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Economic efficiency and soybean yield due to the use of different fungicide combinations

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Abstract

In Brazil, Asian rust is the main disease that affects the soybean crop, which is responsible for the great inventiveness of financial resources with fungicides to control this pathogen. The objective of this work was to evaluate the grain yield and economic viability of the different combinations of fungicides used in the soybean crop. The experiment was conducted in the 2014/2015 agricultural year in the experimental field located in the municipality of Campo Novo-RS, Brazil. The treatments used correspond to 15 combinations of fungicides, and these were applied at different times during the soybean cycle. The characters measured weremass of 1000 seeds, grain yield, gross income, fungicide cost, total cost, net income, income gain and profitability. The grain yield of soybeans was reduced by 35% due to the absence of fungicide applications. Combinations of fungicides that provide the highest yields and profitability for soybean are based on the use of different active principles such asstrobilurins and carboxamides.

Keywords: agrarian sciences, phytosanitary management, economic efficiency.
Abbreviation:kg ha^{-1}_kilograms per hectare;US$_United States Dollar;r_ correlation, %_percentage;CO_2_carbon dioxide.

Introduction

The soybean (*Glycine max* (L.) Merril) stands out as the most important oilseed crop in the world due mainly to its nutritional and industrial characteristics, cultivation capacity in different latitudes, soils and climatic conditions. Soy is a strong component of the Brazilian economy, with grain production reaching 114 million tons, in the 2016/2017 harvest (Conab, 2017).

Among the main factors that limit the productive potential is the action of pathogens. A large number of diseases caused by fungi, bacteria, nematodes and viruses have been reported in Brazil (Yorinori, 1986). Almeida et al. (2005), reports that in Brazil approximately forty diseases affect the soybean crop, having a great economic importance for certain regions and agricultural crops.

Among the factors that negatively affect soybean yield is the susceptibility of some cultivars due to the incidence of diseases, monoculture and climatic conditions. In this way, it is justified the use of different measures to minimize losses through the control of diseases involving an integrated management (Szareskiet al., 2016; Ferrari et al., 2016; Meier et al., 2016; Carvalho et al., 2016). Among the main techniques are the use of resistant cultivars, seed treatments, balanced mineral fertilization, use of fungicides in the area and crop rotation (Balardin, 1999; Pelegrin et al., 2017; Gabriel et al., 2018).

The severity of fungal diseases in soybean crop occurs due to the greater susceptibility characteristic of some genotypes. While the breeding promotes the increase of the productive potential of the plants and these may show less phenotypic plasticity in relation to diseases, in the same way, the lower efficiency expressed by some chemical groups of fungicides. The use of fungicide control is the main method used by farmers, as it is characterized as a fast, practical and efficient means to minimize the action of disease-causing pathogens in cultivated plants (Oliveira, 2002; Pelegrin et al., 2016).

The grain yield is related to the photosynthetic efficiency, photosynthetically active leaf area and the leaf area index, in this way, it is sought to minimize leaf tissue losses through preventive and curative chemical control, in order to maximize the accumulation of assimilates and grain yield of the crop (BergaminFilho et al., 1997; Rigo et al., 2018).

The fungicides currently used correspond to the chemical compounds of protective, curative and systemic action (Juliatti et al., 2010). In this context, the use of mixtures can increase the efficiency of disease control. According to Sinclair and Hartman (1995), fungicide applications must be sequential with short time intervals, to allow a residual active principle in the plant where it guarantees the reduction of the injuries caused by pathogens that affect the leaf area of the plant. Applications should be weighted rationally, making it economically feasible and with minimal damage to the environment and human health (Godoy andCanteri, 2004). The objective of this work was to evaluate the grain yield and economic viability of the different combinations of fungicides used in the soybean crop.

Results and discussion

Analysis of variance

From the results of the analysis of variance (Table 2), it was observed that for both variables, grain yield and mass of one thousand seeds, there was a significant effect of fungicide application in soybean. From the values of the coefficients of variation obtained below, these were lower than 5%, where they revealed high experimental precision for this study (Pimentel Gomes, 2009).

