the maximum loss in the earnings of a commercial activity, considering specifics time horizon and confidence interval. Mathematically, the EAR for date T, analyzed in t with confidence level of (1-α%) can be defined as:

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2 Specifically, it was considered the costs of seeds, fertilizers, pesticides, labor, maintenance, operational and financial expenses, depreciation, and taxes.

$$P(Earnings \leq EAR) = \alpha\%$$

The comparison between the risk exposure of the analyzed systems was conducted through the construction of a Modified Sharpe Index (MSI). Differently than the index originally proposed by Sharpe (1966), MSI is not calculated in percentage terms but in a monetary basis. This index is based on the profitability differences of the production systems, measuring the ratio of profitability gains to its degree of risk. This index is represented by the following formula:

$$MSI = \frac{\mu_i}{EAR_i}$$

wherein EAR_i is the EAR calculated for system i, and μ_i is the return's differential for system i, wich is given by:

$$\mu_i = \frac{\sum_{j=1}^{t} R_{ij} - R_{fj}}{t}$$

wherein R_{ij} is risky system's return, R_{fj} risk-free system's return, and t is the considered time interval.

The conventional production was considered as the risk-free system, while the PA was the risky one. This option was made because of the presumption that the precision system could generate profit gains when compared to the conventional system, providing positive differentials in the returns of the soybean cultivation.

The EAR metric was empirically operationalized with a simulation-based approach, wherein the distribution of future economic results is generated by a large set of scenarios, considering the effects of key-components that are treated as stochastic variables. It is summarized in five steps: i) metric specification; ii) exposure mapping; iii) scenario generation; iv) valuation; and v) risk measure computation.

Based on the precision system used by the analyzed agricultural company and its differences with the conventional system, soybean productivity and fertilizer costs were chosen as the stochastic variables of the model. It was not considered the stochastically nature of the soybean prices because the focus was to capture the variations of the agriculture's economic results solely related to the production systems and their specific characteristics.

As stated earlier, the database comprehends the harvests from 2008/2009 up to 2014/2015, corresponding to seven observations for each one of the soybean production systems. Due to the sparse nature of the data, the series of the stochastic variables were treated with the kernel smooth approach, generating smoother cumulative density functions. The probability distributions of the stochastic variables were empirically determined. Scenarios were generated by Latin Hypercube sampling technique (McKay *et al.*, 1979).

3. Results

In order to compare risks and returns of precision and conventional systems, each of the studied harvests was separately considered as basis for the stochastic simulation. With this procedure, different scenarios were generated for both of the analyzed systems. Table 1 shows expected earnings for the seven scenarios and for both of the production systems. As the base harvest changes, moving from 2008/2009 to 2014/2015, real earnings by hectare systematically decreased for both systems. This pattern could be explained by the substantive fall of real soybean prices.

Tab. 1. Expected earnings for soybeans production under precision and conventional systems in US$ per hectare.

Production system	Harvest						
	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015
Precision	1,261.37	967.14	1,019.29	705.12	637.64	540.33	287.96
Conventional	1,178.39	924.16	902.92	633.16	592.63	504.25	280.92

Source: Research results.

For all scenarios the precision system presented higher expected earnings by hectare than the conventional system. These last results, on the other hand, could be explained by the meaningful productivity gains of the precision system in comparison to the conventional system. Examining the same region, Silva *et al.* (2007) found similar results. Their paper shows that, considering the harvests of 2002/2003, 2003/2004, and 2004/2005, soybean production under precision system had higher profitability than conventional production.

Similar to the present study, Tozer (2009) also relied on a farm case study, but he applied the real options method for the evaluation of investment returns from an investment in a precision agriculture system relative to a conventional system. Besides methodological differences, his study found favorable results to the returns of precision system as found here and by Silva *et al.* (2007).

Based on the Earnings-at-Risk (EAR) methodology, the worst possible variation on earnings by harvest was estimated for both production systems. It was considered a confidence level of 95%. Table 2 presents the EAR estimations for precision and conventional systems. For a better understanding of risk exposure, the EAR was also presented – in parentheses – in percentage terms, measured in relation to expected earnings.

