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ECONOMIC INFLUENCES OF THE APPLICATION OF DIFFERENT MANAGEMENTS, FORMULATIONS AND DOSES OF GLYPHOSATE ON ROUNDUP READY® SOYBEAN

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ABSTRACT: The choices regarding agricultural practices used in the production system directly reflect the economic profitability of the crop to farmers. The application of glyphosate is one of the most widespread practices in RR soybeans, however aiming to solve the control, problem in the fields, this practice sometimes is mistakenly used, damaging the development of RR soybeans, which reflects in its productivity and hence in gross income provided by culture. For quantifying economically possible losses caused by RR soybean, this study aims to analyze the economic impact regarding glyphosate application. RR Soybean income productivity data were used subjected to the application of glyphosate, in different managements, formulations and doses. In experiments conducted in two distinct regions, located in the State of Paraná, during 2011/2012 and 2012/2013 crops and, the soybean sack values (60 kg) between the years 2011 and 2015, establishing an average of 62.59 reais per soybean sack (R$ sc^{-1}), used for the calculation of income in reais per hectare (R$ ha^{-1}). The obtained results show that there is a potential of RR soybean crop reduced profitability when used high doses of glyphosate, regardless of formulations or managements. This draws attention to conducting more studies in this area, aiming at a more conscious positioning of this technology, thus enabling increases in profitability for the soybean producers.

KEY WORDS: *Glycine max*; Transgenic crops; Profitability.

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IMPACTOS ECONÔMICOS DA APLICAÇÃO DE DIFERENTES MANEJOS, FORMULAÇÕES E DOSES DE *GLYPHOSATE* NA SOJA RR

RESUMO: As escolhas em relação às práticas agrícolas utilizadas em um sistema de produção refletem diretamente na rentabilidade econômica da cultura ao produtor rural. A aplicação de *glyphosate* é uma das práticas mais disseminadas no cultivo da soja RR, entretanto na busca em solucionar o problema de controle de plantas daninhas na lavoura, essa prática em alguns casos é utilizada erroneamente, prejudicando o desenvolvimento da soja RR, o que reflete em sua produtividade e, consequentemente, na receita bruta proporcionada pela cultura. Para quantificar economicamente esses possíveis prejuízos promovidos à soja RR, este estudo teve como objetivo analisar o impacto econômico da aplicação de *glyphosate*. Foram utilizados os dados de produtividade da soja RR submetida à aplicação de *glyphosate*, em diferentes manejos, formulações e doses, em experimentos realizados em duas regiões distintas, situadas no Estado do Paraná, durante as safras 2011/12 e 2012/13 e, os valores da saca da soja (60 kg) entre os anos de 2011 e 2015, estabelecendo-se um valor médio de 62,59 reais por saca de soja (R$ sc^{-1}), utilizado para os cálculos do rendimento, em reais por hectare (R$ ha^{-1}). Os resultados obtidos mostraram que há um potencial de redução na rentabilidade da cultura da soja RR quando são utilizadas altas doses de *glyphosate*, independente das formulações ou manejos utilizados. Isso chama a atenção para a realização de mais estudos nessa área, visando um posicionamento mais consciente desta tecnologia, e assim possibilitando aumentos na rentabilidade do sojicultor.

PALAVRAS-CHAVE: Culturas transgênicas; *Glycine max*; Rentabilidade.

INTRODUCTION

The currently increase of foodstuffs production is becoming essential, but at the same time, the farmers' profitability must be improved aiming sustainability within the production system. For this to be achieved, it is necessary the appropriate use of new technologies available, such as Roundup Ready (RR), which is tolerant to glyphosate.

The soybean crop, due to its high production potential and its chemical composition that adds a complete nutritional value to their grains, constitutes in the main specie grown in Brazil. This crop presents a large source of protein for humans

and animals as well as being one of the major oil sources, presented as a meaningful "commodity" in Brazilian market.

According to the latest survey of the Brazilian grain crop (2018/2019), from 62.5 million hectares (ha) cultivated, soybean occupies 35.8 million ha; it means 57.2% of the planted grain area in the country. Regarding the domestic production of grains, soybean accounts for 48.6% of total production by adding all crops, corresponding to 96.04 million tons of soybean grain, which represents 113.5 million t (CONAB, 2019).