Effect of fungicides

For the mass of a thousand grains the treatments that obtained the best results were I, VIII, XII and XIV (Table 3). These treatments have in common two intermediary applications of the fungicide *Azoxystrobin* + *Benzovindiflupyr*. All the treatments differed from the treatment that represents the absence of fungicide application (VII), emphasizing the importance of the application as a tool to maintain the productive potential of the soybean crop. A study revealed that the character mass of a thousand grains is more sensitive to the effects of diseases when compared to grain yield (Gaspareto et al., 2011; Carvalho et al., 2017; Ferrari et al., 2018)

Grain yield showed that many combinations of fungicides did not differ, where the best results were expressed by treatments I, IV, V, VIII, X, XI, XII, XIV and XV, in this way, the farmer has a series of fungicides which showed good efficiency in disease control, where all of them had yield above 5100 kg ha^{-1} (Table 3). It was observed that in all the treatments that stood out, three or more chemical groups were carried out.

The largest magnitudes for grain yield were revealed by the association of two or more active ingredients of the strobilurin group. Fagan (2010) defined the grain yield gain due to the use of strobilurin fungicides in relation to the other chemical groups for the phytosanitary control of the soybean crop. These results, who obtained higher grain yields in treatments with mixtures of different chemical groups (Blum et al., 2002; Follmann et al., 2017; Szareski et al., 2017; Rigo et al., 2018).

From the results of grain yield, it can be observed that the great majority of fungicide treatments were efficient in the control of soybean diseases. The treatments with the lowest yields were IX, XIII and VII, and the first one received only *Mancozeb* application in the four applications, proving not to be an interesting practice for the application of only one chemical group. Regarding the chemical groups of the fungicides, it was observed that the treatments with the same chemical groups (I and III) obtained different performances, and treatment I increased the grain yield of soybean by 13.4% in relation to treatment III. This result is due to the responses in phytosanitary control to the same chemical groups. Embrapa (2014) showed that the fungicide *Azoxystrobin* and *Benzovindiflupyr* increased grain yield by 11% compared to the fungicide *Piraclostrobin + Fluxapiroxade.*

The chemical groups Carboxamides and Dithiocarbamates when associated with other groups presented the best results of grain yield. These groups act with different modes of action, distinct sites of action in pathogens, improve disease control and maintain the photosynthetic area of plants over time. Carboxamide is a specific site fungicide that acts on the inhibition of the enzyme *Succinate dehydrogenase*, this new chemical group showed better results than the other chemical groups in the control of *Phakopsorapachyrhizi* (Embrapa, 2014; Zanatta et al., 2018; Aisenberg et al., 2018). Dithiocarbamates are multi-site fungicides that act on several processes vital to pathogens, being an excellent tool to increase the efficiency of systemic fungicides and disease management (Silva, 2015; Zimmer et al., 2016).

From the results, many fungicides with good efficiency were observed, mainly when they were used in associations with other active principles. The presence of the fungicide *Azoxystrobin* and *Benzovindiflupyr* resulted in high grain yields, this efficiency is due to this chemical group being new in the soybean agricultural scenario. Figure 2 shows the linear association between grain yield and the mass of one thousand seeds, it was possible to reveal a positive correlation between these variables (r = 0.92), indicating that the increment of the grain mass results in increases in grain yield of soybeans.

Economic analysis

For the economic analysis of the application of the different combinations of fungicides the treatment with only four applications of *Mancozeb*(IX) showed the lowest cost (US$29.92), revealing a cost amplitude from US$56.26 to US$ 65.05per hectare sown. The net yield of soybean showed the best results for treatments XIV, XII and XV. On the other hand, treatment VII, which represents the absence of application and XIII, obtained the lowest profits per hectare. Treatments IX, III, II, VI and V presented an amplitude of US$926.93 to US$ 1086.07.

Net gains were observed in relation to the absence of fungicide application (VII), ranging from 16.9 to 72%. Gaspareto et al. (2011), obtained an increase from 77 to 210% in profitability due to the use of fungicides. The worst costs were obtained with treatments XIII, IX and III (US$ 104.18, US$ 241.45 and US$ 275.78), respectively. Out of the profitability values from the values invested in the fungicides, it can be observed that treatment IX did not reveal efficient performance, but it obtained a higher profitability, where each US$ 1.00 invested resulted in US$ 8.07.This result is due to the low cost of the fungicide used, which reflected in increments on the net yield of the soybean. It is considered that the use of fungicides in soybean is of vital importance, however, the number of applications, the active principle and the mixtures dynamics should be considered, since it is necessary to maximize profitability and minimize soybean production costs.

Table 1. Soil attributes referring to depth 0.0 and 0.1 meters sampled at the time of the experiment implantation.

