Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252022v35n308rc

FUNGICIDE SPRAYING TECHNOLOGIES IN THE CONTROL OF ASIAN RUST IN SOYBEAN CULTIVARS[1]

LAURÍCIO RIBEIRO DE MORAES[2]*, LILIANNE MARTINS RIBEIRO[2]

ABSTRACT – The adequacy of spraying technology in the control of Asian rust to factors related to soybean cultivars and fungicide type is fundamental for the efficiency in the control of this disease. In this context, the objective was to evaluate the chemical control of Asian soybean rust and the deposition of the fungicide applied in the crop, according to different volumes and spray nozzles. Four field experiments were set up during the 2014/2015 season, each carried out with one soybean cultivar, using: NA 5909 RR®, NS 7237 IPRO®, BMX Potência RR® and W 712 RR®. The experimental design was randomized blocks in a 2x2x2 factorial arrangement, with four replications. The first factor corresponded to the use of fungicides: [pyraclostrobin + epoxiconazole] and [pyraclostrobin + epoxiconazole] + mancozeb; the second factor, types of spray nozzle: double and triple fan; and the last factor, application volume: 60 and 120 L ha^{-1}. The highest application volume resulted in greater deposition of droplets in the canopy of the plants, regardless of the fungicide, type of spray nozzle and cultivar. The association of fungicides [pyraclostrobin + epoxiconazole] + mancozeb showed greater efficacy in controlling rust, regardless of the type of spray nozzle and the volume applied when compared to [pyraclostrobin + epoxiconazole]. The highest volume of application promoted less disease evolution in the cultivars NA 5909 RR®, NS 7237 IPRO® and BMX Potência RR®. The yields of the cultivar were higher when the combination [pyraclostrobin + epoxiconazole] + mancozeb was used.

Keywords: Chemical control. *Glycine max*. *Phakopsora pachyrhizi*. Spray nozzles. Spray volume.

TECNOLOGIAS DE PULVERIZAÇÃO DE FUNGICIDAS NO CONTROLE DA FERRUGEM ASIÁTICA EM CULTIVARES DE SOJA

RESUMO - A adequação de tecnologia de pulverização no controle da ferrugem asiática aos fatores relacionados às cultivares de soja e tipo de fungicida é fundamental para a eficiência no controle dessa doença. Neste sentido, o objetivo foi avaliar a eficácia do controle químico da ferrugem asiática da soja e a deposição do fungicida aplicado na cultura, em função de diferentes volumes de calda e pontas de pulverização. Foram instalados quatro experimentos a campo durante a safra 2014/2015, cada um realizado com uma cultivar de soja, utilizando: NA 5909 RR®, NS 7237 IPRO®, BMX Potência RR® e W 712 RR®. O delineamento experimental foi em blocos casualizados em arranjo fatorial 2x2x2, com quatro repetições. O primeiro fator correspondeu a utilização dos fungicidas: [pyraclostrobin + epoxiconazole] e [pyraclostrobin + epoxiconazole] + mancozeb; o segundo fator, tipos de ponta de pulverização: leque duplo e triplo; e o último fator, volume de aplicação: 60 e 120 L ha^{-1}. A utilização do maior volume de aplicação resultou em maior deposição de gotas no dossel das plantas independente do fungicida, tipo de ponta de pulverização e da cultivar. A associação dos fungicidas [pyraclostrobin + epoxiconazole] + mancozeb, apresentou maior eficácia no controle da ferrugem independente do tipo de ponta e do volume aplicado quando comparado ao [pyraclostrobin + epoxiconazole]. O maior volume de aplicação proporcionou menor progresso da doença nas cultivares NA 5909 RR®, NS 7237 IPRO® e BMX Potência RR®. A produtividade das cultivares foi superior quando se utilizou a associação [pyraclostrobin + epoxiconazole] + mancozeb.

Palavras-chave: Controle químico. *Glycine max*. *Phakopsora pachyrhizi.* Pontas de pulverização. Volume de pulverização.

*Corresponding author
[1]Received for publication in 11/06/2020; accepted in 03/21/2022.
Paper extracted from the master dissertation of the first author.
[2]Department of Agronomy, Universidade de Rio Verde, Rio Verde, GO, Brazil; lauricio.moraes@corteva.com – ORCID: 0000-0001-8197-412X, lilianne.mr@gmail.com - ORCID: 0000-0003-2051-8010.

INTRODUCTION

Each year Brazil has been consolidating itself as one of the world's largest soybean producers and, in the 2019/2020 season, the country ranked first in the production of this oilseed crop (CONAB, 2020). Despite all this volume produced and the constant increases of yield in the national average visualized in each season, it is important to highlight that several factors affect soybean development, negatively impacting its final production.

Within this context, Asian rust, a disease caused by the fungus *Phakopsora pachyrhizi* is listed among the major phytosanitary problems of soybean crop (TORMEN et al., 2012). Considering the damage described in the first reports of occurrence of this disease in Brazil, in the 2001/2002 season, it is estimated that the average annual costs for the control of Asian rust in soybean reach values close to 2 billion dollars (GODOY et al., 2016). It is important to point out that these calculations did not consider the damage caused by the fungus to crop yield; when control measures are not adopted, it can cause reductions of 10 to 90% in soybean yield (HARTMAN, MILES, FREDERICK, 2005; HARTMAN et al., 2015).

Due to the aggressiveness characteristics of the fungus which causes Asian rust, combined with yield losses that are visualized in each season, the need to adopt measures for the management of this disease in soybean crop is evident. In this context, based on the integrated management of Asian rust in soybean, it is recommended to eliminate alternative hosts of the fungus which causes the disease (REIS, 2019), avoid sowing the crop in the period of sanitary break (DUHATSCHEK et al., 2018), use tolerant cultivars (LIMA et al., 2012), and adopt chemical control, through the application of fungicides (GODOY et al., 2016). However, it is important to highlight that to date, the use of tolerant cultivars has not become a reality, and preventive application of fungicides is considered a fundamental practice in Asian rust management.

