Australian Journal of Crop Science AJCS

AJCS 12(02):265-273 (2018) ISSN:1835-2707
doi: 10.21475/ajcs.18.12.02.pne750

Effects and management of foliar fungicide application on physiological and agronomical traits of soybean

Everton Vinicius Zambiazzi[1], Adriano Teodoro Bruzi[1], Maria Laene Moreira de Carvalho[1], Scheila Roberta Guilherme[2], Alan Mario Zuffo[3*], Antonio Henrique Fonseca de Carvalho[1], Alan Eduardo Seglin Mendes[1], Igor Oliveri Soares[1], Isabela Maria Monteiro Borges[1], Mariane Cristina Bianchi[1] and Nelson Junior Dias Villela[1]

[1]Department of Agriculture, Federal University of Lavras, 37200-000, Lavras, Minas Gerais, Brazil
[2]Department of Biology Federal University of Lavras, 37200-000, Lavras, Minas Gerais, Brazil
[3]Department of Crop Production, State University of Mato Grosso do Sul, 79540-000, Cassilândia, Mato Grosso do Sul, Brazil

***Corresponding author: alan_zuffo@hotmail.com**

Abstract

Among the main factors limiting the yield of soybean, diseases stand out as the most important and difficult to control, causing up to 100% loss in the crop. The occurrence of diseases in soybean in Brazil is directly related to the tropical climate. Thus, the need to maintain high yield led to an increase in the number of foliar applications with fungicides. The aim of the study was to evaluate the response to the increase number of foliar fungicide applications on physiological and agronomic aspects and the economic viability of this management, contributing to the research of fungicide management in soybean. The experiment was performed in Minas Gerais state, in two environments (Ijaci and Lavras), during 2014/15 crop year, with the cultivar BRSMG 850GRR. The experiment was performed in a randomized block design, in split-plot, with three replications. The plots were composed of the number of applications (0, 1, 2, 3, 4 and 5). The applications started at the R_1 stage (beginning of bloom), with a 15-day interval to the next application (R_1; R_1+15d; R_1+30d; R_1+45d; R_1+60d). The sub plots were composed of different chemical fungicides (Elatus®, Fox®, Opera®, Orkestra®, and BAS – 702 - a not registered product). Chlorophyll content, dry mass, crop cycle, plant height, number of pods, number of grains, thousand-seed weight , grain yield, harvest index, daily increment and economic viability were evaluated. Individual and joint variance analyses were performed. The means were grouped by the Scott-Knott test and the regression analysis was applied to study the sources of quantitative variation. The phenotypic correlation between the number of applications and the physiological and agronomic traits were also estimated. The increase in the number of foliar fungicide applications provides an increase in grain yield, thousand-seed weight, daily increment, dry mass and harvest index, and also provides changes in crop cycle, chlorophyll content and a higher net margin, generating a greater gain revenue.

Keywords: *Glycine max*, grain yield, physiology, plant protection products.
Abbreviations: INMET_ National Institute of Meteorology; R_1_ stage beginning bloom; GY_ grain yield; CC1_ crop cycle; CC2_ chlorophyll content; DI_ daily increment_ TSW_ thousand-seed weight; HI_ harvest index; DM_ dry mass_ NP_ number of pods; NG_ number of grains; PH_ plant height; PG_ productivity gain; FC_ fungicide cost; AC_ application cost; NM_ net margin; NI_ net income; GR_ gain revenue.

Introduction

Soybean is one of the major crops among the world and the cultivated area has increased significantly every year, being an important protein source for the growing world population (Quinebre, 2014). In Brazil, this evolution is very clear and the country is one of the leading soybean producers and exporters (Gesteira et al., 2015). However, this crop is subjected to disease pressure which can reduce significantly the yield, and may reach 100% of crop loss (Quinebre, 2014). About 40 diseases caused by fungi, bacteria, viruses and nematodes have been identified in Brazil (Finoto et al., 2011; Vello and Carvalho, 2013). This number keeps increasing due to the expansion of the crops to new areas. The economic importance of each disease varies according to the crop year and the region, depending on the climatic conditions of each harvest season (EMBRAPA, 2010). Soybean diseases can be controlled with proper management techniques. For example, the use of chemical fungicides has promoted relevant results in the prevention and/or control of these pathogens. Foliar fungicide application has been the most effective and immediate control method when the plants are already established in the field. The preventive application of fungicides is one of the most effective strategies in the control of diseases (Azevedo, 2001). Vitti et al. (2004) observed a longer residual period and a better performance of fungicides due to the preventive application. Similarly, Oliveira (2004) observed an increase in yield up to 100% when the preventive control was performed.

Thus, a growing number of fungicides applications in soybean have been observed in the last crop years. According to Hikishima et al. (2010), under favorable weather conditions, a large number of sprayings is required to control the disease, increasing production costs. On average, in previous crop years, four sprayings of fungicides were performed in soybean producing regions, which are considered a high amount for disease management, which generally needs two or three sprayings (Martins, 2009).

Currently, there are several registered fungicides for soybean in the Brazilian market. Considering the favorable soybean quote and the need to maintain a high yield, the producers have used different products associated with a growing number of applications on the crop in order to obtain a good efficiency in disease control. Therefore, physiological changes such as cycle modification, leaf retention and senescence have been observed (Silva et al., 2013). Thus, the aim of this study was to evaluate the response to the growing number of foliar fungicide applications on physiological and agronomic aspects of soybean in different production environments and also assess the economic viability of this management.