In addition to the soybean yield increase achieved during the recent years in Brazil, there was also a higher adoption of RR soybean, (93.5% of the total soybean crop area in 2014/2015) (CÉLERES, 2015). These values represent a significative growth if considered that RR soybean was released in Brazil in 2004. Thus, the current RR soybean cultivation in the country reached similar levels to those of Argentina and United States, where RR technology was introduced earlier (CIB, 2015).

According to data obtained from Sindicato Nacional da Indústria de Produtos para Defesa Vegetal (SINDIVEG, 2015), in 2014 the soybean crop represented 55.6% of pesticide sales in Brazil, which corresponds to 6.8 billion dollars. From all pesticides sold in the country during 2014, 52% of the volume was represented by herbicides, which corresponded to 476.860 tons.

In this context, the RR technology is noteworthy fully supported in the efficient use of glyphosate, which is representing around 12 to 14% of the pesticides' market on the world and has a stake between 38 to 40% in the herbicide market. The annual output of glyphosate acid is around one billion kilograms, which represented an average growth rate of 15% per year in the world market, according to the previous years evaluated (VELINI *et al.*, 2009; MONSANTO, 2011).

The glyphosate is relevant both in the global and in national pesticides' market, highlighting the significance of this product and its large use. Products containing glyphosate are registered in more than 130 countries. Worldwide, there are over 150 brands sold containing glyphosate, and its control is proven to more than 300 weed species, being used in more than 100 crops (MONSANTO, 2012; VELINI *et al*., 2009).

RR soybean has the enzyme EPSPs from the *Agrobacterium* sp. (PADGETTE *et al*., 1995), which is insensitive to glyphosate, thereby making the transgenic plant tolerant to this herbicide. Even if the glyphosate mechanism of action is extensively researched and known, some of its possible effects on plants are not fully elucidated. These effects may have implications on plant growth and microorganisms (OLIVEIRA JR. *et al*., 2011), and eventually on the RR crops.

Research results show that glyphosate, applied in post-emergence of RR soybeans, can influence in the nutritional balance, as well as cause phytotoxic effects. It can also affect the water use efficiency in photosynthesis, biomass accumulation, seed quality, yield as well as the crop development (ZABLOTOWICZ; REDDY, 2007; ZOBIOLE *et al*., 2010a, 2010b, 2010c; ALBRECHT; ÁVILA, 2010, ALBRECHT, *et al*., 2011a, 2011b, ALBRECHT, *et al*., 2012a, 2012b, ALBRECHT, *et al.*, 2014a, 2014b, 2014c; ALONSO *et al*., 2013). These results present the possible decrease in crop income and consequently may affect its gross incomes, then minimize the profits made by the soybean producer.

Due to the huge economic importance of the soybean crop in the national and world scenario, this is the focus of many researches aimed at obtaining information by allowing increases in yield and production costs' reduction, achieving greater profitability for farmers. It has required a constant adaptation and further study of technologies, as well as carrying out a work for demonstrating the economic impacts of these technologies and products.

In this context, the current literature that economically quantify the possible losses arising from the use of glyphosate on RR soybean are not found. This study aims to analyze the actual economic impact regarding of the application of different managements, formulations and doses of glyphosate on RR soybean and consequently on the soybean producer profitability.

2 MATERIAL AND METHODS

The yield data were grouped in two experiments evaluated from two crop seasons. These experiments could show, among other variables, the RR soybean income when glyphosate was spayed into different managements, formulations and

doses. These studies evaluated the effects of different trademarks of glyphosate, applied under different ways, and doses, simulating actual field situations.

The yield results used in this study are referent to experiments carried out during 2011/2012 and 2012/2013 seasons in different locations, as well as Assis Chateaubriand (Experiment I), situated in the western of Paraná state, and Marialva (Experiment II), located in the north of the same state. These regions are well known for its great production potential related to soybean and other crops.

The experimental design used for both experiments, was a randomized block with four replications, where the treatments were arranged in triple factorial design 2x2x5 (formulations x managements x doses), totalizing 20 treatments and 80 plots (Table 1).

Table 1. Treatments carried out with both formulations of glyphosate (isopropylamine salt and potassium salt). Paraná - 2011/2012 and 2012/201 crops seasons

Glyphosate doses (g a. e. ha^{-1})	
Management 1 - single application	Management 2 – sequential application
0	0 + 0
720	360 + 360
1440	720 + 720
2160	1080+ 1080
2880	1440 + 1440

The management 1 was conducted by the single application of glyphosate (two formulations) in V4 stage, and the treatment 2 was comprised of sequential glyphosate applications (two formulations), the first in V4 stage and the second between the V5 stage and V6 (10 days after the first application). All doses are expressed in grams of acid equivalent per hectare (g a.e.ha^{-1}). The glyphosate formulations used are: Isopropylamine salt (Roundup Ready) and potassium salt (Zapp QI) (RODRIGUES; ALMEIDA, 2011). Both are registered and widely used in brazilian soybean cultivation.