Considering all measures for Asian rust management, undoubtedly, chemical control is the main method used in soybean crop, due to the ease of execution and good benefit/cost ratio when used at the appropriate time and within the recommendations of fungicides. Among the most widely used fungicides for Asian rust control, demethylation inhibitors (DMI - triazoles), quinone outside inhibitors (QoI - strobilurins) and succinate dehydrogenase inhibitors (SDHI - carboxamides) stand out (REIS; REIS; ZANATTA, 2018). An option that may be feasible to expand the spectrum of disease control in the applications and that enables protective action against Asian rust refers to the addition of multi-site fungicides (SILVA et al., 2015). In addition, the mixtures of site-specific fungicides with multi-site fungicides as an anti-resistance strategy of the fungus *P. pachyrhizi* to site -specific fungicides is also a relevant practice in Asian rust management.

Despite the good efficacy of the chemical method, some challenges are still present to increase the efficacy of fungicides against Asian rust, especially those related to application technology (CHECI et al., 2020). To ensure less progress of Asian rust, the fungicide application solution must be deposited in the middle and lower thirds of soybean plants, which constitute the starting point of infection by the fungus (GASPARETTO et al., 2011). In this context, soybean breeders have sought to select materials that have plants with distinct architectures and growth habits in order to favor the penetration of products applied in the crop canopy, which can help improve the efficacy of fungicides (LEE et al., 2011).

In addition, the pesticide application technology has undergone alterations related to the adoption of the soybean cultivars of indeterminate growth habit currently used, which have greater preference over the materials of determinate growth habit. In this context, using the application technology to increase fungicide deposition on the disease infection points, such as increased volumes of application solution and use of spray nozzles that promote greater coverage, can contribute to better management of Asian rust in soybean.

Given the information previously addressed, it is hypothesized in the present work that changes in the volume of application solution, as well as the use of spray nozzles more appropriate for fungicide applications, can help in the penetration of droplets in the lower thirds of soybean plants, promoting a better control of Asian rust. In this context, the objective of this study was to evaluate the efficacy of chemical control of Asian soybean rust and the deposition of fungicides applied in the crop, as a function of different volumes of solution and spray nozzles.

MATERIAL AND METHODS

Four experiments were conducted in an experimental station located in the municipality of Rio Verde, Goiás, specifically at the geographic coordinates of 17º47'06.00"S and 50º59'56.93"W, at 765 m altitude. The experiments were conducted within the period from December 2014 to April 2015.

The climate of the municipality where the experiments were carried out, according to Köppen's classification, is Aw, which is called "tropical with dry season", characterized by having more intense rainfall in summer compared to winter, with well-defined drought period. The climatological data related to precipitation and minimum, mean and maximum temperatures during the conduction period of the experiments are shown in Figure 1. Before the experiment was set up, soil analysis was performed for the 0-20 cm layer, which showed the following physicochemical properties: pH ($CaCl_2$) = 5.1; 1.84 $cmol_c$ dm^{-3} of H^{+}+Al^{+3}; 3.09 $cmol_c$ dm^{-3} of Ca^{+2}; 0.88 $cmol_c$ dm^{-3} of Mg^{+2}; 0.11 $cmol_c$ dm^{-3} of K^{+}; 6.54 mg dm^{-3} of P; 14.80 g dm^{-3} of OC; 485 g kg^{-1} of clay; 133 g kg^{-1} of silt; and 382 g kg^{-1} of sand (clayey texture).

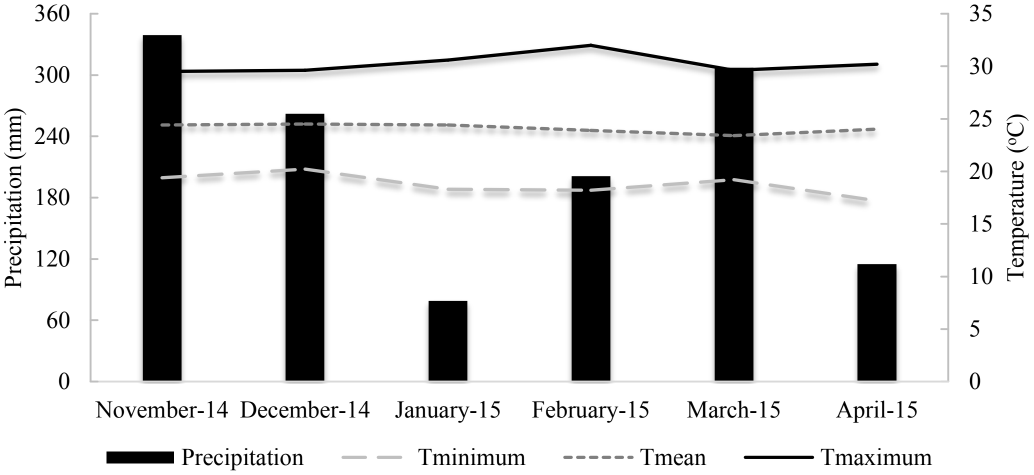


Figure 1. Precipitations and temperatures (maximum, mean and minimum) during the conduction period of the experiments. Source: INMET - National Institute of Meteorology (2015), Official Station of Rio Verde (Goiás).

Each experiment corresponded to the use of a distinct soybean cultivar, among the following: NA 5909 RR®, BMX Potência RR®, W 712 RR® and NS 7237 IPRO®. The criterion for choosing the cultivars used in the experiment took into account the area of cultivation occupied by each material in the Southwest region of the Goiás state, as well as morphological differences between them. The main characteristics of the cultivars are: NA 5909 RR®, maturity group (MG) = 6.0, semi-erect growth habit and recommended population of 480,000 plants ha^{-1}; BMX Potência RR®, MG = 6.1, erect growth habit and population of 480,000 plants ha^{-1}; W 712 RR®, MG = 7.1, erect growth habit and population of 360,000 plants ha^{-1}; and NS 7237 IPRO®, MG = 7.0, semi-erect growth habit and population of 360,000 plants ha^{-1}, all materials with indeterminate growth.

In each experiment, the design used was randomized blocks, with treatments distributed in a 2x2x2 triple factorial arrangement, with four replicates. The first factor corresponded to the application of fungicide associations between [pyraclostrobin + epoxiconazole] at dose of 66.5 + 25 g ha^{-1} or [pyraclostrobin + epoxiconazole] + mancozeb at dose of 66.5 + 25 + 1125 g ha^{-1}; the second factor corresponded to the spray nozzles: double fan and triple fan; and the third factor corresponded to the application of solution volumes equivalent to 60 and 120 L ha^{-1}. Experimental units that did not receive fungicide application were set up next to each experiment, which served exclusively to monitor the progress of Asian rust in the experimental area.

