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Spray solution deposition and Asian rust control in soybean cultivars[1]

Deposição de calda e controle da ferrugem asiática em cultivares de soja

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HIGHLIGHTS:

Medium-sized droplets provide better coverage in the lower layers of the soybean canopy under limiting climate conditions.
Nozzles 11002BD and AIXR11005 provide better spray solution deposition in soybean cultivars with lower leaf area indexes.
Leaf area can be used as a parameter in selecting the appropriate droplet size for spraying.

ABSTRACT: The control of Asian soybean rust depends on fungicide efficacy and the application technology; however, the leaf architecture of soybean cultivars may also interfere in disease control. This study aimed to evaluate Asian rust control and fungicide deposition using spray nozzles in three soybean cultivars. A randomized block design was used, with treatments arranged in a split-plot scheme; the plots were three soybean cultivars (SYN 1561 IPRO, M6410 IPRO, and M6210 IPRO) and the subplots three spray nozzles (11002 BD, AIXR 110015 and TTJ60 11002), in addition to a control with no fungicide application, and four replicates. The volume median diameter, droplet coverage, leaf area index, area under the disease progress curve, 1,000-grain weight and crop yield were evaluated. The 11002BD and AIXR11005 nozzles provided better spray deposition in cultivars with lower leaf area indexes at the R1 phenological stage. Nozzles 11002BD, AIXR110015 and TTJ60 ensured better management of Asian rust than that of the control treatment, regardless of leaf area index. Cultivar SYN1561 obtained the largest grain yield and highest leaf area index in the season with the highest rainfall, regardless of the spray nozzle used.

Key words: *Glycine max*, *Phakopsora pachyrhizi*, application technology, droplet density, fungicides

RESUMO: O controle da ferrugem asiática da soja depende da eficácia do fungicida e da tecnologia de aplicação empregada, entretanto, a arquitetura foliar de cada cultivar de soja também pode ser um fator a interferir no controle da doença. O objetivo do estudo foi avaliar a deposição de calda fungicida e o controle da ferrugem asiática da soja utilizando pontas de pulverização em três cultivares de soja. O delineamento experimental utilizado foi em blocos ao acaso, com tratamentos arranjados no esquema de parcelas subdivididas, em que as parcelas eram três cultivares de soja (SYN 1561 IPRO, M6410 IPRO e M6210 IPRO) e as subparcelas três pontas de pulverização (11002 BD, AIXR 110015 e TTJ60 11002), e uma testemunha sem aplicação, com quatro repetições. Foram avaliados o diâmetro mediano volumétrico, cobertura de gotas, índice de área foliar (IAF), área abaixo da curva de progresso da doença, massa de 1000 grãos e produtividade da soja. Os bicos 11002BD e AIXR11005 fornecem melhor deposição de calda naquelas cultivares com menores índices de área de foliar, no estágio fenológico da soja R1. Os bicos 11002BD, AIXR110015 e TTJ60 fornecem controle da ferrugem asiática comparada ao tratamento controle, independentemente do índice de área de folha da cultivar. A cultivar SYN1561 apresentou a maior produção de grãos e o maior índice de área de folha, independentemente do bico de pulverização utilizado, na época com a maior precipitação pluviométrica.

Palavras-chave: *Glycine max*, *Phakopsora pachyrhizi*, tecnologia de aplicação, densidade de gotas, fungicidas

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Introduction

Asian rust is the main disease in most soybean-growing [*Glycine max* (L.) Merrill] countries. Caused by the fungus *Phakopsora pachyrhizi* H. Sydow & Sydow, the first symptoms of the disease are small brown-to-dark brown lesions on the abaxial portion of the leaves (Godoy et al., 2018; Nascimento et al., 2018). Chemical control with fungicides is the primary means of controlling this pathogen, supported by other practices such as nutrition, sowing time, row spacing and biological vacuum (Stefanello et al., 2016; Godoy et al., 2018).