Tab. 2. Estimated Earnings-at-Risk for soybeans production under precision and conventional systems, in US$ per hectare and as percentage of expected earnings, confidence interval of 95%.

Production system	Harvest						
	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015
Precision	125.82	113.82	115.64	110.38	99.41	100.25	84.82
	9.99	*11.79*	*11.36*	*15.69*	*15.63*	*18.61*	*29.62*
Conventional	83.05	81.05	81.34	80.38	78.45	78.59	75.89
	7.05	*8.77*	*9.00*	*12.67*	*13.21*	*15.55*	*26.91*

Note: Percentage in italic.
Source: Research results.

While precision system achieved the highest expected earnings, it can be seen that the lowest risk exposure was obtained by the conventional system. For all analyzed scenarios the worst possible variations were related to soybean production with PA. Both in monetary and relative terms precision system proved more risky than conventional system. This situation perfectly illustrates the tradeoff between risk and return, meeting the theoretical framework developed by Markowitz (1952, 1959). Therefore, one can consider that, compared to conventional system, the greater earnings of precision system were obtained through increased exposure to risk.

Going further, the tradeoff between risk and return evidenced in previous results were explored more deeply. For this, the Modified Sharpe Index was used. This tool demonstrates the return obtained per unit of risk and was previously used in other agricultural risk analysis (e.g. Leissman *et al.*, 2004; Lazzarotto *et al.*, 2009; Pereira *et al.*, 2010; Moreira *et al.*, 2014). Table 3 shows MSI estimations for each harvest considered as the basis of the simulation.

All harvests presented positive indexes. Since the numerator of the MSI equation is the simple difference between precision and conventional soybean production earnings, these results were expected since, as we previously dem-

Tab. 3. Estimated Modified Sharpe Index for soybeans production, confidence interval of 95%.

Harvest	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015
MSI	0.66	0.38	1.01	0.65	0.45	0.36	0.08

Source: Research results.

onstrated, soybean production under precision system generates higher earnings than conventional production.

On the other hand, it is evident that for most harvests the index presented values smaller than one. The single exception is when the 2010/2011 harvest was taken as the base, although for this scenario the index is only slightly larger than one. That is, for six of the seven scenarios considered, the positive premium received – precision expected earnings minus conventional expected earnings – was proportionally lower than the assumed risk, given by the estimated EAR.

Together, these results suggest that the highest earnings per hectare reached by soybean production via precision system have their price, given that this system proved to be more risky than the conventional system, considering the possibility of a decrease in earnings per hectare.

4. Conclusions

This study demonstrated that, for the soybean production in the analyzed region, the possibility of a decrease in earnings per hectare is higher under precision system than under the conventional system. Initial expenses for precision tools acquisition were not explicitly considered, but the greater investment required by this production system could led to the result previously highlighted.

Although it was more risky than conventional production, precision system showed the highest expected earnings per hectare. These results then lead to the known tradeoff between risk and return. While being more risky, precision agriculture can achieve a greater reward. In this sense, one can expect farmers with less risk aversion to prefer the precision system. Nevertheless, it was also shown that, in general, the additional gain obtained by the precision system is not able to cover its risks.

Following this, it was concluded that risk averse farmers will tend to produce soybeans under conventional system. However, the use of risk management tools as crop insurance could make precision agriculture attractive even for this kind of farmers. Therefore, the results found here could guide public policies to promote the utilization of PA techniques.

Given the particular characteristics of the analyzed farm, one should take parsimony in the generalization of the results found here. Still, these results can give an idea of the nature of the risks and returns of soybean production in Mato Grosso do Sul state, Brazil. It should also be noted the fact that this research, as a single-case study, relies on data observed for a specific farm. Although the analyzed farm potentially represents the reality of its region, more comprehensive results could be achieved by analyzing a set of farms that use precision agriculture techniques.

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