The commercial products used were Opera® (BASF) and Unizeb Gold® (UPL), which have as active ingredients the association between [pyraclostrobin + epoxiconazole] and mancozeb, respectively. According to the recommendation contained in the label of the commercial products used, all fungicide treatments received the addition of the mineral oil Assist® (BASF) at the dose of 0.5 L c.p. ha^{-1}. The experimental units consisted of eight soybean sowing rows with five meters in length, spaced at 0.5 m between rows. The usable area was represented by the four central rows, disregarding 0.5 m from the initial and final ends of the experimental unit, totaling 8 m^2.

It is worth pointing out that the area where the experiments were set up had been cultivated under no-tillage system, having soybean as previous crop in the 2013/2014 season and millet as previous crop in the second season of 2014. Sowing of the experiments was carried out on 12/02/2014, and the seeds of all cultivars were treated with the association of [fipronil + pyraclostrobin + thiophanate-methyl] at dose of 25 + 2.5 + 22.5 g per 100 kg of seeds and inoculated with peat inoculant based on *Bradyrhizobium japonicum* at the concentration recommended by the manufacturer, $5x10^9$ mL. The sowing density used in each experiment aimed at the final population according to the values recommended for each cultivar. Fertilization was performed following the recommendations of soil analysis, by applying 400 kg ha^{-1} of the 04-20-20 formulation in the sowing furrow.

During soybean development, all cultural practices were carried out as recommended by

Embrapa (2013), controlling pests and weeds to prevent them from influencing the development of the crop. All maintenance applications were performed using a drag sprayer, adopting volume of applied solution equivalent to 200 L ha^{-1}. It is important to point out that there was no artificial inoculation of the pathogen which causes Asian rust, which occurred naturally in the area, and the first symptoms of the disease were recorded in the experimental area at the end of the first half of February 2015.

Treatments were applied using two motorized backpack sprayers, containing 3-m-long boom and six spray nozzles spaced every 0.5 m, one with double fan nozzles (LD110.02) and the other with triple fan nozzles (LT110.02). The spray nozzles used in the experiments were acquired from the manufacturer MagnoJet®. To adjust the volumes of application solution established in the treatments (60 or 120 L ha^{-1}), the spray pressure was maintained at 60 psi and 90 psi, respectively, changing only the displacement speed.

During the development of the crop, three fungicide applications were performed according to the disease monitoring in the field, the first on 02/02/2015, at the phenological stage R5.1, the second on 02/14/2015, at the phenological stage R5.5, and the third on 02/28/2015, when soybean plants were in R6. During the applications, the environmental conditions were monitored with the Kestrel 3000 weather meter, positioned close to the apex of the plant. At the time of applications, the temperature was between 27.8 and 33.0 ºC, relative humidity varied between 45.2 and 62.4%, and the maximum wind speed recorded was 3.6 km h^{-1}.

The variables analyzed were droplet density cm^{-2}, disease severity (percentage of injured leaf area), area under the disease progress curve (AUDPC), defoliation, 1000-grain weight and yield. In all applications, the quantity of droplets cm^{-2} was evaluated by fixing water-sensitive paper in the lower, middle and upper thirds of soybean plants in all experimental units. In order to measure these variables, photographic images of the water-sensitive papers positioned in all experimental units were captured, and the density and quantity of droplets applied were analyzed using Gotas software (CHAIM; CAMARGO NETO; PESSOA, 2006).

Regarding disease severity, the percentage of injured leaf area was evaluated in two parts of the plant (lower and upper) using the diagrammatic scale proposed by Godoy, Koga and Canteri (2006), as illustrated in Figure 2. For this, six points were sampled in the usable area of each experimental unit and then the average severity in the plant was calculated. In these evaluations, disease severity was always evaluated in trifoliate leaves arranged at the same height of the plant in all treatments, using the second fully expanded trifoliate leaf from the apex to the base. The average severity data were used to calculate the AUDPC, according to the model proposed by Shaner and Finney (1977).

Figure 2. Diagrammatic scale of soybean rust severity as a function of the percentage of leaf area with the disease. Source: Godoy, Koga and Canteri (2006).

To measure plant defoliation, an evaluation was performed in R7 (03/16/2015), when the plants in the control had defoliation rates ≥ 80%. This analysis was performed based on the visual percentage of defoliation of the plants present in all experimental units. In addition, at the time of harvest, the evaluation of 1000-grain weight was performed, by counting 1000 grains, weighing them on a precision scale, and correcting their moisture to 13%. To determine the yield (kg ha^{-1}), all plants present in the usable area of each experimental unit were manually harvested, threshed, packed, identified and weighed, and the moisture content of the grains was corrected to 13% in all treatments.

Data from all experiments were analyzed using SISVAR software (FERREIRA, 2011). The data were subjected to analysis of variance by the F test (*p≤0.05*) and, when a significant effect was found between the factors, or between the levels of each factor, the means of the factors were compared by the F test (*p≤0.05*).

RESULTS AND DISCUSSION

Since Asian rust initiates the infection process in the middle and lower thirds of plants, variations in application technology that allow the deposition of fungicides in the lower third of soybean can improve the disease control spectrum, preventing its progression to the younger trifoliate leaves (GASPARETTO et al., 2011; AUGUSTI et al., 2014). In this context, to measure the effect of spray nozzles and application volumes on droplet deposition in the different thirds of soybean plants subjected to fungicide treatments, evaluations of density (number) of droplets per cm^2 were performed. The analysis of variance showed no significant effect of the interaction between the factors fungicides, nozzles and application volumes on droplet deposition for the cultivars NA 5909 RR® and W 712 RR®, regardless of the time when the evaluations were performed or position (third) on the plant (Table 1).

Table 1. Deposition of droplets (number of droplets cm^{-2}) in the lower, middle and upper thirds of soybean plants (cultivars: NA 5909 RR® and W 712 RR®) after fungicide application.