Chemical control is only carried out with knowledge of the application technology. The choice of spray nozzles for fungicide application is an important decision, aimed at producing the most homogeneous droplets possible (Vieira et al., 2019). The nozzles must provide efficient coverage of the target to ensure minimum fungicide wastage (Prado et al., 2015).

Pesticide coverage on the soybean canopy is not typically uniform, especially in the lower, resulting in inefficient control, even with the use of systemic products (Cunha et al., 2014). Successful droplet deposition in the lower soybean canopy also depends on the cultivar's architectural characteristics. Cultivars with a higher leaf area index (LAI) and more lateral branches enable faster canopy closure, making it difficult for droplets to penetrate to the lower layers of the canopy (Tormen et al., 2012). Additionally, droplet penetration through the canopy may differ depending on the soybean cultivar used, since the LAI may vary according to the cultivar.

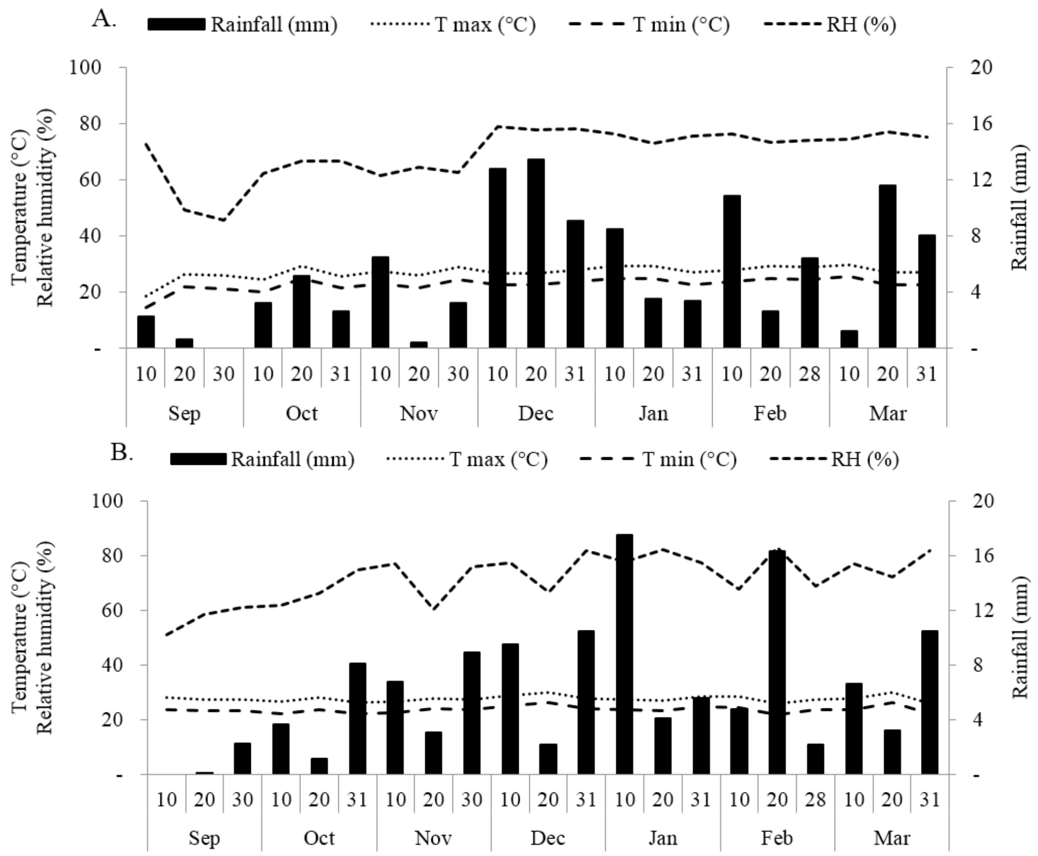
This study aimed to evaluate fungicide deposition and Asian rust control in three soybean cultivars, using three different spray nozzles.

