ISSN: 1984-5529

Científica

Dracena, São Paulo, Brasil v.50, 2022

DOI: https://doi.org/10.15361/1984-5529.2022.v.50.1403

Agronomic, economic and energy performance of imidazolinone-tolerant soybean (with *csr1-2* gene)

Desempenho agronômico, econômico e energético de soja tolerante a imidazolinonas (com gene *csr1-2*)

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Recebido em: 22-02-2022; Aceito em: 02-09-2022

Abstract

Cultivance® (CV) transgenic soybeans are tolerant to imidazolinone herbicides, conferred by the *csr1-2 gene*. Even in herbicide-tolerant crops, negative effects on plant performance can be observed. In this context, the objective of this study was to evaluate agronomic performance, economic viability, oil content and energy balance of soybean tolerant to imidazolinones under application of imazapic + imazapyr doses. The test was conducted in an area located in Palotina, state of Paraná, Brazil, in the 2015-2016 season. A randomized block design was used, in which the treatments consisted of the application of 11 doses of imazapic + imazapyr in post-emergence (V4) of soybeans. Agronomic performance, economic viability, oil content and energy balance of soybeans were evaluated. Decrease at CV soybean yield were observed from the application of 157.5 + 52.5 g of acid equivalent (a.e.) ha-1 imazapic + imazapyr. Negative effects were observed on other parameters for application of high doses. Decrease in profit were found from the dose 78.75 + 26.25 g a.e. ha-1, decrease in oil content from 131.25 + 43.75 g a.e., and from 105/35 g a.e. ha-1 a negative energy balance was observed. The application, in post-emergence of soybean (V_4), of imazapic + imazapyr up to the maximum dose recommended in the package insert (52.5 + 17.5 g a.e. ha-1) was safe for soybean plants tolerant to imidazolinones (with gene *csr1-2*), regarding agronomic performance, oil content, economic viability and energy balance. Doses above 52.5 + 17.5 g a.e. ha-1 negatively influenced the performance of soybeans in one or more of these aspects.

Additional keywords: Acetolactate synthase (ALS); cultivance**®** soybean; imazapic + imazapyr; soybean oil; soybean yield.

Resumo

A soja transgênica Cultivance® (CV) é tolerante aos herbicidas imidazolinonas, conferida pelo gene *csr1-2*. Mesmo em culturas tolerantes a herbicidas, podem ser observados efeitos negativos no desempenho das plantas. Nesse contexto, o objetivo deste trabalho foi avaliar o desempenho agronômico, viabilidade econômica, teor de óleo e balanço energético da soja tolerante a imidazolinonas sob aplicação de doses imazapic + imazapyr. O experimento foi realizado em uma área localizada em Palotina, estado do Paraná, Brasil, na safra 2015-2016. Utilizou-se delineamento em blocos casualizados, os tratamentos consistiram na aplicação de 11 doses de imazapic + imazapyr em pós-emergência (V_4) da soja. Foram avaliados o desempenho agronômico, viabilidade econômica, teor de óleo e balanço energético da soja. Reduções na produtividade de soja CV foram observadas a partir da aplicação de 157,5 + 52,5 g de equivalente ácido (e.a.) ha^{-1} imazapic + imazapyr. Efeitos negativos foram observados em outros parâmetros para aplicação de altas doses. Reduções nos ganhos foram observadas a partir da dose 78,75 + 26,25 g e.a. ha^{-1}, no teor de óleo a partir de 131,25 + 43,75 g e.a. ha^{-1}, e a partir de 105 + 35 g e.a. ha^{-1} observou-se balanço energético negativo. A aplicação, em pós-emergência da soja (V_4), de imazapic + imazapyr até a dose máxima recomendada na bula (52,5 + 17,5 g e.a. ha^{-1}) não teve efeito negativo para plantas de soja tolerantes a imidazolinonas (com o gene *csr1-2*), quanto ao desempenho agronômico, teor de óleo, viabilidade econômica e balanço energético. Doses acima de 52,5 + 17,5 g e.a. ha^{-1} influenciaram negativamente o desempenho da soja em um ou mais desses aspectos.