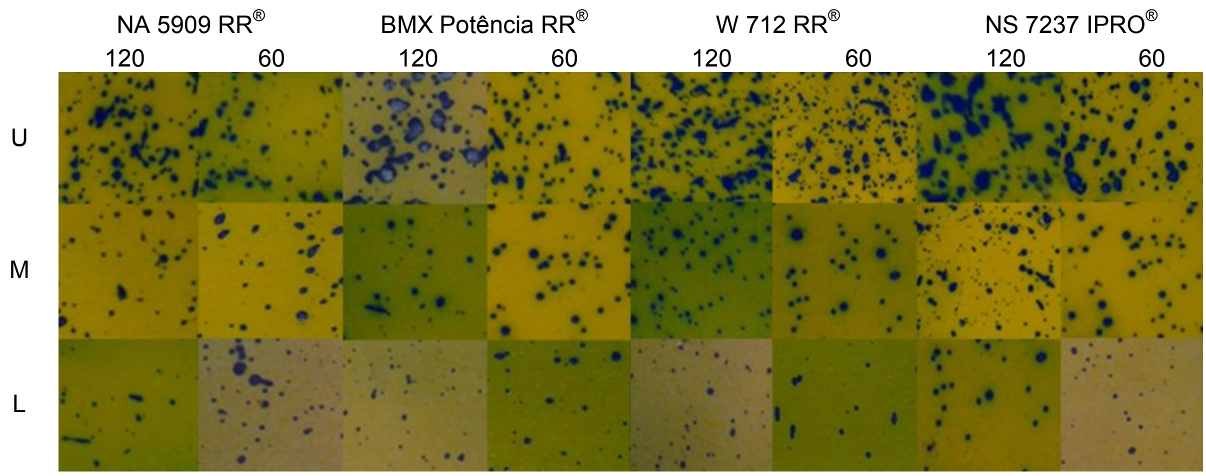
	R5.1			R5.5			R6		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Fungicides	NA 5909 RR®								
[PYR+EPO]	22.03 a	32.13 a	49.75 a	20.06 a	31.22 a	53.75 a	18.81 a	30.12 a	57.23 a
[PYR+EPO]+MAN	21.95 a	32.27 a	51.00 a	21.00 a	31.31 a	54.25 a	19.75 a	30.25 a	57.12 a
Nozzles									
Double fan	22.20 a	31.18 a	50.00 a	20.37 a	32.20 a	53.81 a	18.50 a	31.13 a	55.10 a
Triple fan	22.00 a	31.08 a	50.75 a	20.69 a	32.18 a	54.19 a	19.06 a	31.07 a	55.25 a
Volume (L ha^{-1})									
60	18.25 b	27.89 b	37.87 b	17.00 b	27.75 b	41.62 b	15.50 b	27.75 b	45.00 b
120	25.75 a	34.75 a	62.87 a	24.06 a	34.85 a	66.37 a	22.06 a	34.75 a	69.50 a
CV (%)	6.82	6.60	5.87	8.27	6.60	5.09	11.07	6.60	4.68
Fungicides	W 712 RR®								
[PYR+EPO]	21.87 a	31.75 a	50.56 a	20.00 a	31.56 a	54.06 a	17.52 b	33.12 a	58.75 a
[PYR+EPO]+MAN	21.94 a	31.50 a	50.37 a	21.06 a	31.44 a	54.06 a	19.85 a	33.22 a	59.02 a
Nozzles									
Double fan	21.81 a	31.37 a	50.75 a	20.37 a	31.37 a	54.25 a	18.68 a	32.33 a	55.45 a
Triple fan	22.00 a	31.87 a	50.19 a	20.69 a	31.62 a	53.87 a	18.98 a	32.45 a	54.75 a
Volume (L ha^{-1})									
60	18.20 b	28.37 b	37.81 b	17.12 b	28.12 b	41.62 a	16.45 b	28.78 b	46.15 b
120	25.56 a	34.87 a	63.12 a	23.94 a	34.87 a	66.50 a	22.12 a	34.45 a	68.25 a
CV (%)	9.72	7.42	5.76	9.73	6.66	5.06	10.59	6.45	4.72

PYR = pyraclostrobin; EPO = epoxiconazole; MAN = mancozeb. Equal lowercase letters in the column do not differ statistically by F test (*p≤0.05*).

For the cultivars mentioned above (NA 5909 RR® and W 712 RR®), the only factor which caused differences in droplet deposition in all evaluations was the volume of application. For applications performed with 120 L ha^{-1}, there was a higher density of droplets captured compared to the treatments in which the volume equivalent to 60 L ha^{-1} was applied (Figure 3). Additionally, for the cultivar W 712 RR®, there was a significant effect for the deposition of droplets as a function of fungicides in the lower third of the plants, in evaluation carried out in the R6 stage. On this occasion, the association between the fungicides [pyraclostrobin + epoxiconazole] + mancozeb led to higher values of droplet deposition compared with the application of [pyraclostrobin + epoxiconazole] with no addition of mancozeb.

For the cultivar NS 7237 IPRO®, a significant double interaction was observed between the factors fungicides and application volumes, and this behavior was observed in all the evaluations, always in the upper third of soybean plants (Table 2). No significant effect was observed on the number of droplets among the fungicides used for the application volume equivalent to 60 L ha^{-1}; however, when the volume of 120 L ha^{-1} was adopted, there was an increase in droplet density in the association of [pyraclostrobin + epoxiconazole] + mancozeb compared to the fungicides [pyraclostrobin + epoxiconazole] without mancozeb. The droplet formation process can be significantly altered by the modification of the physical characteristics of the solution, notably by the use of certain formulations and by the addition of surfactants (CONTIERO et al., 2016), which may explain the differences observed in the deposition of droplets between fungicide treatments.

Also in relation to the effect of treatments on droplet deposition for the cultivar NS 7237 IPRO®, it can be observed that in all evaluations, the adoption of higher volume of solution promoted an increase in the quantity of droplets per cm² in all thirds of soybean plants (Table 2). Moreover, in the evaluation performed when the plants were in R6 stage, there was a single effect of the spray nozzles in the lower third of soybean plants, with greater deposition when the double fan was used.



Legend: L = Lower; M = Middle; U = Upper.

Figure 3. Visual aspect of the deposition of droplets on water-sensitive paper in the different thirds of soybean plants subjected to application of fungicides with different volumes.

Table 2. Deposition of droplets (number of droplets cm^{-2}) in the lower, middle and upper thirds of soybean plants (cultivar: NS 7237 IPRO®) after fungicide application.