Material and Methods

The study was carried out in the 2016/17 and 2017/18 growing seasons at the Federal Institute of Education, Science and Technology of Mato Grosso do Sul state, in Ponta Porã, Brazil (22°33'07" S and 55°39'02" W, 755 meters above sea level). Climate conditions during the study were determined using data from the INPE Ponta Porã-A703 Weather Station, as shown in Figure 1. Soil preparation was performed in the experimental area to adjust soil physical, chemical and biological properties to the soybean crop. Base dressing consisted of 350 kg ha^{-1} of the 02-20-20 fertilizer formulation. The seeds were inoculated with *Bradyrhizobium japonicum* at a dose of 300 mL per 100 kg of seed. Sowing was performed with rows spaced 0.45 m apart, 13.5 plants m^{-1}, and a final population of 300,000 plants ha^{-1}.

A randomized block design was used, with treatments arranged in a split-plot scheme in which the plots were the three soybean cultivars (SYN 1561 IPRO, M6410 IPRO and M6210 IPRO) and the subplots the spray nozzles (Table 1), in addition to a control with no fungicide application, and four replicates. Each experimental unit consisted of ten 15-meter-long rows, disregarding the four outer rows and two meters at either end, totaling a study area of 29.7 m^2.

The fungicide was applied using a hydraulic sprayer with a 600 L tank and working boom width of 12 m. The nozzles



Source: National Institute of Meteorology - INMET

Figure 1. Rainfall, maximum and minimum temperatures, and relative air humidity (RH) during the soybean cycle in the 2016/17 (A) and 2017/18 (B) growing seasons in Ponta Porã, MS, Brazil

Table 1. Description of spray nozzles used in the experiment

Spray Nozzle Tips	Description	Manufacturer	Droplet size category*	Approximate VMD range (μm)**
Magno 11002 BD	Simple flat jet	Magno Jet	Fine	100 - 235
AIXR 110015	Air-induction simple flat jet	Teejet	Medium	235 - 335
TTJ60 11002	Double-flat jet	Teejet	Medium	

* - Information supplied by the manufacturers; ** - Estimated based on the S-572.1 standard (ASABE, 2009)

were spaced 0.5 m apart, with a spray volume of 200 L ha^{-1} and speed of 5.0 km h^{-1}, as recommended by the fungicide manufacturer. The following working pressures were used for the nozzles: 11002 BD of 320 kPa, AIXR 110015 of 600 kPa, and TTJ60 11002 of 340 kPa, according to the manufacturers' recommendations. The fungicide Fluxapyroxad + Pyraclostrobin (167 + 333 g L^{-1}) with 350 mL c.p. ha^{-1} + 0.5 L ha^{-1} mineral oil (Assist®) was used in the spray solution. The first application was performed when the initial symptoms of the disease were observed and the plants had reached phenological stage R1 (Fehr & Caviness, 1977). This was followed by a second application 14 days later, as recommended by the manufacturer. The temperature, relative humidity and wind speed during fungicide applications were monitored with a Digital Lux-meter Thermo-Hygroanemometer (LM8000). For treatments applied in the 2016/17 growing season, temperature ranged from 23.9 to 26.0 °C, relative humidity from 64.5 to 75.0%, and wind speed from 3.8 to 7.4 km h^{-1}, with respective measurements of 27.4 to 31.3 °C, 55.0 to 77.0% and 2.5 to 5.4 km h^{-1} in the 2017/18 growing season. All applications were performed at 5 p.m. The droplet spectrum was obtained by selecting the spray nozzle and adjusting the working pressure and speed according to the manufacturers' recommendations, without changing the application rate.

After the first fungicide application, droplet deposition was evaluated using water-sensitive paper specially designed for droplet assessment, since there are no restrictions on spray nozzles that produce larger than very fine drops (Cunha et al., 2016).