Results and Discussion

There was a significant difference for the environment for most characters ($p \leq 0.01$), except for thousand-seed weight and harvest index (Table 3). Regarding the number of fungicide applications, significant differences for most traits ($p \leq 0,05$) were observed. The fungicides differed significantly ($p \leq 0.05$) for the cultivation cycle, harvest index and dry mass. Significant results were also observed for the interactions of number of applications x environment (NA x E) and number of applications x fungicides (NA x F), indicating differences for the number of applications for each fungicide and production place, highlighting the importance of studying these interactions. In literature, there are reports of these interactions in some crops such as soybean, corn and oats (Federizzi et al., 1993; Brandao et al., 2003; Wysmiersky, 2015).

Effect of production environment

In general, better results were found for physiological and agronomic traits in Ijaci (Table 4), associating higher grain yield to a smaller crop cycle, which is a desired trait in soybean production. This fact is related to a better soil fertility (Table 1) and also to a better distribution of rainfall for Ijaci, especially in the grain filling period (Fig. 1). Precipitations of 1031 mm in Ijaci and 804 mm in Lavras were observed during the experiment. This difference of 227 mm negatively affected the grain yield and, consequently, the daily increment, causing lower development of plants observed through height, dry mass and fewer pods and grains. The yield potential is set according to the environment that the crop is inserted, without soil, climate and nutritional limitations, free from the action of pests and diseases and other stresses effectively controlled (Evans, 1993). In this context, the average grain yield in Ijaci and Lavras were higher at 1015.00 and 484.00 kg ha^{-1} respectively, than the obtained at national and state level (3033 kg ha^{-1} and 3000 kg ha^{-1} respectively), according to Conab (2015).

Effect of fungicides

Fungicides did not show differences among them for most of the characters when they were evaluated in an isolated way. Differences were observed in a subtle way for the cultivation cycle, with variation of just one additional day in the cycle for the product with the active ingredient (trifloxystrobin + prothioconazole). It was observed a lower dry mass for products with active ingredients (pyraclostrobin + epoxiconazole + fluxapyroxad) and (azoxystrobin + benzovindiflupir), but a higher harvest index for the fungicide (azoxystrobin + benzovindiflupir). The negative association between harvest index and dry matter indicates that plants with higher vegetative vigor convert smaller proportion of biological yield into grain production (Colasante and Costa, 1981). In this case, when the crop cycle is extended, there is a trend towards greater accumulation of vegetative part, resulting in a smaller harvest index.

Effect of the number of pplications

Regarding the number of applications, it was observed a similar behavior between the environments and harvest index (Fig. 2a and 2b). The crop cycle was influenced by the number of applications and the linear model was the one which that best fit, where the senescence of the crop delayed 12 days when compared to the control. Changes in the soybean cycle due to the growing number of fungicides applications has also been reported by Barros et al. (2008), being observed up to 11 days longer in the cycle when compared to the treatment without fungicides. According to Bertelsen et al. (2001) this value was expected because when the crop does not receive the preventive application of fungicides, the plant presents defense reactions which cause an energy cost and senescence acceleration. Among the physiological effects of the fungicides on crop metabolism, the inhibition of ethylene biosynthesis results in the green effect, which generates a delay in senescence (Dunne, 2005).

The harvest index (Fig. 2b) was also influenced by the number of applications, showing positive linear response and better results with five fungicide applications. Similar results were observed by Carniel et al (2014) evaluating the soybean cultivars response to late season diseases with different application managements with fungicides and also by Ludwig et al (2010) who evaluated soybean yield in relation to fungicides management. They observed linear increase in harvest index with the increase in the number of applications, providing reduction in late season diseases and improving conditions for grain filling. For grain yield characters, thousand-seed weight and dry mass, there were difference among production environments, with linear behavior for daily increment and chlorophyll content and quadratic behavior for the number of applications (Fig. 3). The response with the growing number of fungicides

Table 1. Nutrient content of the soil layer (0-20 cm) in Ijaci and Lavras-MG, before the experiments, during 2014/15 crop year.

Environments	pH	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^{+}+Al^{3+}$	SB	CEC	P	K	OM	V
	H_2O	----------------- $cmol_c\ dm^{-3}$ ------------------						- $mg\ dm^{-3}$ -		dag/kg^{-1}	%
Ijaci	6.3	5.0	1.8	0	2.9	6.7	9.6	28.4	118	5.4	69.8
Lavras	6.2	3.8	0.8	0	0.9	4.8	5.7	20.8	92	2.2	83.5

H + Al: potential acidity; SB: sum of bases; CEC: cation exchange capacity at pH 7.0; OM: organic matter; V: base saturation.