Attributes								
pH	O.M*	K	P	Ca	Mg	CEC	BS	Al
1:1	%	--- mg dm^{-3} ---		------ cmolcdm^{-3} ------			------ % ------	
5.94	4	234.3	13.20	7.20	2.50	13.80	75.00	0.00

* O.M: organic matter; K: potassium; Ca: calcium; Mg: magnesium; CEC: cation exchange capacity; BS: base saturation; Al: aluminum saturation

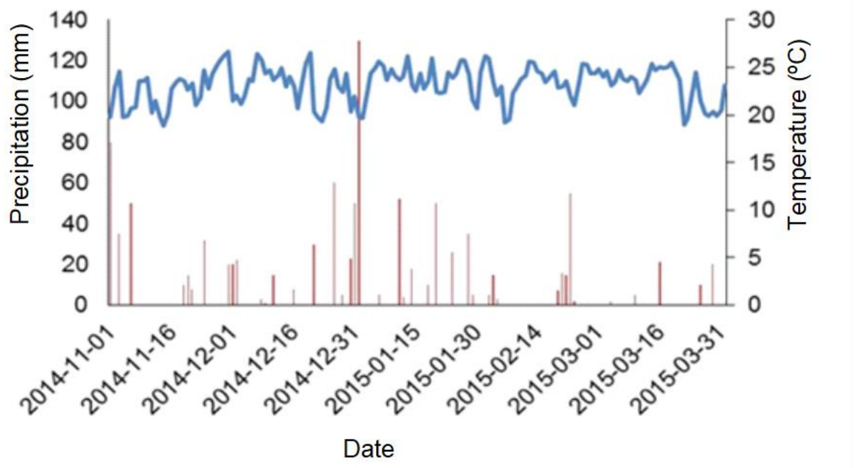

Fig 1. Climatic information (precipitation and average air temperature) from November 2014 to March 2015.

Table 2. Summary of the analysis of variance for the yield and mass of one thousand soybean seeds.

VF	DF	Mean Square	
		Mass of 1000 seeds	Grainyield
Blocks	5	21.73*	345.287.50*
Treatments	14	838.01*	1.821.371.01*
Residue	70	5.25	38.979.21
CV (%)		1.61	3.99

*Significant at 5% of probability by the F test.

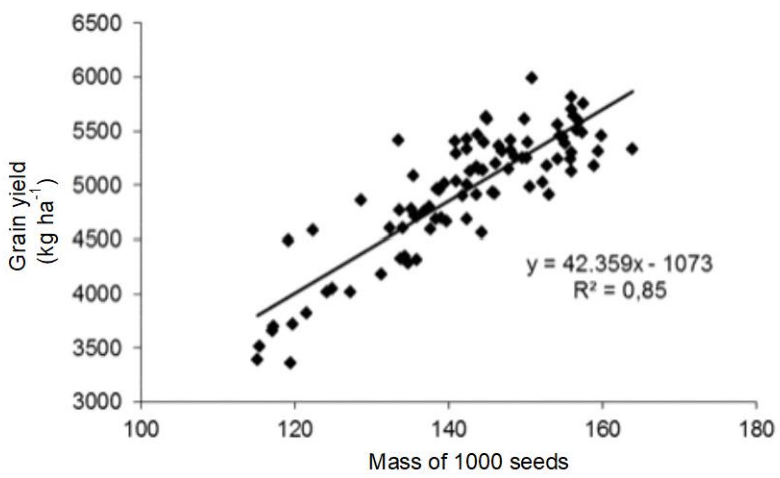

Fig 2. Linear correlation between grain yield and the mass of one thousand grains of soybean.

Table 3. Averages for the mass of one thousand seeds and grain yield of the soybean as a function of different combinations of fungicide applied in aerial part.

Treatments	Mass of 1000 seeds ----------------g---------------	Grainyield ----------kg ha^{-1}----------
I	157.80 a	5345.50 a
II	136.98 ef	4812.14 bcd
III	136.31ef	4627.40 cd
IV	142.72 cd	5173.67 ab
V	143.22 c	5105.62 ab
VI	138.46 de	4908.15 bc
VII	117.38 h	3555.12 f
VIII	154.64 a	5381.57 a
IX	132.50 f	4431.53 de
X	145.78 bc	5330.01 a
XI	144.83 bc	5164.19 ab
XII	154.35 a	5422.98 a
XIII	123.25 g	4161.49 e
XIV	156.30 a	5455.04 a
XV	148.88 b	5400.40 a

Means followed by the same lowercase letter in the column do not differ among themselves by Tukey with 5% of probability.