The water-sensitive paper was placed inside the canopy by stapling it onto the adaxial surface of leaves. At the R1 stage the soybean cultivars were 0.85 ± 0.06 m tall. The plants were divided vertically into three equal sections (upper, middle, and lower), with two sheets of water-sensitive paper per section in each experimental unit.

Immediately after spraying, the water-sensitive paper was stored in a wooden box with blue silica gel to prevent moisture from the environment interfering with the results. These were digitalized and subsequently evaluated in GOTAS® image analysis software. Next, volume median diameter (VMD) and droplet coverage (%) were determined.

The leaf area index (LAI) was calculated at application. To that end, three plants were randomly collected in each of the experimental plots, and their leaves removed. A metal perforator was used to remove leaf discs with a known area from four points on the leaf blade in each leaflet, avoiding the sampling of the central rib. Next, the leaf discs were dried in an air circulation oven at 70 ºC for 36 hours to obtain dry matter. The same procedure was used to dry the leaves from which the leaf discs were removed. The LAI was calculated based on the ratio between the total (leaves + leaf discs) and leaf disc dry matter. The LAI methodology used in the experiment was based on Tormen et al. (2012).

At 0, 7, 14, 21, and 28 days after the first fungicide application, 10 trefoils were collected from the lower and middle third of plants in each experimental unit.

The severity of soybean rust was determined based on the percentage of leaf area with symptoms of the disease, using the scale proposed by Godoy et al. (2006). These data were used to construct the progress curve and area under the disease progress curve (AUDPC), calculated based the methodology proposed by Campbell & Madden (1990), as follows:

$$\mathrm{AUDPC}=\sum_{i=1}^{n-1}\left(\frac{y_i+y_{i+1}}{2}\right)\left(t_{i+1}-t_i\right) \quad (1)$$

where:

AUDPC - area under the disease progress curve;
y_i - disease progress at the i^{th} observation;
y_{i+1} - disease progress at the subsequent i^{th} observation;
t_i - time in days at the i^{th} observation;
t_{i+1} - disease progress at the subsequent i^{th} observation; and,
n - total number of observations.

Yield (kg ha^{-1}) and 1000-grain weight were evaluated. Harvesting was performed by manually removing all the plants in the 5.4 m^2 area, followed by threshing. Next, the grains were packed in paper bags, correctly identified, and stored for subsequent manual cleaning and moisture content determination. The samples were weighed and the value corrected to 13% moisture, with results expressed in kg ha^{-1}.

The data were submitted to analysis of variance. The treatments with fungicide application were compared by Tukey's test, at $p \leq 0.05$, and Dunnett's test ($p \leq 0.05$) was used to compare the fungicide treatments and the control.

Results and Discussion

A significant effect of spray nozzles and soybean cultivars was observed for VMD, droplet density and coverage in the 2016/17 and 2017/18 growing seasons. Wind speed may have negatively affected the deposition of fine droplets on soybean plants in the 2016/17 growing season. The TTJ60 nozzle obtained lower VMD values in the middle and lower thirds for cultivars M6410 and M6210 in the 2016/17 growing season (Table 2). The spray nozzles used produced fine droplets in the middle and lower thirds in almost all treatments, according to the ASABE S-572.1 droplet size classification. The AIXR 110015 nozzle resulted in higher VMD values in the middle and lowers thirds of cultivars M6410 and M6210 in the 2016/17 growing season. Air-inducing nozzles such as AIXR 110015 tend to produce thicker drops (Sasaki et al., 2016).