Palavras-chave adicionais: Acetolactato sintase (ALS); soja Cultivance®; imazapic/imazapir; óleo de soja; produtividade da soja.

Introduction

Transgenic soybean Cultivance® (CV), event BPS-CV127-9, shows tolerance to imidazolinone herbicides, which is conferred by the *csr1-2* gene, derived from *Arabidopsis thaliana*, which encodes a modified acetolactate synthase (ALS) enzyme, insensitive to imidazolinones (Roux et al., 2005; EFSA, 2014). The insertion of the *csr1-2* gene does not interfere with the levels of amino acids in the plant, and the nutritional composition of the grains produced is equivalent to that of non-GMO soybeans (EFSA et al., 2018).

Imidazolinones are ALS-inhibiting herbicides, thereby inhibiting the synthesis of branched amino acids (leucine, isoleucine, and valine). Consequently, protein synthesis is interrupted, which in turn interferes with DNA synthesis and cell growth. Examples of ALS-inhibiting herbicides include imazaquin, imazethapyr, imazamox, imazapic, and imazapyr. They are systemic herbicides recommended for pre- and post-emergence control of many monocots and broadleaf weeds in cereals, soybeans and in non-agricultural areas (Hess et al., 2010).

The imazapic + imazapyr formulated premix can be applied in pre-emergence and initial post-emergence (up to stage V_1) of CV soybeans, up to a dose of 52.5 + 17.5 g acid equivalent (a.e.) ha^{-1} (Rodrigues & Almeida 2018). The application of imazapic + imazapyr, up to a dose of 157.5 + 52.5 g a.e. ha^{-1} did not affect the agronomic performance of the soybean cultivar BRS-397 CV at the phenological stages V_1, V_3 and V_6 (Biazoto et al., 2020). While Hungria et al. (2015) did not observe any effects on the biological fixation of the CV soybean, either by the transgenic event or by the application of imazapyr. Pereira et al. (2021) observed the tolerance of CV soybeans to imazapic + imazapyr, but doses higher than recommended (52,5 + 17,5 g a.e. ha^{-1}) negatively affected the agronomic performance of soybeans. Even so, there are few studies evaluating the agronomic performance, especially economic and energetic performance of CV soybean.

Even in transgenic crops tolerant to herbicides, negative effects on plant performance can be observed. For glyphosate-tolerant soybeans, in application of doses of the herbicide above that recommended by the package insert, Moreno et al. (2018) reported decrease in economic return and negative energy balance. In turn, Striegel et al. (2020) analyzed yield of soybean tolerant to glufosinate, to dicamba and glyphosate or non-transgenic soybean, and observed similarity in profits for tolerant transgenic cultivars and with superiority over the non-transgenic cultivar. However, the authors did not evaluate the use of herbicides at doses above the official recommendation. Applications of herbicides above the maximum recommended dose are eventually used under field conditions. Therefore, it is necessary to investigate the effects of such doses. As well as there are no studies that evaluate the agronomic performance, economic viability, oil content and energy balance of soybean tolerant to imidazolinones.

Therefore, the objective of this study was to evaluate agronomic performance, economic viability, oil content and energy balance of soybean tolerant to imidazolinones under application of imazapic + imazapyr doses.

Material and Methods

Description of the experimental site

The study was conducted in an area located in Palotina, state of Paraná (PR), Brazil (24°20'49"S 53°51'32"W), in the 2015-2016 season. The soil in the experimental area was classified as clayey (45% clay, 32% silt and 23% sand), the chemical properties in the 0-20 cm layer are listed in Table 1. The climate of the region is Cfa, according to the Köppen classification, 346 m altitude. Data of temperature and rainfall during the experimental period are illustrated in Figure 1.