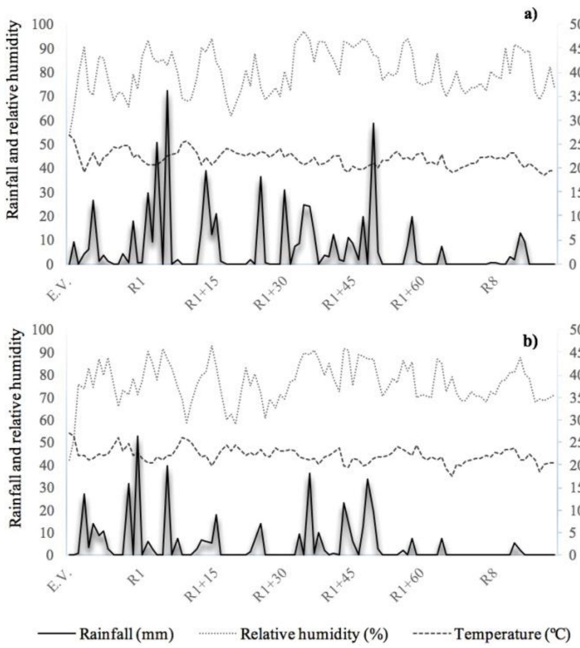

Fig 1. Rainfall daily averages, temperature and relative air humidity in Ijaci (a) and Lavras (b), Minas Gerais, during 2014/15 crop year, during the applications of fungicides. Source: National Institute of Meteorology (INMET). E.V. vegetative phase. R_1 – beginning of bloom (1st application).

Table 2. Number of fungicides applications used in the development stages of soybean.

Number of Aplications	Application phenological stage
0	No application (Control)
1	R_1*
2	R_1 e R_1 + 15 days**
3	R_1, R_1 + 15 e R_1 + 30
4	R_1, R_1 + 15, R_1 + 30 e R_1 + 45
5	R_1, R_1 + 15, R_1 + 30, R_1 + 45, R_1 + 60

* Beginning of Bloom, ** Days after R_1.

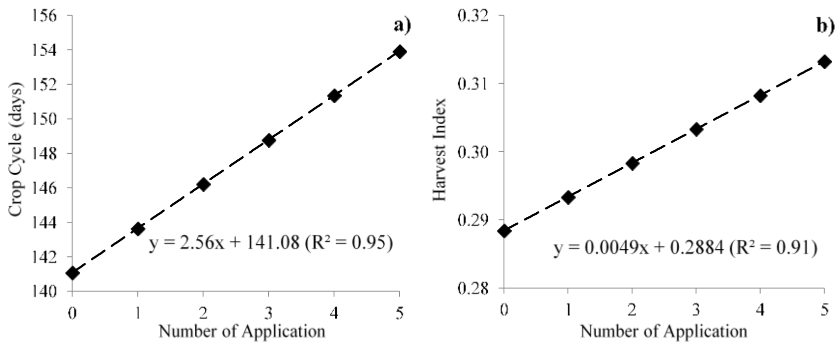

Fig 2. Regression analysis for crop cycle (a) and harvest index (b), for soybean under different number of applications with foliar fungicides during 2014/2015 crop year, in Lavras and Ijaci, MG, Brazil.

Table 3. Analysis of variance summary for grain yield (GY), crop cycle (CC1), chlorophyll content (CC2), daily increment (DI), thousand-seed weight (TSW), harvest index (HI), dry mass (DM), number of pods (NP), number of grains (NG) and plant height (PH), in relation to the sources of variation during 2014/2015 crop year, in Lavras and Ijaci, MG, Brazil.

SV	DF	*prob > Fc*									
		GY	CC1	CC2	DI	TSW	HI	DM	NP	NG	PH
Blocks/Environments	4	NS	NS	*	NS	NS	*	NS	NS	NS	**
Environment (E)	1	**	**	**	**	NS	NS	**	**	**	**
N of Aplications (NA)	5	**	**	**	**	**	*	**	NS	NS	NS
NA x E	5	*	NS	**	*	*	NS	**	NS	NS	NS
Error (a)	20	-	-	-	-	-	-	-	-	-	-
Fungicides (F)	4	NS	**	NS	NS	NS	*	**	NS	NS	NS
NA x F	20	*	NS	NS	*	*	NS	**	NS	NS	NS
F x E	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NA x F x E	20	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error (b)	96	-	-	-	-	-	-	-	-	-	-
CV (a) - %		9.8	2.5	14.3	10.3	5.2	8.9	10.5	10.7	12.2	8.3
CV (b) - %		9.4	0.6	12.0	9.5	4.1	9.8	10.6	10.2	12.5	5.8
General Average		3781.8	147.5	30.4	25.7	167.5	0.3	121.5	71.7	130.8	82.3

** Significant at 1%, *significant at 5%, and (NS) Not significant according to F test. SV - sources of variation; DF - degree of freedom; CV - coefficient of variation; Fc - F calculated.