The general managements as fertilization and pests' control followed the requirements of Embrapa (2011). Experimental areas were kept free from weeds by hand hoeing, in order to isolate only the glyphosate effect sprayed on the crop.

All other field operations followed the recommended standards for agricultural experimentation.

After harvesting these experiments, which the data were expressed in kilograms per hectare (kg ha^{-1}), it was transformed into sacks per hectare (sc ha^{-1}), because the sack of 60 kilograms is the measurement unit for soybean sales in Brazil (CEPEA, 2015a). These results in sc ha^{-1} were then multiplied by the value considered in this study for soybean sack, with the final result in reais per hectare (R$ ha^{-1}), related to gross incomes or profitability the farmer would have in one hectare.

The value applied in this study for the soybean sack was obtained through the Cepea/Esalq indicator for the Paraná state, where they caught a complete source of prices from Cepea to the State. Thus, it was calculated an average of the soybean sack between 07/01/2011 and 07/01/2015, which includes since the early period of the experiments, until the last year in the final crop season evaluated, totaling four years raised prices. The price applied in this study was R$ 62.59 per soybean sack (R$ sc^{-1}) (CEPEA, 2015b). At that moment the dollar exchange rate average was R$ 2.04, considering the same period evaluated, which corresponds to a price of US$ 30.68 (US$ sc^{-1}).

To explain the economic impact of glyphosate application on RR soybean, a statistical analysis was performed, as well as the creation of tables and figures for displaying the effects of this herbicide on soybeans gross income. In addition, there were some practical and applicable calculations to the current scenario, for quantifying the possible economic losses of this.

The data (R$ ha^{-1}) were analyzed according to Pimentel-Gomes and Garcia (2002). After observing the assumptions for the analysis of variance, the post analysis was performed ($p<0,05$). To evaluate the factor dose, it was used a regression analysis, while the F test was conclusive in the comparison of means, for qualitative treatments (managements and formulations).

3 RESULTS AND DISCUSSION

Based on the results presented on tables 2, 3, 4 and 5, it is clear that occurred few significant differences, being displayed only on Tables 3 and 5, but these do not establish a defined pattern of behavior.

Table 2. RR soybean income, subjected to the application of two managements, two formulations and five doses of glyphosate. 2011/2012 crop, experiment I, Assis Chateaubriand - PR

Doses (g a. e. ha^{-1})	Isopropylamine salt (R)		Potassium salt (Z)		Average
	Income (R$ ha^{-1})				
	M 1	M 2	M 1	M 2	
0	1967.47	2005.73	1933.56	1960.49	1966.81
720	1739.86	2056.31	1909.17	1979.16	1921.12
1440	1842.97	1850.73	2006.83	1810.29	1877.70
2160	1869.20	1882.59	1936.97	1859.73	1887.12
2880	1963.64	2148.01	1847.55	1881.03	1960.06
Average	1876.63	1988.67	1926.82	1898.14	
	1932.65		1912.48		1922.56
CV (%)	7.00				

No significant (P <0.05) by F test.

Source: Created by the author (2015).

Table 3. RR soybean income, subjected to the application of two managements, two formulations and five doses of glyphosate. 2012/2013 crop, experiment I, Assis Chateaubriand - PR

Doses (g a. e. ha^{-1})	Isopropylamine salt (R)		Potassium salt (Z)		Average
	Income (R$ ha^{-1})				
	M 1	M 2	M 1	M 2	
0	3398.03 Aa	3393.41 Aa	3276.22 Aa	3181.00 Aa	3312.16
720	3345.24 Aa	3387.59 Aa	3277.82 Aa	2886.46 Bb	3224.28
1440	3231.60 Aa	3318.68 Aa	2976.37 Aa	3220.45 Aa	3186.77
2160	3085.29 Aa	3106.99 Aa	3278.25 Aa	2961.56 Aa	3108.02
2880	3425.38 Aa	3082.86 Aa	3169.77 Aa	2955.24 Aa	3158.31
Average	3297.10	3257.91	3195.68	3040.94	
	3277.51		3118.31		3197.91
CV (%)	8.58				

Capital letters in the same line among the formulations (R and Z) within each management and dose do not differ significantly (P <0.05) by F test. Lowercase letters in the same line, between management (application only - M1 and sequential application - M2) in each formulation and dose not differ significantly (P <0.05) by F test.