Experimental design

It was used the soybean cultivar BRS 397 CV (event BPS-CV127-9, with gene *csr1-2*), from the maturity group 6.2, with an indeterminate growth habit, average levels of protein and oil of 38.2% and 22%, respectively. Sowing, in no-till system, took place on October 01, 2015, with a density of 310,000 seeds ha^{-1}, with row spacing of 0.45 m. The experimental units consisted of plots with 6 rows of 5 m, with a useful area of 3.6 m^2 for the evaluations. The experimental area was kept free from weed interference throughout development, through manual weeding.

This was a randomized block design with four replications and 11 treatments represented by the doses of imazapic + imazapyr: 0; 26.25 + 8.75; 52.5 + 17.5; 78.75 + 26.25; 105 + 35; 131.25 + 43.75; 157.5 + 52.5; 183.75 + 61.25; 210 + 70; 236.25 + 78.75, and 262.5 + 87.5 g a.e. ha^{-1}. These doses correspond respectively to 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, and 5 X the dose recommended in the product package insert. It was used the commercial product Soyvance® Pré (imazapic + imazapyr 525/175 g a.e. kg^{-1}, Basf S.A., São Paulo, SP, Brazil).

Treatments were applied when the soybean was at the V_4 stage. A CO_2 pressurized backpack sprayer at a constant pressure of 2 bar at a flow dose of 0.65 L $min.^{-1}$, equipped with 6 fan nozzles Teejet® XR 110.02. With application at 50 cm from the target and speed of 1 m s^{-1}, providing an application volume of 200 L ha^{-1}. The treatments were applied on October 30, 2015, under temperature of 25.6 ºC, wind speed 5 km h^{-1} and relative humidity of 63.7%.

Table 1 - Results of the chemical analysis of the soil of the experimental area.

P	K^+	C	Ca^{2+}	Mg^{2+}	$H^+ + Al^{3+}$	Al^{3+}	SB[1]	CEC[2]	pH ($CaCl_2$)	V[3]
mg dm^{-3}					$cmol_c\ dm^{-3}$					%
30.44	0.30	14.45	2.67	0.95	3.69	0.00	3.92	7.61	4.5	51.51

[1] sum of bases, [2] cation exchange capacity, [3] base saturation.