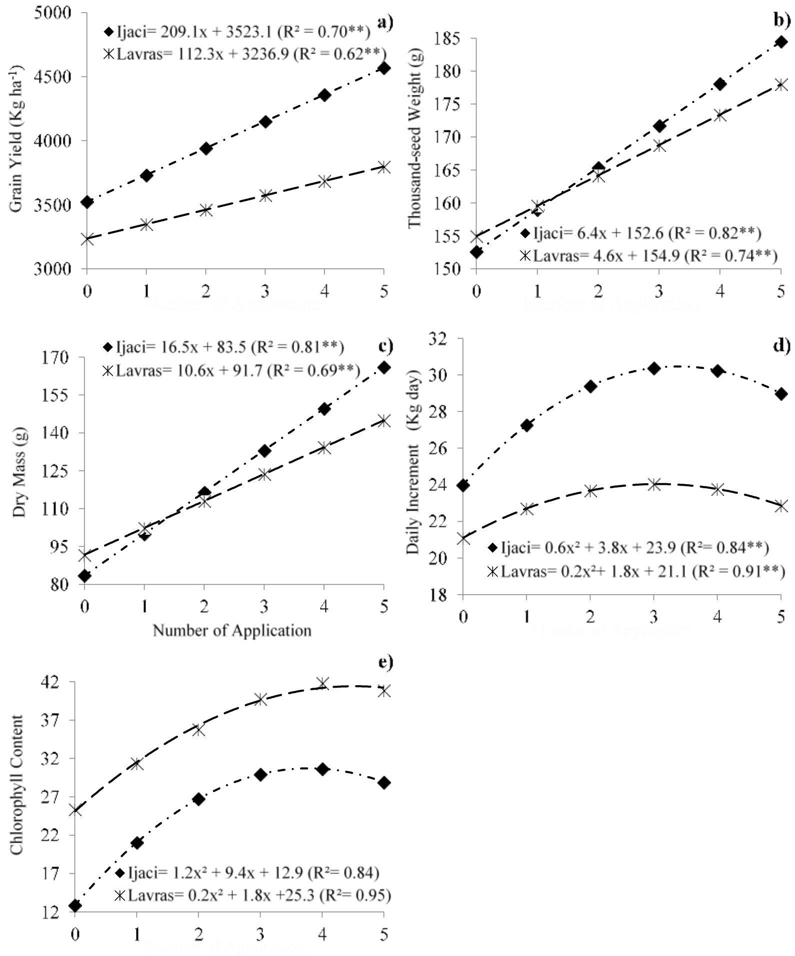

Fig 3. Regression analysis for grain yield (A), thousand-seed weight (B), dry mass (C), daily increment (D) and chlorophyll content (E) in soybean crop under different number of applications with foliar fungicides during 2014/2015 crop year, in Lavras and Ijaci, MG, Brazil.

Table 4. Mean values and phenotypic correlation (r) between the number of applications and grain yield (GY - $Kg.ha^{-1}$), crop cycle (CC1 - days), chlorophyll content (CC2), daily increment (DI - Kg.dia) , Thousand-seed weight (TSW - g), harvest index (HI), dry mass (DM - g), number of pods (NP), number of grains (NG) and plant height (PH - cm) in relation to the production environments and products during 2014/2015 crop year, in Lavras and Ijaci, MG, Brazil.

FV	GY	CC1	CC2	DI	TSW	HI	DM	NP	NG	PH
Environments										
Ijaci	4045.8 a	142.0 b	25.0 b	28.4 a	168.6 a	0.30 a	124.8 a	81.0 a	148.0 a	92.2 a
Lavras	3517.8 b	153.0 a	35.9 a	23.0 b	166.5 a	0.29 a	118.3 b	63.0 b	114.0 b	72.5 b
Fungicides										
BAS [1]	3685.7 a	147.0 b	30.5 a	24.9 a	167.6 a	0.30 b	113.9 b	69.0 a	124.0 a	82.0 a
ELA [2]	3816.3 a	147.0 b	30.4 a	26.0 a	167.3 a	0.31 a	116.7 b	74.0 a	137.0 a	82.8 a
FOX [3]	3733.1 a	148.0 a	30.5 a	25.3 a	168.2 a	0.30 b	127.9 a	71.0 a	129.0 a	82.5 a
OPE [4]	3818.7 a	147.0 b	30.9 a	25.9 a	169.1 a	0.29 b	127.5 a	70.0 a	128.0 a	81.5 a
ORK [5]	3855.3 a	147.0 b	29.9 a	26.3 a	163.4 a	0.29 b	121.8 a	75.0 a	137.0 a	82.8 a
r	0.829	0.975	0.952	NS	0.909	0.931	0.891	NS	NS	NS

Means followed by the same letter in the column belong to the same group, by Scott Knott test (1974)at 5% probability. (NS) not significant. (r) phenotypic correlation. [1] BAS – 702 (pyraclostrobin + epoxiconazole + fluxapyroxad), [2] Elatus® (azoxystrobin + benzovindiflupir), [3] Fox® (trifloxystrobin + prothioconazole), [4] Opera® (pyraclostrobin + epoxiconazole), [5] Orkestra® (pyraclostrobin + fluxapyroxad).

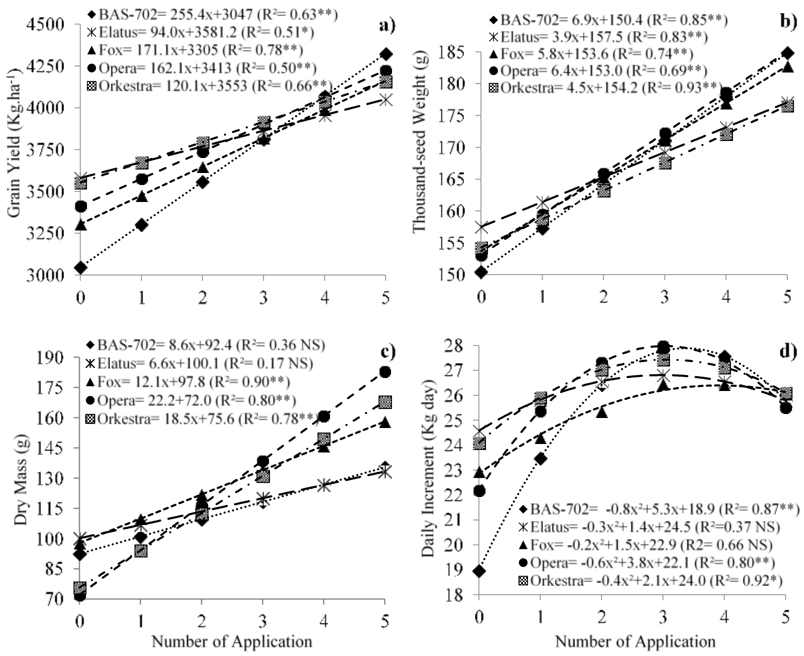

Fig 4. Regression analysis for grain yield (A), thousand-seed weight (B), dry mass (C) and daily increment (D) in soybean under different number of applications, with foliar fungicides during 2014/2015 crop year in Lavras and Ijaci, MG, Brazil.