Fungicides	R5.1		R5.5		R6	
	Upper					
	Application volume (L ha^{-1})					
	60	120	60	120	60	120
[PYR+EPO]	34.62 aB	62.25 bA	41.87 aB	66.50 bA	45.87 aB	70.12 bA
[PYR+EPO]+MAN	37.00 aB	66.62 aA	41.00 aB	70.25 aA	45.00 aB	73.62 aA
CV (%)	4.47		4.32		4.05	
Nozzles	R6					
	Lower		Middle		Upper	
Double fan	20.81 a		32.44 a		58.87 a	
Triple fan	19.12 b		32.12 a		58.44 a	
CV (%)	10.73		7.84		4.05	

PYR = pyraclostrobin; EPO = epoxiconazole; MAN = mancozeb. Equal lowercase letters in the column and uppercase letters in the row between application volumes do not differ statistically by F test (*p≤0.05*).

For the cultivar BMX Potência RR®, a triple interaction was observed between the factors for the deposition of droplets cm^{-2} in soybean plants, and this behavior was visualized in the evaluations performed at stages R5.1 and R5.5 (Table 3). In both stages, based on the mean values of the treatments, there was a significant effect among the fungicides in the upper third of the plants, since the association of [pyraclostrobin + epoxiconazole] + mancozeb for the volume of 120 L ha^{-1} led to higher values of droplet deposition compared to the treatment with application of [pyraclostrobin + epoxiconazole].

Among the spray nozzles, there was a higher value of deposition in the upper third of soybean plants at R5.1, when the double fan was adopted to the detriment of the triple fan, with application performed using the volume of 60 L ha^{-1} (Table 3). Finally, regardless of the stage at which the evaluation was performed or third of the plant, for the cultivar BMX Potência RR®, on all occasions a greater deposition of droplets was visualized when the highest volume of application was adopted (120 L ha^{-1}). It is worth pointing out that, in addition to the characteristics related to application technology, in order to be successful in the application in the lower and middle thirds of the plants, there will also be an influence of the architectural characteristics of the soybean cultivar, which could facilitate the penetration of the sprayed droplets (TORMEN et al., 2012).

Table 3. Deposition of droplets (number of droplets cm^{-2}) in the lower, middle and upper thirds of soybean plants (cultivar: BMX Potência RR®) after fungicide application.

Fungicides	Nozzles	R5.1					
		Lower		Middle		Upper	
		Application volume (L ha^{-1})					
		60	120	60	120	60	120
[PYR+EPO]	Double fan	19.75 aAß	26.50 aAα	28.50 aAß	34.75 aAα	39.00 aAß	61.25 bAα
	Triple fan	18.75 aAß	26.50 aAα	28.00 aAß	35.25 aAα	35.75 aBß	63.75 aAα
[PYR+EPO]+MAN	Double fan	21.50 aAß	29.25 aAα	29.25 aAß	37.25 aAα	37.50 aAß	66.50 aAα
	Triple fan	19.25 aAß	27.50 aAα	28.50 aAß	36.75 aAα	38.00 aAß	65.50 aAα
CV (%)		13.72		8.09		4.04	
		R5.5					
[PYR+EPO]	Double fan	18.50 aAß	24.00 aAα	28.50 aAß	34.75 aAα	43.25 aAß	65.50 bAα
	Triple fan	17.25 aAß	24.75 aAα	28.00 aAß	35.25 aAα	40.50 aAß	67.25 aAα
[PYR+EPO]+MAN	Double fan	20.50 aAß	27.50 aAα	29.25 aAß	37.25 aAα	41.50 aAß	70.50 aAα
	Triple fan	17.50 aAß	25.50 aAα	28.50 aAß	36.75 aAα	41.75 aAß	69.50 aAα
CV (%)		11.93		8.09		4.08	

PYR = pyraclostrobin; EPO = epoxiconazole; MAN = mancozeb. Equal lowercase letters in the column between fungicides, uppercase letters in the column between nozzles and Greek letters in the row between volumes do not differ statistically by F test (*p≤0.05*).

In general, the fungicide association of [pyraclostrobin + epoxiconazole] + mancozeb applied in the volume of 120 L ha^{-1} promoted higher droplet deposition in the cultivars NS 7237 IPRO® and BMX Potência RR®, with no influence of the type of nozzle used. As observed in the present result, the literature has already reported the observation of no differences in droplet deposition when single fan, double fan or hollow cone nozzles were used (OZKAN et al., 2006). On the other hand, Farinha et al. (2009) found differences in droplet deposition due to the use of different spray nozzles, observing that there was a higher droplet deposit at the apex of soybean plants in reproductive stage. Moreover, these authors found that the nozzles that promoted greatest droplet deposition were those that had lowest uniformity in droplet distribution.

Before discussing the effects of treatments on Asian rust control, it is appropriate to highlight that environmental conditions during the period in which the experiments were conducted had great influence on the occurrence and rapid development of this disease in soybean plants. The volume of precipitation occurred in December 2014 and January 2015 allowed the maintenance of relative humidity at high values, with the presence of dew during the night, which combined with the mild temperatures recorded during the days in the aforementioned months contributed to the process of infection and development of the pathogen (Figure 1). From the first record of occurrence of Asian rust in soybean plants in the experimental area, the precipitation volumes recorded in February and March contributed to the progress of the disease.

The statement above becomes more evident when analyzing the data presented in Figure 4, which show the rapid evolution of the severity of Asian rust in soybean plants that did not receive fungicide application (control), demonstrating that, regardless of the cultivar, the behavior related to the rapid progression of the disease was similar. To give an idea of the aggressiveness that the rust-causing fungus had in the experimental area, in less than 30 days, the mean severity values among soybean cultivars exceeded 80%. These data show the high aggressiveness that the Asian rust-causing fungus has in causing damage, pointing to the importance of preventive actions for the integrated management of this disease in soybean crop (AUGUSTI et al., 2014).

When analyzing the effect of factors influencing the AUDPC results of Asian rust, it was possible to observe a triple interaction in the experiments conducted with the cultivars NA 5909 RR®, NS 7237 IPRO® and BMX Potência RR® (Table 4). The behavior of the treatments with reduction in the AUDPC values was similar among the cultivars that had triple interaction. In general, it was found that the increase in application volume, using rates equivalent to 120 L ha^{-1}, promoted a decrease in the progress curve of Asian rust in soybean plants treated with fungicides.