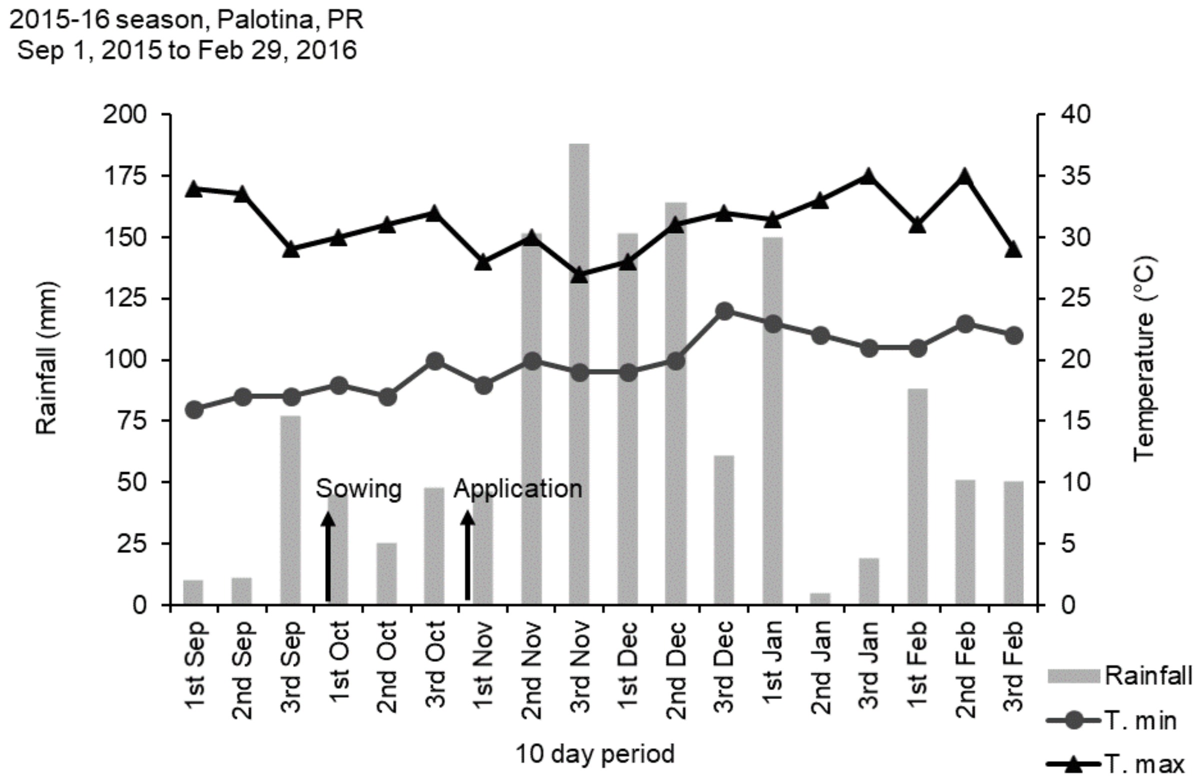

Figure 1. Meteorological conditions for the period of conduct of the experiment. Palotina, Parana state, Brazil, 2015-16.

Agronomic performance

Soybean plants in the useful area were harvested manually at full maturity (R_8). After harvesting, pods were threshed in an experimental thresher, cleaned with the aid of sieves and packed in paper bags. For yield, total grains harvested in the useful area had the mass measured, with the values extrapolated to kg ha^{-1}. For 100-grain mass, we measured the mass of 8 sub-samples of 100 grains per plot. For both variables, values were corrected for 13% moisture of the grains.

The statistical analysis of the data was performed following univariate procedures, with application of analysis of variance by F-test ($p \leq 0.05$), and the means were compared by Tukey's test, at the level of 5% probability. These analyses were run in the Sisvar 5.6 software (Ferreira, 2011).

Total production cost

The series of soybean prices for the formation of its average for the same period was US$ 23.30 per bag of 60 kg (CEPEA, 2017). In turn, the cost of phytosanitary products was determined from the average of practical costs in the region where the study was conducted. Other production costs were estimated based on data from CEPEA (2017). To estimate the total production cost (TPC), it was based on the effective operating cost (EOC) and the administrative and social charges (Matsunaga et al., 1976).

Economic viability

For the economic viability analysis of oil production from soybeans, the following factors were used according to the methodology proposed by Martin et al. (1998):

a) Gross income (GI): is the expected revenue for a given activity and technology and the respective yield per hectare, for a preset sale price.

GI = Y . UP,

Where: Y = yield of the activity per unit area; UP = unit price of the product of the activity.

b) Operating profit (OP) or net revenue: the difference between GI and TPC per hectare. The operating profit result indicator measures the profitability of the activity in the short term, showing the financial and operating conditions of the activity.

OP = GI – TPC,

c) Profitability index (PI): this indicator shows the relationship between OP and GI, in percentage. It is an important measure of profitability of the agricultural activity, since it shows the available dose of revenue of the activity, after the payment of all operating costs.

PI = (OP / GI) . 100,

d) Leveling point (LP): cost indicator in relation to the unit produced, that is, it determines what is the minimum production necessary to cover the total cost, given the unit selling price.

LP = TPC / UP, (

e) Equilibrium price (EP): cost indicator in relation to the unit sold, that is, it determines what is the minimum price necessary, based on the production obtained, to cover the total cost.

Oil content

To analyze the soybean oil content of each treatment, the Soxhlet method, with petroleum ether solvent was used. It consists of the successive and intermittent treatment of the sample immersed in a pure solvent (petroleum ether, diethyl ether or n-hexane), by siphoning and subsequent condensation of the heated solvent inside the flask that is at the base of the apparatus (Cavalcante et al., 2011). Thus, the oil content and cake from the extraction, in kg ha^{-1}, were determined. The percentages were calculated in relation to soybean yield for the respective dose.

Data for oil contents (%) were subjected to statistical analysis, following univariate procedures, with application of analysis of variance by F-test ($p \leq 0.05$), and the means were compared by Tukey's (1949) test, at the level of 5% probability. These analyses were run in the Sisvar 5.6 software (Ferreira 2011).