Table 5. Economic viability of the increase in number of foliar fungicide applications (NA) with different products for soybean crops, based on grain yield average during 2014/2015 crop year, in Lavras and Ijaci, MG, Brazil.

Products	NA	GY[1] kg.ha	YG[2] kg.ha	FC[3] kg.ha	AC[4] kg.ha	NM[5] kg.ha	NI[6] R$.ha	RG[7] (%)
Elatus	0	3581.3	-	-	-	-	2171.3	-
Elatus	1	3675.3	94.0	62.9	14.9	16.2	2192.7	1.0
Elatus	2	3769.3	188.0	125.8	29.8	32.4	2214.1	2.0
Elatus	3	3863.3	282.0	188.6	44.8	48.6	2235.4	3.0
Elatus	4	3957.3	376.0	251.5	59.7	64.8	2256.8	3.9
Elatus	5	4051.3	470.0	314.4	74.6	81.0	2278.2	4.9
Fox	0	3305.3	-	-	-	-	1806.9	-
Fox	1	3476.4	171.2	43.9	14.9	112.3	1955.2	8.2
Fox	2	3647.6	342.3	87.9	29.8	224.6	2103.4	16.4
Fox	3	3818.7	513.5	131.8	44.8	336.9	2251.6	24.6
Fox	4	3989.9	684.6	175.8	59.7	449.2	2399.9	32.8
Fox	5	4161.0	855.8	219.7	74.6	561.5	2548.1	41.0
Opera	0	3413.3	-	-	-	-	1949.6	-
Opera	1	3575.5	162.1	36.4	14.9	110.9	2095.9	7.5
Opera	2	3737.6	324.3	72.7	29.8	221.7	2242.3	15.0

Opera	3	3899.8	486.4	109.1	44.8	332.6	2388.6	22.5
Opera	4	4061.9	648.6	145.5	59.7	443.4	2534.9	30.0
Opera	5	4224.0	810.7	181.8	74.6	554.3	2681.3	37.5
Orkestra	0	3553.1	-	-	-	-	2134.1	-
Orkestra	1	3674.0	120.9	53.0	14.9	52.9	2204.0	3.3
Orkestra	2	3794.9	241.7	106.1	29.8	105.8	2273.8	6.5
Orkestra	3	3915.7	362.6	159.1	44.8	158.7	2343.6	9.8
Orkestra	4	4036.6	483.4	212.1	59.7	211.6	2413.5	13.1
Orkestra	5	4157.4	604.3	265.2	74.6	264.5	2483.3	16.4

[1] Grain Yield (GY – kg ha^{-1}). [2] Yield Gain (PG – kg ha^{-1}) compared to the control. [3] Fungicide cost - according to regional price of the product (FC - kg ha^{-1}). [4] Fungicide application cost (AC – kg ha^{-1}) (IMEA, 2016). [5] Net margin: increase promoted by fungicide application (NM – kg ha^{-1}). [6] Net income (NI- R$.ha^{-1}): production value minus production costs, which corresponds to R$ 2,556.01/ha in 2015/2016 crop year, in the absence of foliar diseases control (IMEA, 2016). [7] Revenue Gain (GR - %) compared to the control. [I] soybean price for 5/20/2016 (R$ 1,32) – price for Minas Gerais (Scot Consultoria). [II] It was not performed the economic viability analysis for the product BS-702 because it is not commercially available.

applications was linear and positive for grain yield (Fig. 3a), in other words, a better performance was observed with five applications for both production locations. In Lavras and Ijaci, the yield with five applications of fungicides exceeded the control in 561 and 1045 kg ha^{-1}, respectively, which represents an increase of 15 to 30%. The yield with five applications in Ijaci was 770 kg ha^{-1} superior to Lavras. Similar results were observed by Finoto et al. (2011) and Barros et al. (2008), where the increase in number of applications provided increase in grain yield of 22 and 28%.

Fungicides act positively on the physiology of plants by increasing chlorophyll levels and reducing ethylene production. These effects contribute directly for less stress in the field, ensuring higher quality and yield for the plants (Töfoli, 2002). This fact can be confirmed through thousand-seed weight and dry mass (Fig. 3c and 3d), where the linear response was also observed for the improvement of plants quality and seeds weight, which is directly related to grain yield . For crops in general, the dry mass accumulation can be an important characteristic because part of this dry mass can be remobilized for grains during their formation, particularly in periods of stress, constituting an important factor in the determination of grain yield (Chaves et al., 2002).