Source: Created by the author (2015).

Table 4. RR soybean income, subjected to the application of two managements, two formulations and five doses of glyphosate. 2011/2012 crop, experiment II, Marialva - PR

Doses (g a. e. ha^{-1})	Isopropylamine salt (R)		Potassium salt (Z)		Average
	Income (R$ ha^{-1})				
	M 1	M 2	M 1	M 2	
0	1075.19	1002.62	942.62	1065.46	1021.47
720	998.08	1039.18	982.22	1082.47	1025.49
1440	954.10	1017.55	1036.52	1092.29	1025.11
2160	1027.32	996.63	1014.76	1017.30	1014.00
2880	1002.51	928.95	1056.59	949.00	984.26
Average	1011.44	996.99	1006.54	1041.30	
	1004.22		1023.92		1014.07
CV (%)	11.26				

No significant (P <0.05) by F test.

Source: Created by the author (2015).

Table 5. RR soybean income, subject to the application of two managements, two formulating and five doses of glyphosate. 2012/2013 crop, experiment II, Marialva - PR

Doses (g a. e. ha^{-1})	Isopropylamine salt (R)		Potassium salt (Z)		Average
	Income (R$ ha^{-1})				
	M 1	M 2	M 1	M 2	
0	4009.42 Aa	3791.71 Aa	3906.74 Aa	3998.98 Aa	3926.71
720	3738.36 Ab	4169.01 Aa	4026.13 Aa	3957.61 Aa	3972.77
1440	4142.51 Aa	3959.19 Aa	4199.58 Aa	4154.06 Aa	4113.84
2160	3851.70 Aa	4177.16 Aa	3654.12 Ab	4107.69 Aa	3947.67
2880	4046.73 Aa	4031.09 Aa	4127.43 Aa	3842.99 Aa	4012.06
Average	3957.74	4025.63	3982.80	4012.27	
	3991.69		3997.54		3994.61
CV (%)	7.12				

Capital letters in the same line among the formulations (R and Z) within each management and dose do not differ significantly (P <0.05) by F test. Lowercase letters in the same line, between management (application only - M1 and sequential application - M2) in each formulation and dose do not differ significantly (P <0.05) by F test.

Source: Prepared by the author (2015).

Thus, it can be noted that the single or sequential application of doses (management 1 and 2), and two formulations used (R and Z), showed effects which could not determine that a formulation or handling caused greater damage than the other on the RR soybean income (R$ ha^{-1}), in these two experiments conducted during two crop seasons. Significant effects on gross income soybeans were evident in the factor doses, regarding the interaction, as shown on Figures 1, 2 and 3.

Comparing the tables, it is clear that there was a large difference in gross income between the periods. This occurred due to unfavorable weather conditions in 2011/2012, in which a drought period in some regions of Paraná affected crop production (GLOBO RURAL, 2012), and consequently its profitability. This can be seen when comparing Figure 1 and 3 with Figure 2. Regarding the 2012/2013 crop, the environmental conditions were according to historical averages for the two regions, thus the soybean income was different from the expected for this crop season.

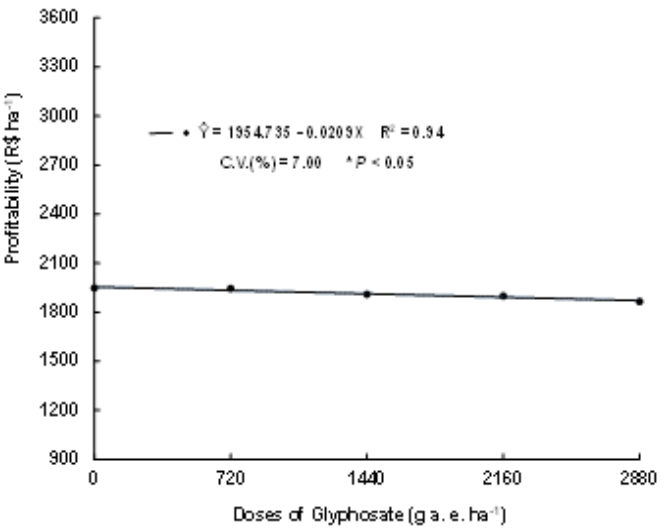

Figure 1. RR soybean income, according to the doses of glyphosate in Z formulation (potassium salt). 2011/2012 crop, experiment I, Assis Chateaubriand - PR

Source: Created by the author (2015).