Energy balance

The energy expenditure for the production of biodiesel from soybean oil was estimated based on the consumption of seeds, fertilizers, pesticides and other factors involved, based on studies by Gazzoni et al. (2005), and which provided the necessary energy for the production of each unit. To establish the energy balance of biodiesel production, three phases were divided: energy inputs and outputs in the soybean production (labor, machinery, fuel, inputs); energy input for industrial production (electricity, steam, water, losses and materials, such as steel and cement); and energy outputs from the production system (oil, cake and hull).

In relation to the agricultural stage, the calculations were focused on energy expenditure in pre-sowing, sowing, crop treatment (pesticides and fertilizers), harvesting and transportation during the production phase in the field. Adopting, according to Pimentel & Patzek (2005), the expenditure of 6.3 hours of labor ha^{-1} for the no-till sowing system, with the expense of 66 liters diesel oil ha^{-1} and for transportation (machinery, fuel, seeds and production flow), we considered the average distance of the crop from the distribution of inputs and production collection, at 150 km. For the herbicide values, the amount used was adopted according to each treatment and for the grains according to the yield of the experiments.

In the phase of energy inputs for industrial production, energy costs were calculated for converting the grain into oil and then converting the oil into biodiesel, based on data from Pimentel & Patzek (2005). The energy balance was calculated following the methodology of Risoud (1999), with the following equations:

EB = ∑ GEP - ∑ NREI,

Where, EB: energy balance; GEP: gross energy of products; NREI: non-renewable energy inputs.

EE = ∑ GEP / ∑ NREI, (

Where, EE: energy efficiency.

The total energy supplied by soybeans came from the calculation based on the sum of the energy equivalent of the product and its by-product resulting from the process. The main one is oil and cake is the by-product, which can be used in animal supplementation. In which, it is considered that 1 kg soybean oil ha^{-1} contains 9,000 kcal energy and that for each 1 kg cake ha^{-1} contains 4,000 kcal energy. On average, for every 1,000 kg soybeans, 180 kg oil and 820 kg cake are extracted (Gazzoni et al., 2005).

Results and Discussion

The TPC estimate is presented in Table 2. In the EOC, the value of US$ 511.20 ha^{-1} is observed, which involves the costs of operating machinery and implements, maintenance and general expenses, fertilizers, seeds, pesticides as insecticides, fungicides and herbicides, technical assistance, transport and taxes. Administrative charges amount to US$ 121.71 ha^{-1}, which range from charges to some unforeseen costs, while social charges totaled US$ 266.45 ha^{-1}.

Table 2 - Estimated production cost of CV soybeans. Palotina, Parana state, Brazil, 2015-16

Specification	US\$ ha^{-1}
Operation of machines and implements	96.04
Temporary employment	11.80
Soybean seeds	120.60
Fertilizers	120.64
Pesticides (insecticide and fungicide)	88.47
Imazapic + imazapyr[1] (herbicide)	35.00
External transport	28.61
Technical assistance	10.04
Effective operating cost (EOC)	511.20
Depreciation of machines and implements	77.51
Depreciation of improvements and facilities	14.08
Systematization and correction of soil	23.12
Capital insurance	7.00
Administrative charges	121.71
Permanent workforce	46.67
Remuneration of equity	60.03
Land remuneration	159.75
Social charges	266.45
Total production cost (TPC)	899.36

[1]Cost based on the application of imazapic + imazapyr (Soyvance® Pré) at the maximum recommended dose of package insert (52.5/17.5 g a.e. ha^{-1} equivalent to 100 g cp ha^{-1}).

The TPC operated at a value of US\$ 899.36 ha^{-1}, which consists of the sum of all production costs. Without considering the herbicide cost, we have a TPC of US\$ 864.36 ha^{-1}, this value was used for other calculations of the economic indices in Table 3, since the herbicide cost varied with the dose used.