However, for daily increment and chlorophyll content, the quadratic model was the one that best adjusted (Fig. 3b and 3e), with increasing values from the control to the treatment with four applications. The difference observed between the treatments with four and five applications was very close, but did not influence the grain yield (Fig. 3a). The treatments with the highest number of fungicide applications were those who had higher grain yield . Thus, the results of this study are similar to the ones checked by Ypema and Gold (1999), who observed an increase in grain yield, dry matter, chlorophyll content and delayed senescence, evaluating fungicides characteristics and their physiological effects,

The interaction between the number of applications x fungicide showed a linear behavior for grain yield, thousand-seed weight and dry mass (Fig. 4a, 4b and 4c). For these traits, the best response was obtained when five applications were performed, regardless the fungicide that was used. Among the fungicides used, the ones that showed better results were the ones with the not commercially registered active ingredient (pyraclostrobin + epoxiconazole + fluxapyroxad) and pyraclostrobin + epoxiconazole. According to Fagan (2007) the yield difference found in soybean is directly related to the grain filling period and, consequently, to plant dry mass. Therefore, the use of fungicides with those ingredients provides greater accumulation of dry mass, being an important factor for the increase in soybean yield.

Products based on these active ingredients have action mechanism, acting biosynthesis inhibitor of ergostherol (a constituent of the cell membrane of fungi) and as an inhibitor of electron transport in the mitochondria of fungal cells, inhibiting the formation of ATP that is essential to the metabolic processes of fungi. Besides, they present a protection action due to their role in inhibiting spore germination, development and penetration of germ tubes (AGRO NEWS, 2016).

The quadratic model was the one that best fit for daily increment (Fig. 4d). The reduction of daily increment from the fourth application is related to the increase in cycle observed with the increase of fungicided applications (Fig. 2a). Gesteira et al. (2015) observed this relation between yield and the cultivation cycle for this trait in the soybean. With the increase of cycle, there was a reduction in daily increment.

Phenotypic correlation

Most of the estimates of phenotypic correlations between the number of applications and other characters were high (Table 4). As expected, there were positive and high estimates ($r \geq 0.891$) between the number of applications, chlorophyll content, thousand-seed weight, harvest index and dry mass. The grain yield also had high positive correlation with the number of fungicide applications. There was no correlation with the number of applications regarding daily increment, number of pods, number of grains and plant height. The knowledge of the association among characters is very important to research, especially when the selection of them presents difficulties due to measurement or identification problems (Cruz et al., 2012).

Economic viability

With the globalization and the fast increase of new technologies, the companies need to reorganize the business management in order to harmonize with the international standards of quality and yield required by the world market. In this high level of competitiveness, strategies and management tools are important to analyze the consistency and profitability. One primary focus is the cost management, which is an essential requirement for maintaining a company, because the real profit is not always in the organizations (Santos, 2016).

So, it is necessary to conduct an economic viability study of the increase in foliar fungicide applications and the products used. The economic viability study is the ideal tool for any activity in agribusiness since it provides the information needed for rural producers, so they can check in numbers if the investment originates profit to the rural property.

Soybean cultivation promoted net profit of at least 1806.9 R$ ha^{-1} in the absence of disease control (Table 5) during 2014/2015 crop year (Fig. 1). However, the increase in foliar fungicide applications generated higher revenue up to 41% compared to control, with net margin of 561.5 kg ha^{-1} higher than the control. It was noted that Fox product (trifloxystrobin + prothioconazole) was superior to the others in all application levels, generating higher net margin, and higher revenue gain. The economic viability analysis was not performed for BAS-702 product because it is not commercially available.

Materials and Methods

Description of the study environments

The experiment was performed in two different environments in Minas Gerais state, during 2014/15 crop year. The experimental unit in Lavras is situated at 21°14' S latitude, 45°00' W longitude and 918 m of altitude, with soil classified as typical dystrofic Red Latosol. In Ijaci, situated at 21°09' S latitude, 44°55' W longitude and 843 m of altitude, with soil classified as typical dystrophic Red Yellow Latosol. The nutrient content of the 0-20 cm soil layer before the experiment, for both environments, is presented on table 1. According to Köppen classification, the region climate is Cwa, with average annual temperature of 19.3ºC and normal annual rainfall of 1,530 mm (Dantas et al., 2007). Daily weather data from the beginning of the applications (Fig. 1) were provided by the National Institute of Meteorology - INMET.

Experimental design and trial management

The experiment was conducted in a 6 x 5 factorial arrangement, using a randomized block design, with split-plots and three replications. The plots consisted of the number of applications (Table 2) and the sub-plots consisted of different chemical fungicides Elatus® (azoxystrobin + benzovindiflupir), Fox® (trifloxystrobin + prothioconazole), Opera® (pyraclostrobin + epoxiconazole), Orkestra® (pyraclostrobin + fluxapyroxad), and BAS – 702 - a not registered product (pyraclostrobin + epoxiconazole + fluxapyroxad).

The experimental plots consisted of four planting rows with 5 meters, spaced at 0.50 m. The area of each plot was of $10m^2$ (5 m x 2 m). Two central rows were considered as the useful area. In the first half of November, the sowing was performed in tillage system on corn stover in both environments. The cultivar BRSMG 850GRR, which has a determined growth habit and belongs to the maturity group 8.2, of medium late cycle (126-145 days) with sowing density of 12 seeds per meter, was used. In-furrow fertilization was applied and consisted of 350 kg ha^{-1} $N\text{-}P_2O_5\text{-}K_2O$ (02-30-20). The inoculation was performed by *Bradyrhizobium japonicum* bacteria after sowing, with dose of 18 mL p. c. kg^{-1} of seed - SEMIA 5079 and 5080 strain, with 10.8 x 10^6 UFC/seeds of Nitragin Cell Tech HC® ($3x10^9$ UFC/mL), using a motor backpack sprayer coupled to a bar with four spray nozzles XR 11002, applying a spray volume of 150 L ha^{-1}. Pest control was performed with the active ingredients Neonicotinoid, Chlorpyrifos and Pyrethroid, according to the necessity of insecticides use. Weed control after emergence was performed using 2 L ha^{-1} of glyphosate.