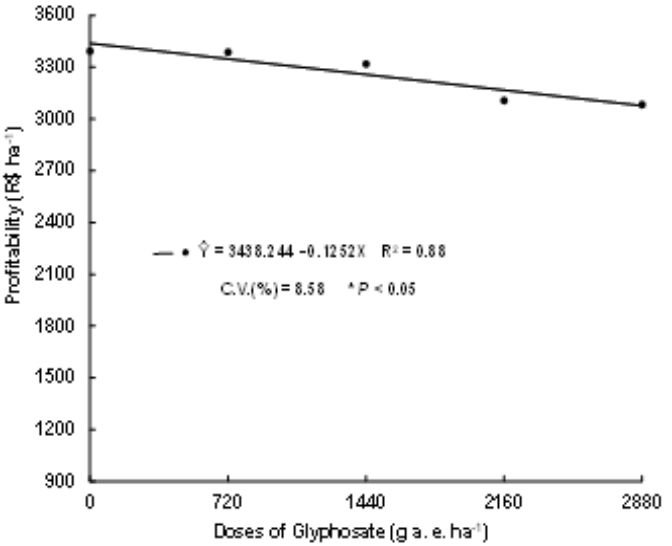

Figure 2. Income of RR soybean, according to the doses of glyphosate in the formulation R (isopropylamine salt), within management 2 (sequential application). 2012/2013 crop, experiment I, Assis Chateaubriand - PR

Source: Created by the author (2015).

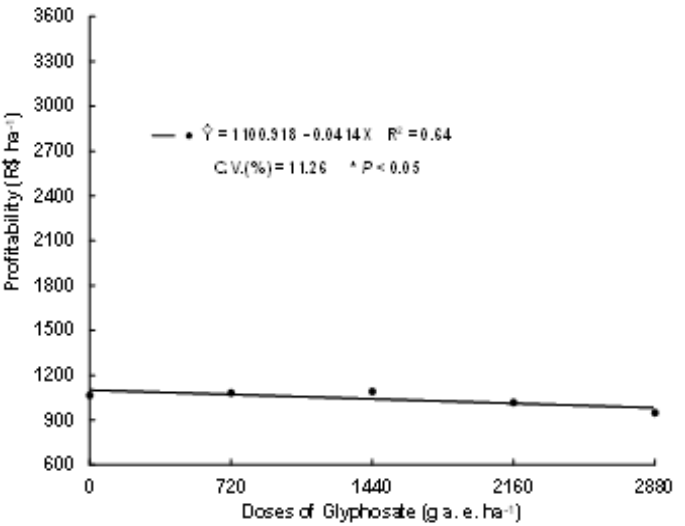

Figure 3. RR soybean Income, according to the rates of glyphosate in Z formulation (potassium salt) within the management 2 (sequential application). 2011/2012 crop, experiment II, Marialva- PR

Source: Created by the author (2015).

The results showed significant effects ($P<0, 05$), as shown in Figures 1, 2 and 3. In the results presented in these figures it was possible to set a negative linear model due to the increase of doses.

The data represents a reduction of soybean income, with the increase of the glyphosate doses. In Figure 1, using the regression equation, there was a decrease of R$ 0.0209 ha^{-1} (2.09 cents) for each g e.a.ha^{-1} of glyphosate, or R$ 60.19 ha^{-1} (US$ 29.5 ha^{-1}) loss in the highest dose (2880 g a.e.ha^{-1}). Making the same calculations for Figure 2, there is a decrease of R$ 0.1252 ha^{-1} (12.52 cents) to each g e.a.ha^{-1} of glyphosate, corresponding to R$ 58 ha^{-1} (US$ 28.4 ha^{-1}) in the highest dose as well. Finally, in Figure 3 we have a decrease of R$ 0.0414 ha^{-1} (4.14 cents) to each g e.a.ha^{-1} of glyphosate, or a loss of R$ 119.23 ha^{-1} (US$ 58.4 ha^{-1}) in the biggest dose.

As explained, in some experiments there were not financial losses according to increased doses, however it should be noted that in some situations it is observed high values in return loss, such as shown in Figure 2. These damages are variable according to the production system, crop and cultivar (Albrecht et al, 2014b), but it can indeed exist. It is also important to note that, according to recent results, the damage often affects the soybean production and consequently its financial return, without showing any visual effect (ALBRECHT *et al*., 2014b).