Doses equal to or greater than 157.5 + 52.5 g a.e. ha^{-1} imazapic + imazapyr resulted in decrease in soybean yield in relation to the control (0 g a.e. ha^{-1}). With greater decrease for the highest dose (262.5/87.5 g a.e. ha^{-1}). Up to the dose of 131.25/43.75 g a.e. ha^{-1}, the application of the herbicide did not reduce soybean productivity in relation to the control (Table 3). For 100-grain mass, analysis of variance by F-test did not evidence a significant effect for the application of imazapic + imazapyr doses ($p > 0.05$), with a mean value of 16.67 g (data not shown).

Table 3 - Yield and economic indicators for cultivating CV soybeans. Palotina, Parana state, Brazil 2015-16.

Dose[1]	Yield	GI[2]	HC[3]	TPC[4]	OP[5]	PI[6]	EP[7]	LP[8]
g a.e. ha^{-1}	kg ha^{-1}			US\$		%	US\$	kg ha^{-1}
0	3,790 b	1,471.78	0.00	864.36	607.42	41.27	5.31	2,226
26.25 + 8.75	3,834 b	1,488.87	17.50	881.86	607.01	40.77	5.36	2,271
52.5 + 17.5	4,418 a	1,715.66	35.00	899.36	816.30	47.58	4.74	2,316
78.75 + 26.25	3,809 b	1,479.16	52.50	916.86	562.30	38.01	5.61	2,361
105 + 35	3,698 bc	1,436.06	70.00	934.36	501.70	34.94	5.89	2,406
131.25 + 43.75	3,534 bc	1,372.37	87.50	951.86	420.51	30.64	6.28	2,451
157.5 + 52.5	3,338 c	1,296.26	105.00	969.36	326.90	25.22	6.77	2,496
183.75 + 61.25	3,302 c	1,282.28	122.50	986.86	295.42	23.04	6.96	2,541
210 + 70	3,382 c	1,313.34	140.00	1.004.36	308.98	23.53	6.92	2,586
236.25 + 78.75	3,198 c	1,241.89	157.50	1.021.86	220.03	17.72	7.45	2,631
262.5 + 87.5	3,026 d	1,175.10	175.00	1.039.36	135.74	11.55	8.00	2,676
CV (%)	9.59	-	-	-	-	-	-	-

[1] Imazapic + imazapyr doses.
[2] Gross income, [3] herbicide cost, [4] total production cost (without HC), [5] operating profit, [6] profitability index, [7] equilibrium price, [8] leveling point.
Means followed by the same letter, on the rows, do not differ by Tukey's test, at the level of 5%.

With the increase in the doses of imazapic + imazapyr, from 78.75/26.25 g a.e. ha^{-1}, there was a decrease in profit from soybean production. At the recommended dose of the package insert, 52.5/17.5 g a.e. ha^{-1} equivalent to 100 g commercial product (cp) ha^{-1}, the highest profit (US\$ 816.30) was found, with PI of 47.58%, EP of US \$ 4.74 and LP of 2,316 kg ha^{-1}. Consequently, doses above 100 cp ha^{-1} also had a negative impact on PI, EP and LP, since, in addition to increasing costs, high doses can reduce soybean yield (Table 3).

The use of the herbicide at high doses can be harmful to the CV soybean crop, directly impairing its development and minimizing yield. When evaluating yield, it is noticed that it is linked to economic variables, which allow to compare performances. Thinking of herbicide-tolerant crops, in general, their adoption represented a decrease in costs and a consequent increase in profits (Striegel et al., 2020; Smyth et al., 2015; Swinton & Van Deynze, 2017).

Decrease in yield of CV soybean were found after the application of 157.5 + 52.5 g a.e. ha^{-1} imazapic + imazapyr in post-emergence. Pereira et al. (2021) observed the tolerance of CV soybeans for post-emergence application of imazapic + imazapyr, but doses above 52.5 + 17.5 g a.e. ha^{-1} negatively affected the agronomic performance of soybeans. Biazoto et al. (2020) observed the tolerance of CV soybeans to the application of imazapic + imazapyr in post-emergence (up to 157.5 + 52.5 g a.e. ha^{-1}), while Matte et al. (2018) in pre-emergence up to the same dose, which reinforces the selectivity of this herbicide, but the results of the present study and that of Pereira et al. (2021) indicate the risks of doses above the recommended by the package insert.