A pressurized backpack sprayer with CO_2 equipped with a two-meter bar with four nozzles Teejet XR 11002, 50 cm spaced and calibrated for a flow of 200 liters ha^{-1} was used for the application of fungicides. During the application, the adjuvant was added with the recommended dose for each fungicide. Applications started at R_1 stage (beginning of bloom), followed by a 15-day interval for the next application (R_1, R_1 + 15d, R_1 + 30d, R_1 + 45d; R_1 + 60d).

Data collections

Seven days after each fungicide application, chlorophyll levels were obtained with the aid of portable chlorophyll meter SPAD 502 Plus®, by measuring five points in each trifoliate leaf trefoil, in the leaf blade between the nerves in the third trefoil from top to bottom. Dry mass was obtained seven days after the fifth application. The shoot part of five plants per plot was sampled, then dried using a forced air circulation oven at 60°C for 72 hours, with a subsequent weighing of plant residues.

During harvest, the crop cycle was evaluated, including the number of days from sowing to physiological maturity, represented by 95% of plants with mature vegetables. The plant height was measured with the aid of a millimeter ruler in five plants per plot. The number of pods and grain number per plant were evaluated by manual counting. Thousand-seed weight was evaluated according to the methodology proposed by Brasil (2009). Grain yield was obtained with a standard moisture at 13%. Grain harvest index was determined according to Finoto et al (2011), daily increment, ratio of grain yield and crop cycle (Gesteira et al., 2015).

Statistical analysis

Individual and joint variances analysis were performed adopting the statistical model and an analysis procedure similar to the one provided by Ramalho et al. (2012). The grouping by Scott-Knott test (1974) was adopted for qualitative factors. Regression analysis was performed to study the quantitative sources of variation. All analyses were performed using the statistical program SISVAR® (Ferreira, 2014). The phenotypic correlation between the number of applications and the physiological and agronomic traits was also estimated (Cruz et al., 2012), with the aid of the statistical program SAS version 9.0 of the Statistical Analysis Systems (2009). The economic viability analysis on the increase in foliar applications number with fungicides in soybean was performed using a similar methodology as the one proposed by Gasparetto et al. (2011).

Conclusion

The growing number in foliar fungicide applications provides an increase in grain yield, thousand-seed weight, daily increment, dry mass and harvest index. Moreover, it provides changes in crop cycle and chlorophyll content and a higher net margin, generating a greater revenue gain.

Acknowledgments

The authors would like to thank FAPEMIG (Foundation for Research Support of the State of Minas Gerais), CNPq (National Council for Scientific and Technological Development) and CAPES (Coordination for the Improvement of Higher Education Personnel) for the scholarships and financial support.

References

Agro News (2016) BASF – We create chemistry. Soluções para agricultura – Fungicidas. http://www.agro.basf.com.br/agr/ms/apbrazil/pt_BR/content/APBrazil/solutions/fungicides/fungicides_product/OPERA (accessed 05 Feb. 2016).

Azevedo LAS (2001) Proteção Integrada de Plantas com Fungicidas: teoria, prática e manejo. São Paulo.

Barros HB, Sediyama T, Reis MS, Cecon PR (2008) Efeito do número de aplicações de fungicidas no controle da ferrugem asiática da soja. Acta Sci. Agron. 30(2):239-245.

Bertelsen JR, Neergaard E, Smedegaard-Petersen V (2001) Fungicidal effects of azoxystrobin and epoxiconazole on phyllosphere fungi, senescence and yield of winter wheat. Plant Pathol. 50(2):190-250.

Brandao AM, Juliatti FC, Brito CH, Gomes LS, Vale FXR, Hamawaki OT (2006) Fungicidas e epocas de aplicacao no controle da ferrugem comum (*Puccinia sorghi* Schw.) em diferentes hibridos de milho. Biosci. J. 19(1):43-52.

Brasil. Ministério da Agricultura, Pecuária e Abastecimento (2009) Regras para análise de sementes, Brasília.

Carniel LA, Menosso R, Junior AAB (2014) Reação de cultivares de soja às doenças de final de ciclo com e sem aplicação de fungicidas. Unoesc & Ciência-ACET, 5(1):83-90.

Chaves MM, Pereira JS, Maroco JP, Rodrigues MP, Ricardo CPP, Osório ML, Carvalho I, Faria T, Pinheiro C (2002) How plants cope with water stress in the field: photosynthesis and growth. Annals of Botany, 89(7):907–916.

Colasante LO, Costa JÁ (1981) Índice de colheita e rendimento biológico na comparação da eficióncia de variedades de soja. Pesq. Agropec. Bras. 16(2):225-30.

CONAB. Companhia Nacional de Abastecimento (2015) Acompanhamento da safra brasileira de grãos, v.2 - Safra 2014/15, n.4 - Quarto Levantamento, Brasília, p. 1-90.