Table 4. Economic analysis of the application of different combinations of fungicides applied on the aerial part of the soybean.

Treatments	Gross income	Fungicide cost	Total cost*	Net income (US$ ha^{-1})	Income gain	Profitability
VII	1100.62	0.00	414.86	685.76	0.00	0.00
XIII	1288.39	71.21	486.07	802.32	116.56	0.51
IX	1371.99	29.92	444.78	927.21	241.45	2.50
III	1432.63	56.23	471.09	961.54	275.78	1.52
II	1489.83	64.19	479.05	1010.78	325.02	1.57
VI	1519.55	64.19	479.05	1040.50	354.75	1.71
V	1580.69	79.59	494.46	1086.23	400.47	1.56
IV	1601.76	71.92	486.78	1114.98	429.22	1.85
XI	1598.82	68.67	483.54	1115.28	429.53	1.93
X	1650.16	87.26	502.12	1148.04	462.28	1.64
VIII	1666.12	94.77	509.63	1156.49	470.73	1.54
I	1654.95	78.98	493.84	1161.12	475.36	1.86
XV	1671.95	93.63	508.50	1163.46	477.70	1.58
XII	1678.94	93.02	507.88	1171.06	485.30	1.62
XIV	1688.87	91.95	506.81	1182.06	496.30	1.67

*The total cost was calculated from all expenditures with inputs applied throughout the soybean cycle that resulted in a value of US$414.86, plus the value of fungicide treatments.

Materials and methods

Plant material

The experiment was conducted in the 2014/2015 agricultural year in the experimental field of CooperativaTritícolaMista Campo Novo Ltda®, located in the municipality of Campo Novo-RS, Brazil. The coordinates are corresponded to latitude 27°40'40 "S and longitude 53°49'54" W, with an average elevation of 483 meters. The climate of the region is characterized as Cfa, subtropical humid, according to Köppen (Maluf, 2000). Climatological information was obtained daily through the meteorological station provided by the AgroDetecta® system. The soil of the experimental area is classified as typical ferric red Latosol (Table 1).

The experimental design was a randomized block design, where the treatments were arranged in six replicates.

Combinations of fungicides used

The treatments used correspond to 15 combinations of fungicides, and these were applied at different times during the soybean cycle (Supplementary table 1).

The treatments were applied with CO_2 pressurized backpack type sprayer, equipped with a three meter spray bar and fan-type nozzles (XR 11002). The spray volume used was 200 L ha^{-1} in all applications. During the crop cycle four fungicide applications were performed (01/07/2015, 01/26/2015, 02/12/2015 and 02/26/2015). When the crop reached full maturation stage (first half of April 2015), the plots were harvested with a plot harvester.

Management and farming practices

The experimental units consisted of four lines of eight meters in length. For the measurement of the variables, the two central lines of each unit were considered, with a total area of 8 m^2. The cultivar NA5909RG of approximately 130 days cycle was used. The predecessor crop was wheat, where it was sown in a no-tillage system in the second half of November, with 17 seeds m^{-1} distributed, with a final plant population of 283,961 plants ha^{-1}. The basic fertilization used was 18.2 kg of N ha^{-1}; 88.4 kg of P_2O_5 ha^{-1} and 31.2 kg of K_2O ha^{-1}. For top dressing and at 40 days after emergence, 60 kg of K_2O ha^{-1}were applied.

Measured characters

After harvesting, the data were adjusted to 13% of moisture and expressed in kg ha^{-1}, the mass of one thousand grains was measured by manual counting of eight replicates of one hundred seeds, results in grams (g).
For the economic analysis, the mean values obtained from the 6 replicates of each treatment were used, and the cost of production was initially determined through the cost estimate, which was the same for all treatments.
After that the gross yield of each treatment was determined by multiplying grain yield values by the mean value of soybean that has been applied in the region (US$ 18.57bag^{-1}). The average yield and yield gain were calculated by subtracting the values obtained in each treatment by the treatment results without application of fungicide (T7).

Statistical analysis

The data were submitted to analysis of variance at 5% of probability. The significant characters were compared by Tukey. Later the linear correlation was carried out with the purpose of identifying the tendency of association among the characters. For the economic analysis, the mean values of each treatment were used, and the costs were initially determined.

Conclusion

The grain yield of soybeans is reduced by 35% due to the absence of fungicide applications.Combinations of fungicides that provide the highest yields and profitability for soybean are based on the use of different active principles, strobilurins and carboxamides.

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