Table 2. Volume median diameter (VMD, µm) of fungicide droplets on water-sensitive paper, applied to three soybean cultivars with three different nozzles in the 2016/17 and 2017/18 growing seasons

Nozzle	2016/17 growing season			2017/18 growing season		
	Cultivar			Cultivar		
	SYN 1561	M6410	M6210	SYN 1561	M6410	M6210
			Upper third VMD			
11002BD	295.2 aA	275.2 aA	263.3 aA	322.2 aA	293.3 aA	282.0 aA
AIXR110015	278.7 aA	272.7 aA	222.1 aA	306.8 abA	286.2 aA	307.7 aA
TTJ60	275.5 aA	303.8 Aa	256.5 aA	260.8 bA	266.2 aA	266.1 aA
			Middle third VMD			
11002BD	184.0 abAB	250.9 aA	171.4 aB	190.5 aB	226.9 aA	210.0 aAB
AIXR110015	240.3 aA	214.9 abA	235.5 aA	248.1 aA	218.9 aA	245.6 aA
TTJ60	163.0 bA	167.4 bA	192.4 aA	201.2 aB	207.4 aA	196.2 aB
			Lower third VMD			
11002BD	182.1 aA	164.6 bA	158.3 aBA	158.8 aA	191.0 aA	175.5 aA
AIXR110015	118.5 bB	214.2 aA	201.2 aA	192.6 aA	155.2 aA	142.0 aA
TTJ60	183.2 aA	161.2 bA	141.0 bA	175.1 aA	163.6 aA	170.2 aA

Means followed by the same lowercase letter in the column (between nozzles) and uppercase letter in the row (between cultivars) do not differ according to Tukey's test at $p \leq 0.05$

Only fine droplets were found in the mid and lower canopy for 11002 BD and TTJ60 nozzles and medium-sized droplets for nozzle AIXR 110015, demonstrating the importance of selecting tips that produce drops of this size. Tormen et al. (2012) reported that smaller droplets may provide greater coverage in the middle and lower thirds of soybean plants.

Analysis of the upper canopy indicated that the high spray rate may have compromised drop impact assessment since some drops overlapped, increasing the impacted area on the water-sensitive paper and contributing to the fact that higher values were obtained for artificial targets than those estimated in Table 1.

According to Cunha et al. (2014), there is no clear definition regarding the ideal spray nozzle; however, nozzles that produce medium-sized drops generally provide better droplet density and coverage. Fine droplets have a greater risk of drift (Rodrigues et al., 2015), but can provide better coverage of the target (Maciel et al., 2017). An appropriate value for fungicide application would be around 50 to 70 droplets per cm^2 (Baesso et al., 2014).

In a study with a droplet spectrum sprayed onto two soybean cultivars, Debortoli et al. (2012) obtained values greater than 250 drops cm^{-2}. According to the authors, spectra of very fine and fine droplets are expected to provide better droplet deposition than their medium-sized and large counterparts. Nevertheless, the same authors observed a greater than 10-fold reduction in droplet deposition in the lower third when compared to the upper canopy. Cunha et al. (2014) emphasize the importance of seeking strategies that increase deposition, especially in the lower canopy of soybean crops.

Droplet density analysis may be hampered by overlapping droplets on the water-sensitive paper, whereby the values obtained may be underestimated. However, precise values of actual droplet coverage were similar to those obtained by Meyer et al. (2016). Additionally, the 11002 BD and AIXR 110015 nozzles generally provided greater droplet coverage (Table 3). Droplet coverage declined as the spray solution penetrated the plants canopy, which is expected result as the droplets begin to find barriers to penetrate the canopy.

In the 2016/17 growing season, nozzle AIXR 110015 provided greater droplet coverage than that of TTJ60 in the middle third of the plants. The same nozzle also obtained better coverage in the lower canopy of the M6410 cultivar when compared to nozzle 11002 BD and TTJ60. Based on the data obtained, the air induction nozzle with a medium-sized droplet spectrum was more efficient in covering the lower canopy. Fine droplets do not always provide better droplet coverage, with climate conditions at application defining droplet size (Nascimento et al., 2013).