Cruz CD, Regazzi AJ, Carneiro PCS (2012) Modelos biométricos aplicados ao melhoramento genético. v. 1, 4.ed. Viçosa: UFV.

Dantas AA, Carvalho LG, Ferreira E (2007) Classificação e tendências climáticas em Lavras, MG. Ciênc. Agrotec. 31(6):1862-1866.

Dunne B (2005) Strobilurin use on cereals. Crop Prot. 23:17-20.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária (2010) Centro Nacional de Pesquisa de Soja. Tecnologias de produção de soja - região central do Brasil Londrina: Embrapa Soja: Embrapa Cerrados: Embrapa Agropecuária Oeste.

Evans LT (1993) Processes, genes, and yield potential. In: Buxton DR, Shibles R, Forsberg RA, Blad BL, Asay KH, Pausen GH, Wilson RF (Ed.). International crop science I. Madison: Crop Science Society of America.

Fagan EBA (2007) Cultura da soja: modelo de crescimento e aplicação da estrobilurina piraclostrobina. 83f. Thesis (Doctoral Degree in Plant Science) - Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba.

Federizzi LC, Neto JFB, Carvalho FOF, Viau LVM, Severo JL, Floss EL, Silva AC (1993) Estabilidade do rendimento de grão em aveia: efeito do uso de fungicidas. Pesq. Agropec. Bras. 28(4):465-472.

Ferreira DF (2014) Sisvar: A computer statistical analysis system. Ciênc. Agrotec. 38(2):109-112.

Finoto EL, Carrega WC, Sediyama T, Albuquerque JAA, Cecon PR, Reis MS (2011) Efeito da aplicação de fungicida sobre caracteres agronômicos e severidade das doenças de final de ciclo na cultura da soja. Rev. Agro@mbiente 5(1):44-49.

Gasparetto R, Fernandes CD, Marchi CE, Borges MF (2011) Eficiência e viabilidade econômica da aplicação de fungicidas no controle da ferrugem asiática da soja em Campo Grande, MS. Arq. Inst. Biol. 78(2):251-260.

Gesteira GS, Zambiazzi EV, Bruzi, AT, Soares IO, Rezende PM, Silva KB (2015) Seleção fenotípica de cultivares de soja precoce para a região Sul de Minas Gerais. Rev. Agrogeoambiental 7(3):79-88.

Hikishima M, Canteri MG, Godoy CV, Koga LJ, Silva AJ (2010) Quantificação de danos e relações entre severidade, medidas de refletância e produtividade no patossistema ferrugem asiática da soja. Trop. Plant Pathol. 35(2):96-103.

Ludwigi MP, Dutra LMC, Lucca Filho OA, Zabot L, Uhry D, Lisboa JI (2010) Produtividade de grãos da soja em função do manejo de herbicida e fungicidas. Ciênc. Rural 40(7):1516-1522.

Martins MC (2009) Relato da situação da ferrugem e do vazio sanitário no Norte e Nordeste. http://www.consorcioantiferrugem.net/portal//wpcontent/uploads/2010/04/2009_relato_norte_nordeste.pdf. (accessed 20 Jan. 2016).

Oliveira SHF (2004) Época de aplicação de fungicidas no controle da ferrugem asiática (*Phakopsora pachyrhizi*) da soja. Fitopatol. Bras. 29:295.

Quinebre SR (2014) Aplicação de fungicidas no manejo de doenças de soja. Rev. Attalea Agron. ed. 98.

Ramalho MAP, Ferreira DF, Oliveira AC (2012) Experimentação em genética e melhoramento de plantas. Lavras: Editora: UFLA, 3 ed.

Santos WA (2016) A importância do estudo de viabilidade econômica para as empresas. http://www.varginhaonline.com.br/coluna/exibe_artigo.asp?codigo=1535. (accessed 21 Apr. 2016).

SAS (2009) Statistical analysis software. version 9.2. SAS Inst.,Cary, NC.

Scott AJ, Knott MA (1974) Cluster analysis method for grouping means in the analysis of variance. Biometrics 30(3):507-512.

Silva AJ, Canteri MG, Silva AL (2013) Haste verde e retenção foliar na cultura da soja. Summa Phytopathol. 39(3):151-156.

Töfoli JG (2002) Ação de fungicidas e acibenzolar-s-methyl no controle da pinta preta do tomateiro. 123f. Dissertation (Master degree) - Paulista State University "Júlio de Mesquita Filho", Faculty of Agronomic Sciences.

Vello NA, Carvalho RSB (2013) Melhoramento da soja para resistência genética a doenças In: Grupo de Estudos Avançados em Fitopatologia, GEAFIT, Universidade Federal de Viçosa (Eds.). (Org.). Melhoramento genético no manejo de doenças de plantas. 1 ed. Visconde do Rio Branco, MG: Suprema, 1.

Vitti AJ, Paiva SB, Castrro RM, Veiga JS, Garcia L (2004) Efeito residual e curativo de fungicidas para o cotrole de ferrugem da soja (*Phakopsora pachyrhizi*). Fitopat. Bras. 29:290.

Wysmiersky PT (2015) Seleção de linhagens experimentais de soja para tolerância a ferrugem asiática e produtividade. Thesis (Doctorate) - School of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba.

Ypema HL, Gold HE (1999) Kresoxim-methyl modification of a naturally occurring compound to produce a new fungicide. Plant Disease 83(1):4-19.