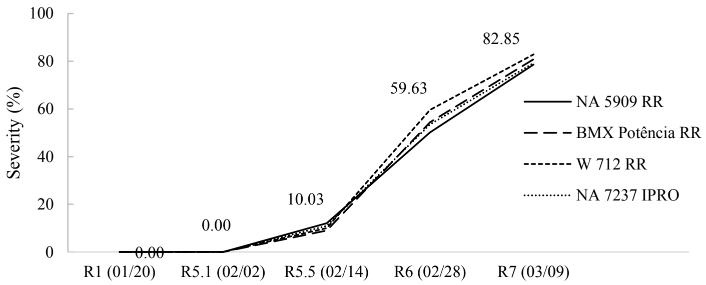


Figure 4. Progress of the severity of Asian rust in plants from the controls of each soybean cultivar.

In this context, it can be observed that, when working with this volume of application (120 L ha^{-1}), the type of nozzle starts to have less influence on the results. On the other hand, with the lowest volume of application evaluated, equivalent to 60 L ha^{-1}, the use of the double fan nozzle showed better performance in reducing the AUDPC values of Asian rust compared to the treatments in which the triple fan nozzle was used.

Finally, still relating the behavior of the treatments for the cultivars NA 5909 RR®, NS 7237 IPRO® and BMX Potência RR®, lower values of Asian rust progress were verified when the association [pyraclostrobin + epoxiconazole] + mancozeb was applied, compared to the use of [pyraclostrobin + epoxiconazole] without the addition of the multi-site fungicide mancozeb (Table 4), which corroborates other studies that added mancozeb in fungicide treatments in the control of Asian rust in soybean (SILVA et al., 2015; GODOY et al., 2017). Moreover, a comparison of the results of deposition with those obtained in the evaluations of AUDPC clearly shows the importance of ensuring that the application solution containing fungicides reaches the middle and lower thirds of soybean plants, regardless of the growth habit of the cultivar, in order to reduce the severity of Asian rust and slow down the progress of the disease. This statement can be supported by the fact that the treatments that promoted higher droplet deposition in soybean plants were the same ones that had lower AUDPC values of Asian rust.

Table 4. AUDPC values of Asian rust in soybean plants (cultivars: NA 5909 RR®, NS 7237 IPRO® and BMX Potência RR®) subjected to fungicide application.

Fungicides	Nozzles	Application volume (L ha^{-1})	
		60	120
		NA 5909 RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	720.80 bBß	508.34 bAα
	Triple fan	554.76 bAα	516.12 bAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	523.70 aBß	285.78 aAα
	Triple fan	434.24 aAß	257.75 aAα
CV (%)		6.09	
		NS 7237 IPRO®	
[Pyraclostrobin + epoxiconazole]	Double fan	665.03 bBß	423.40 bAα
	Triple fan	470.70 bAß	422.47 bAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	427.60 aBß	248.69 aBα
	Triple fan	327.53 aAß	192.77 aAα
CV (%)		7.15	
		BMX Potência RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	646.59 bBß	386.97 bAα
	Triple fan	451.02 bAα	429.03 bBα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	420.40 aBß	226.48 aAα
	Triple fan	339.07 aAß	186.20 aAα
CV (%)		7.18	

Equal lowercase letters in the column between fungicides, uppercase in the column between the nozzles and Greek in the row between the application volumes, do not differ statistically by the F test (*p≤0.05*).

For the cultivar W 712 RR®, a double interaction was verified between the factors fungicides and application volumes, as well as for nozzles and volume (Table 5). In this context, it was found that the association [pyraclostrobin + epoxiconazole] + mancozeb led to lower values of AUDPC of Asian rust in both volumes of application when compared with the fungicides [pyraclostrobin + epoxiconazole]. Regarding the effect of the spray nozzles, it was found that, for this cultivar, the triple fan nozzle promoted better performance aiming at reducing disease progress compared to the double fan nozzle. Regardless of fungicide or spray nozzle, for the cultivar W 712 RR®, there was a reduction in the progress curve of Asian rust in soybean plants when using the highest volume of application, equivalent to 120 L ha^{-1}.

Table 5. AUDPC values of Asian rust in soybean plants (cultivar: W 712 RR®) subjected to fungicide application.

Application volume (L ha^{-1})	Fungicides		Nozzles	
	[PYR+EPO]	[PYR+EPO]+MAN	Double fan	Triple fan
60	559.24 bB	387.03 bA	540.47 bB	405.80 bA
120	431.06 aB	200.78 aA	329.34 aB	302.50 aA
CV (%)	8.16			

PYR = pyraclostrobin; EPO = epoxiconazole; MAN = mancozeb. Equal lowercase letters in the column and uppercase letters in the row do not differ statistically by F test (*p≤0.05*).

In all experiments, a significant triple interaction was verified between the factors evaluated for defoliation (Table 6). In general, lower percentages of defoliation were observed when the fungicide mancozeb was added to the association of [pyraclostrobin + epoxiconazole], regardless of the spray nozzle or application volume. The only exception to this result was the cultivar NA 5909 RR®, which showed no differences in defoliation intensity among fungicides when they were applied in the volume of 120 L ha^{-1}.

Also in relation to defoliation evaluations, it was observed that the higher volume of application (120 L ha^{-1}) reduced the values of this variable compared to the rate of 60 L ha^{-1}. Of the three factors evaluated in the experiments, the type of spray nozzle was the one that had the lowest influence on the defoliation levels of soybean plants. The results of the defoliation evaluations corroborate those observed for AUDPC, since in the treatments which had greater loss of leaf area in soybean plants (defoliation), the values of the Asian rust progress curve were higher. This result highlights again the importance of the preventive management of Asian rust, especially with the objective of reducing defoliation levels, since even at the end of the reproductive period, the importance of maintaining leaf area in terms of production of assimilates for grain filling is still high (PARCIANELLO et al., 2004).

Table 6. Defoliation (%) in soybean plants of different cultivars subjected to fungicide application.