From the 131.25 + 43.75 g a.e. ha^{-1} dose, a decrease in oil contents was observed, similarly to that observed for the other variables presented so far (Table 4). This reinforces the importance of using imazapic + imazapyr up to the maximum recommended dose, for which it was possible to extract 20.71% oil, among the best treatments.

Table 4 - Production of oil of soybean under application of imazapic + imazapyr. Palotina, Parana state, Brazil, 2015-16.

Dose[1]	Oil[2]	Cake[2]	Oil	Cake
g a.e. ha^{-1}	%		kg ha^{-1}	
0	19.93 ab	80.07	755	3,035
26.25 + 8.75	20.19 ab	79.81	774	3,060
52.5 + 17.5	20.71 a	79.29	915	3,503
78.75 + 26.25	20.24 ab	79.76	771	3,038
105 + 35	18.99 bc	81.01	702	2,996
131.25 + 43.75	18.31 cd	81.69	647	2,887
157.5 + 52.5	17.80 cd	82.20	594	2,744
183.75 + 61.25	17.45 d	82.55	576	2,726
210 + 70	18.30 cd	81.70	619	2,763
236.25 + 78.75	17.34 d	82.66	555	2,643
262.5 + 87.5	17.72 cd	82.28	536	2,490
CV (%)	4.53	-	-	-

[1] Imazapic + imazapyr doses.

[2] Percentage values in relation to yield for the respective dose.

For oil content (%), means followed by the same letter, in the rows, do not differ by Tukey's test, at the level of 5%.

For the calculations made for energy balance, it was necessary to establish the oil and the cake kg ha^{-1}. For the application of the maximum recommended dose (52.5 + 17.5 g a.e. ha^{-1}), the highest value (118.9) was observed, in absolute number. From the maximum dose, the increase in dose resulted in a decrease in values. Doses equal to or greater than 105 + 35 g a.e. ha^{-1} resulted in values of a maximum of 91.3, that is, a negative energy balance (Figure 2).