In this context, it is important that the application of high doses of glyphosate on RR soybean, as some that were tested here, have no recommendation (RODRIGUES; ALMEIDA, 2011), but some growers eventually use high doses of this product, without awareness of the possible financial losses caused by increasing the dose, and the growing problem of resistant weeds to herbicides, as well as high infestations, and high weeds, or permanent, make this practice more common. Thus, the farmer ends up acting wrongly, and applying high doses of this product, (C. Vale[7], 2014; Cocamar[8], 2013 - oral information; ALBRECHT *et al*., 2013).

The maximum recommended dose for the two products used herein is around of 1440 g a.e.ha^{-1}, in single or sequential application (RODRIGUES; ALMEIDA, 2011). Following this logic and approaching the damage seen in Figure 2, there is a

[7] Information provided by field technicians C. Vale, Palotina, in 2014 on RR soybean and the use of herbicides by farmers.

[8] Information provided by the COCAMAR field technicians, Maringá, 2013 on RR soybean and the use of herbicides by farmers.

decrease of R$ 0.1252 ha^{-1} (12.52 cents) to each g $a.e.ha^{-1}$ of glyphosate. Therefore, the damage is R$ 180.29 ha^{-1} in the dose of 1440 g $a.e.ha^{-1}$.

According to the Céleres (2015), the State of Paraná presented in 2014/2015 crop season, 91.4% of its soybean acreage being planted with RR soybean, which results in 4,7 million hectares. If extrapolating to the entire State of Paraná, the loss displayed in Figure 2, in a hypothetical scenario, would have lost an amount of R$ 847.4 million (US$ 415.39 million) in one crop season. For the whole country, the damage could be around R$ 5.3 billion (US$ 2.59 billion).

In this conjuncture, where soybean has great importance in the national economic scenario, as an important component of our trade balance, there is a magnitude involving this crop. Regarding exports related to the soybean complex, from September 2013 to August 2014, Brazil exported US$ 24.5 billion in soybeans, US$ 6.65 billion in bran and US$ 1.35 billion in oil, totaling US$ 32.5 billion in that period and, the trend for the next years is that soy would further increase its performance in our economy (DALL'AGNOL, 2015).

Thus, one should beware of the economic impact of some cultural practices, such as applying glyphosate in RR soybean and, in addition to soybeans, this herbicide is also used in other transgenic crops, such as corn and cotton, and in these other crops, this technology is also widespread in Brazil (CIB, 2015; CÉLERES, 2015). Moreover, a product such as glyphosate, even though having inumerous advantages and benefits compared to other herbicides (GALLI; MONTEZUMA, 2005; VELINI *et al.*, 2009), must be used safely due to their immense marketing and representation (VELINI *et al.*, 2009; MONSANTO, 2011; SINDIVEG, 2015).

It is good to emphasize that the economic impact caused by the use of glyphosate, should be carefully analyzed. If the weed management in soybean is not satisfactory, the losses by the weeds' interference can be much larger than those of the glyphosate effect (OLIVEIRA JR. *et al*., 2011). There are also other herbicides in the market and depending on the using conditions, they may lead to higher profitability decreases than the glyphosate.

These results show that even in a consolidated technology as RR soybean, which is widely accepted by brazilian farmers, there are still potential for economic damage occurring regarding the great scenery. Even on a small farm, where a low

loss can be very crucial when considered the small profit margin that the farmer has in some crops, due to a competitive agriculture and constantly having to deal with weather and market instabilities. Besides the loss in produced quantity, it also may occur losses in the product quality, as reported in the literature (ALBRECHT; ÁVILA, 2010, ALBRECHT, *et al.*, 2011a, 2011b, ALBRECHT, *et al*., 2012a, 2012b, ALBRECHT, *et al*., 2014a, 2014c).

In the technological agriculture, it is necessary to apply the best tools and use evolving methods and concepts to improve incomes. In a world where there are ruptures of increasingly frequent technologies, it is important to know how to deal with the complexity of the production environment to make it as profitable as possible.

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CONCLUSION

From the exposed and discussed results, it is possible to note that potential profitability decreases in RR soybean may occur caused by the application of high doses of glyphosate, and its damage can affect the gross farmer's income, regardless of formulations or managements used. Based on that information, it is necessary to be stimulating a more conscious stance of this technology, enabling increases in profitability of the soybean producer, and thus contribute to sustainability in agricultural production systems.

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