Fungicides	Nozzles	Application volume (L ha^{-1})	
		60	120
		NA 5909 RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	81.50 bAß	76.50 bBα
	Triple fan	81.50 bAß	58.25 aAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	64.25 aBß	56.50 aAα
	Triple fan	58.75 aAß	52.50 aAα
CV (%)		3.37	
		NS 7237 IPRO®	
[Pyraclostrobin + epoxiconazole]	Double fan	79.50 bAß	73.50 bBα
	Triple fan	76.25 bAß	58.25 bAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	63.25 aBß	51.50 aAα
	Triple fan	57.00 aAß	50.50 aAα
CV (%)		5.36	
		BMX Potência RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	74.75 bAß	70.25 bBα
	Triple fan	71.50 bAß	48.25 aAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	54.25 aBß	46.50 aAα
	Triple fan	48.75 aAß	42.50 aAα
CV (%)		4.33	
		W 712 RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	64.50 bBß	60.25 bBα
	Triple fan	62.25 bAß	40.25 aAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	44.25 aBα	42.25 aAα
	Triple fan	35.75 aAß	30.25 aAα
CV (%)		3.11	

Equal lowercase letters in the column between fungicides, uppercase letters in the column between nozzles and Greek letters in the row between volumes do not differ statistically by F test (*p≤0.05*).

For 1000-grain weight, no interaction was observed between the factors evaluated in the experiments, with a significant simple effect only for the fungicide factor in the cultivars NA 7232 IPRO® and BMX Potência RR®, where plants that received application of the association [pyraclostrobin + epoxiconazole] + mancozeb showed higher grain weight value compared to those treated with the fungicides [pyraclostrobin + epoxiconazole] (data not shown). The average increase in 1000-grain weight for both cultivars was 5.59%. The increase in the values of this yield component may be related to the fact that soybean plants treated with the fungicides [pyraclostrobin + epoxiconazole] + mancozeb showed lower values of AUDPC and defoliation, which promotes larger leaf area for the photosynthesis process (YOKOYAMA et al., 2018).

In all experiments, for grain yield, the analysis of variance revealed the existence of significant triple interaction between the evaluated factors (Table 7). Regardless of the type of nozzle used and the volume of application, the fungicide association of [pyraclostrobin + epoxiconazole] + mancozeb led to the highest yields in the cultivars NA 5909 RR® and W 712 RR®. However, for the cultivar NS 7237 IPRO®, the application volume promoted an increase in soybean yield, regardless of the type of nozzle used. At 60 L ha^{-1}, the association of [pyraclostrobin + epoxiconazole] led to higher yield values, while with the application volume of 120 L ha^{-1} the fungicide association [pyraclostrobin + epoxiconazole] + mancozeb promoted the highest values.

In general, it is observed that, when the fungicides [pyraclostrobin + epoxiconazole] were used, the lowest volume of solution (60 L ha^{-1}) promoted the highest yields, except for the cultivar NS 7237 IPRO®, for which higher yield was achieved using the volume of 120 L ha^{-1} when using triple fan nozzle. On the other hand, when the fungicide association [pyraclostrobin + epoxiconazole] + mancozeb was used, the yield was higher using the volume of 120 L ha^{-1}. The literature has already reported that the volume of 160 L ha^{-1} applied with flat jet nozzles promotes greater uniformity of distribution of fungicide solution in soybean plants, but despite that, no effect was observed on rust control and crop yield (CUNHA; REIS; SANTOS, 2006). It is important to highlight that, compared to the national average of soybean yield in the 2014/2015 season, 3,012 kg ha^{-1} (CONAB, 2015), only the cultivar NS 7237 IPRO® for the application volume of 60 L ha^{-1} for all fungicides and nozzles used and at a dose of 120 L ha^{-1} for the fungicide [Pyraclostrobin + epoxiconazole] using double fan showed results below the national average.

Table 7. Grain yield (kg ha^{-1}) of different soybean cultivars subjected to fungicide application.

Fungicides	Nozzles	Application volume (L ha^{-1})	
		60	120
		NA 5909 RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	3,505.50 bBα	3,205.14 bBß
	Triple fan	3,685.00 bAα	3,392.02 bAß
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	3,613.88 aAß	3,720.50 aBα
	Triple fan	3,493.62 aBß	3,976.04 aAα
CV (%)		0.73	
		NS 7237 IPRO®	
[Pyraclostrobin + epoxiconazole]	Double fan	2,850.00 aBα	2,845.00 bBα
	Triple fan	3,076.25 aAß	3,217.00 bAα
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	2,325.00 bBß	3,264.67 aAα
	Triple fan	2,988.75 bAß	3,277.00 aAα
CV (%)		0.99	
		BMX Potência RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	3,716.50 bBα	3,408.25 bBß
	Triple fan	3,995.87 aAα	3,795.38 bAß
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	4,143.17 aAα	4,129.82 aAß
	Triple fan	3,845.24 bBß	4,236.59 aBα
CV (%)		0.18	
		W 712 RR®	
[Pyraclostrobin + epoxiconazole]	Double fan	3,984.75 bBα	3,860.50 bBß
	Triple fan	4,480.00 bAα	4,023.75 bAß
[Pyraclostrobin + epoxiconazole] + mancozeb	Double fan	4,831.50 aAα	4,835.22 aBα
	Triple fan	4,721.25 aBß	4,885.45 aAα
CV (%)		0.21	

Equal lowercase letters in the column for fungicides, uppercase letters in the column between nozzles and Greek letters in the row between volumes do not differ statistically by F test (*p≤0.05*).

For all soybean cultivars, in both application volumes (60 and 120 L ha^{-1}), when the fungicides [pyraclostrobin + epoxiconazole] were used, the triple fan nozzle promoted higher yields. On the other hand, when the fungicide association [pyraclostrobin + epoxiconazole] + mancozeb was used, the double fan nozzle promoted higher yields for the cultivars NA 5909 RR® and W 712 RR® in the application volume of 60 L ha^{-1} and for the cultivar BMX Potência RR® in the volumes of 60 and 120 L ha^{-1}. This result proves the importance of taking into account the soybean cultivar and the product used in the choice of the best fungicide spraying technology. These results are in accordance with those reported by Checi et al. (2020), who verified significant effect on Asian rust control and soybean yield due to variations in spray nozzles and droplet size, and this result was also influenced by the architecture of the cultivar used.

CONCLUSIONS

Higher droplet deposition was observed when the application volume was increased from 60 to 120 L ha^{-1}, regardless of the fungicide or spray nozzle used, and this result was visualized for all soybean cultivars.