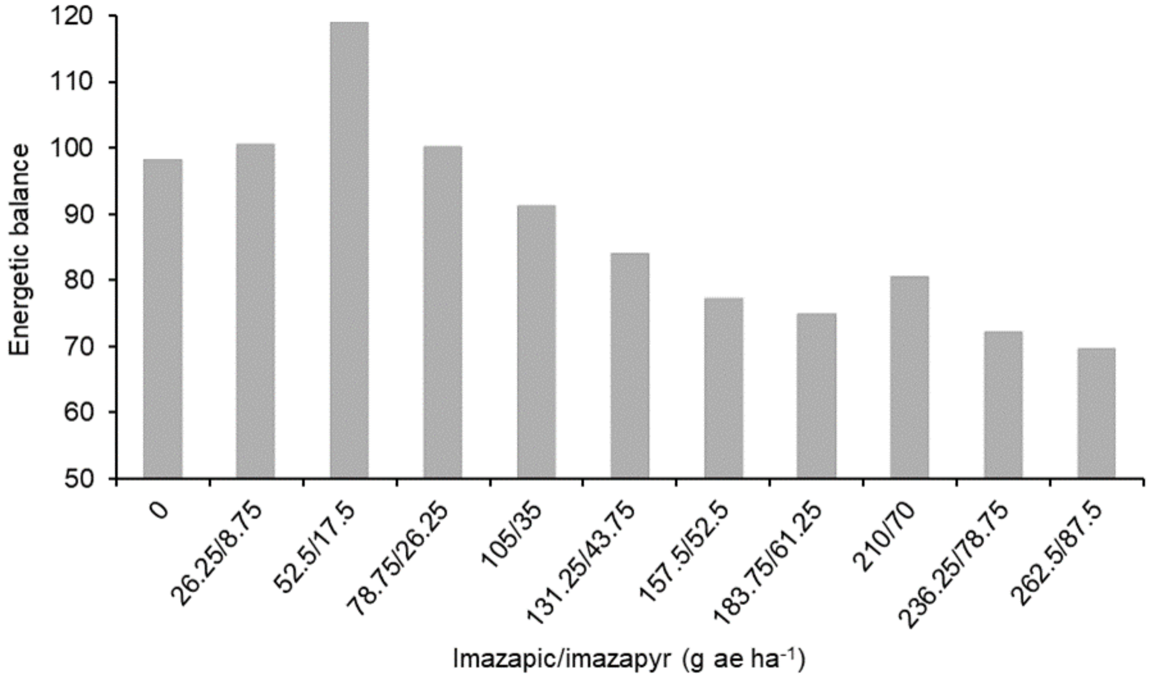

Figure 2. Energy balance of CV soybean under application of imazapic + imazapyr doses. Palotina, Parana state, Brazil, 2015-16

The profitability of the activity and a positive energy balance are linked to good agronomic practices. Sá et al. (2013) analyzed the energy balance of soybean oil in the different planting systems, and observed that the results of no-till were more efficient than those of conventional planting. Affirming that these differences are linked to the different grain productivities, consumption of fuel and herbicides.

In the same way as for yield, negative effects were observed on other parameters for the application of high doses. From the dose of 78.75 + 26.25 g a.e. ha^{-1}, decrease in profit were observed, from 131.25 + 43.75 g a.e. ha^{-1} decrease in oil content and from 105 + 35 g a.e. ha^{-1} a negative energy balance was observed, the energy balance should be greater than 1 (ratio 100) (Sá et al., 2013). This supports the recommendation of imazapic + imazapyr doses up to the maximum recommended dose (52.5 + 17.5 g a.e. ha^{-1} equivalent to 100 g cp ha^{-1}).

Even in tolerant crops, the use of doses above the recommended can have deleterious effects on the cultivation. For glyphosate-tolerant soybeans, high doses of the herbicide may represent decrease in nutrient content (Zobiole et al., 2010) or decrease in seed quality (Albrecht et al., 2012). For glyphosate-tolerant soybeans, in application of doses of the herbicide above that recommended by the package insert, Moreno et al. (2018) observed decrease in economic return and negative energy balance, that indicate the risks of using doses above the recommended. This was also observed in the present study for CV soybean with application of imazapic + imazapyr.

Good agronomic practices include no-till, crop rotation, integrated weed management, among others. Riar et al. (2013) highlights several practices, including the use of recommended doses of herbicides and correct stages of application, in the profitability and sustainability of grain crops. Even if the application of doses above the recommended in tolerant cultivars does not always impact yield for reasons of selectivity, there is an increase in costs, and also an increase in the selection pressure on resistant weed biotypes, such as glyphosate-resistant weeds (Green, 2014).

Thus, the importance of the present study is noted, reinforcing the tolerance of CV soybeans to imazapic + imazapyr up to the maximum recommended dose. As well as showing the risks of using doses above the recommended, not only in relation to agronomic performance, but also in terms of oil content, energy balance and economic performance. This study is a pioneer in the evaluation of CV soybeans under herbicide application, in relation to oil content, energy balance and economic performance.

Therefore, the diversification of production and the application of new technologies are tools for rural producers to increase their economic performance amid the instability and uncertainties of the commodities market, in addition to the essential management of the business through the analysis of production costs and economic viability, which aims to reduce costs, make the best use of the productive space and increase the levels of yield and profitability.

Conclusions

The application, in post-emergence of soybean (V_4), of imazapic + imazapyr up to the maximum recommended dose in the package insert (52.5 + 17.5 g a.e. ha^{-1}) was safe for soybean plants tolerant to imidazolinone herbicides (with gene *csr1-2*), regarding agronomic performance, oil content, economic viability and energy balance. Doses above the recommended maximum negatively influenced the performance of soybeans in one or more of these traits.

Acknowledgements

The authors thank the support of the Federal University of Paraná (UFPR) and the *Supra Pesquisa* team – UFPR.

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