The association [pyraclostrobin + epoxiconazole] + mancozeb showed greater efficacy in the control of Asian rust compared to the fungicides [pyraclostrobin + epoxiconazole] without the addition of mancozeb.

Applications performed with higher volume of solution promoted, on average, lower progress of Asian rust in the soybean cultivars evaluated, a behavior that resulted in lower values of defoliation.

The yield of the cultivars was higher when the fungicide association [pyraclostrobin + epoxiconazole] + mancozeb was used, and these fungicides were more efficient when the volume of 120 L ha^{-1} was used.

Application performed with fungicides [pyraclostrobin + epoxiconazole] promoted better yields when combined with the use of triple fan nozzle with the volume of solution of 60 L ha^{-1}.

REFERENCES

AUGUSTI, G. R. et al. Aplicações preventivas e erradicantes de fungicidas no controle da ferrugem asiática da soja. **Summa Phytopathologica**, 40: 288-289, 2014.

CHAIM, A.; CAMARGO NETO, J.; PESSOA, M. C. P. Y. **Uso do programa computacional Gotas para avaliação da deposição de pulverização aérea sob diferentes condições climáticas**. Jaguariúna, SP: Embrapa Meio Ambiente, 2006. 18 p.

CHECI, A. et al. The combined use of spray volumes and droplet sizes in the chemical control of Asian soybean rust in cultivars with different leaf area indices. **Crop Protection**, 136: 1-7, 2020.

CONAB - Companhia Nacional de Abastecimento. **Boletim da safra de grãos: 11º Levantamento - Safra 2014/15**. Disponível em: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos>. Acesso em: 21 out. 2015.

CONAB - Companhia Nacional de Abastecimento. **Boletim da safra de grãos: 11º Levantamento - Safra 2019/20**. Disponível em: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos>. Acesso em: 17 out. 2020.

CONTIERO, R. L. et al. Effects of nozzle types and 2,4-D formulations on spray deposition. **Journal of Environmental Science and Health**, 51: 888-893, 2016.

CUNHA, J. P. A. R.; REIS, E. F.; SANTOS, R. O. Controle químico da ferrugem asiática da soja em função de ponta de pulverização e de volume de calda. **Ciência Rural**, 36: 1360-1366, 2006.

DUHATSCHEK, E. et al. Sensibilidade de isolados de *Phakopsora pachyrhizi* provenientes da região do centro oeste do Paraná a fungicidas. **Summa Phytopathologica**, 44: 193-194, 2018.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. **Tecnologias de Produção de Soja - Região Central do Brasil 2014**. 1. ed. Londrina, PR: Embrapa Soja. 2013; 265 p.

FARINHA, J. V. et al. Deposição da calda de pulverização em cultivares de soja no estádio R1. **Ciência Rural**, 39: 1738-1744, 2009.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, 35: 1039-1042, 2011.

GASPARETTO, R. et al. Eficiência e viabilidade econômica da aplicação de fungicidas no controle da ferrugem asiática da soja em Campo Grande, MS. **Arquivos do Instituto Biológico**, 78: 251-260, 2011.

GODOY, C.V. et al. Asian soybean rust in Brazil: past, present, and future. **Pesquisa Agropecuária Brasileira**, 51: 407-421, 2016.

GODOY, C.V; KOGA, L.J.; CANTERI, M.G. Diagrammatic scale for assessment of soybean rust severity. **Summa Phytopathologica**, 31: 63-68, 2006.

GODOY, C. V. et al. **Eficiência de fungicidas multissítios e produto biológico no controle da ferrugem asiática da soja, *Phakopsora pachyrhizi*, na safra 2016/17: resultados sumarizados dos ensaios cooperativos**. 2017. Disponível em: https://www.embrapa.br/soja/busca-de-publicacoes/-/publicacao/1073218/eficiencia-de-fungicidas-multissitios-e-produto-biologico-no-controle-da-ferrugem-asiatica-da-soja-phakopsora-pachyrhizi-na-safra-201617-resultados-sumarizados-dos-ensaios cooperativos. Acesso em: 18 out. 2020.

HARTMAN, G. L.; MILES, M. R.; FREDERICK, R.D. Breeding for resistance to soybean rust. **Plant Disease**, 89: 664-666, 2005.

HARTMAN, G. L. et al. **Compendium of soybean diseases and pests**. 5th ed. Saint Paul: APS Press, 2015. p. 56-59.

INMET - Instituto Nacional de Meteorologia. **Banco de dados metereológicos**. Disponível em: <https://portal.inmet.gov.br/>. Acesso em: 21 out. 2015.

LEE, G.A. et al. Archaeological soybean (*Glycine max*) in East Asia: does size matter? **PLoS ONE**, 6: 1-12, 2011.

LIMA, W. F. et al. Resistência da soja à ferrugem-asiática avaliada pela análise da produtividade de grãos. **Summa Phytopathologica**, 38: 73-78, 2012.

OZKAN, H. E. et al. Evaluation of various spraying equipment for effective application of fungicides to control 78 Asian soybean rust. **Aspects of Applied Biology**, 77: 1-8, 2006

PARCIANELLO, G. et al. Tolerância da soja ao desfolhamento afetada pela redução do espaçamento entre fileiras. **Ciência Rural**, 34: 357-364, 2004.

REIS, E. M. Sobre os hospedeiros de *Phakopsora pachyrhizi*, no Brasil. **Summa Phytopathologica**, 45: 113-113, 2019.

REIS, E. M.; REIS, A. C.; ZANATTA, M. Reflexo econômico e desenvolvimento da resistência de *Phakopsora pachyrhizi* a fungicidas em função do número de aplicações. **Summa Phytopathologica**, 44: 289-292, 2018.

SHANER, G.; FINNEY, R. E. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in knox wheat. **Phytopathology**, 70: 1183 -1186, 1977.

SILVA, L. H. C. P. et al. Control of Asian soybean rust with mancozeb, a multi-site fungicide. **Summa Phytopathologica**, 41: 64-67, 2015.

TORMEN, N. R. et al. Deposição de gotas no dossel e controle químico de *Phakopsora pachyrhizi* na soja. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 16: 802-808, 2012.

YOKOYAMA, A. H. et al. Índices de área foliar e SPAD da soja em função de culturas de entressafra e nitrogênio e sua relação com a produtividade. **Revista de Ciências Agrárias**, 41: 953-962, 2018.