Table 3. Coverage (%) of artificial targets by spray droplets using different nozzles in three soybean cultivars in the 2016/17 and 2017/18 growing seasons

Nozzle	2016/17 growing season			2017/18 growing season		
	Cultivar			Cultivar		
	SYN 1561	M6410	M6210	SYN 1561	M6410	M6210
		Upper third coverage			Upper third coverage	
11002 BD	41.7 aA	40.7 aA	29.6 aA	47.1 aA	33.9 aA	33.4 aA
AIXR110015	31.0 aA	34.7 aA	22.6 aA	39.7 aA	31.7 aA	42.3 aA
TTJ60	34.6 aA	54.0 aA	30.9 aA	32.9 aA	29.9 aA	30.7 aA
		Middle third coverage			Middle third coverage	
11002 BD	13.0 aA	26.9 aA	10.4 aA	7.5 aA	12.7 aA	16.2 aA
AIXR110015	24.7 aA	13.4 aA	18.2 aA	18.5 aA	8.5 aA	17.3 aA
TTJ60	8.4 aA	8.0 aA	14.4 aA	12.6 aA	9.3 aA	8.2 aA
		Lower third coverage			Lower third coverage	
11002 BD	5.7 aA	6.1 bA	6.9 aA	4.6 aA	4.7 aA	13.2 aA
AIXR110015	4.4 aB	15.3 aA	4.9 aB	2.9 aA	4.8 aA	3.6 aA
TTJ60	7.8 aA	3.2 bA	2.1 aA	2.1 aA	2.2 aA	2.9 aA

Means followed by the same lowercase letter in the column (between nozzles) and uppercase letter in the row (between cultivars) do not differ according to Tukey's test at $p \leq 0.05$

Table 4. Leaf area index of soybean cultivars in the R5.1 phenological stage in the 2016/17 and 2017/18 growing seasons

Cultivar	2016/17 growing season	2017/18 growing season
SYN 1561	5.2 a	5.0 a
M6410	4.8 b	4.2 b
M6210	4.0 b	4.1 b

Means followed by the same letter in the column do not differ according to Tukey's test at $p \leq 0.05$

The leaf area index of all three cultivars varied from 4.0 to 5.2. Cultivar SYN 1561 obtained the highest LAI in both growing seasons (Table 4). Other factors such as canopy closure, trefoil angle and position and plant height can also affect droplet penetration and coverage.

No differences were observed between the soybean cultivars for VMD, droplet density or coverage, despite the higher LAI recorded for cultivar SYN 1561. Tormen et al. (2012) obtained higher droplet deposition in the upper and mid canopy in two soybean cultivars when fungicide was applied in R1 compared to R4, likely due to architectural differences in canopy closure at application. As such, factors other than LAY contribute to differences in leaf architecture and canopy closure.

In relation to the control treatment (no fungicide application), fungicide application affected the area under the disease progress curve, 1,000-grain weight and yield for all the nozzles and cultivars tested (Table 5).

The SYN 1561 cultivar obtained a higher 1,000-grain weight in both growing seasons and greater yield in 2017/18 season than that of M6410 and M6210 (Table 6). No difference was observed for AUDPC. Durão & Boller (2017) obtained the lowest soybean rust AUDPC values when medium-sized droplets were used. For systemic fungicide application, the droplets must remain in contact with the leaf for a certain period of time to allow the plant to absorb the active ingredient (Yu et al., 2009). As such, very fine drops evaporate before being absorbed by the plant. In the present study, medium-sized drops exhibited better deposition, meaning that the effect of fine droplets was not observed.

Table 5. Area under the disease progress curve (AUDPC), 1,000-grain weight and yield of each soybean cultivar for comparison between the fungicide treatments and control treatment (no fungicide application)

Nozzle	Soybean rust AUDPC		1,000-grain weight (g)		Yield (kg ha^{-1})	
	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
			SYN 1561			
11002 BD	6.3*	33.2*	169.5	166.8	3,635.1	3,664.5*
AIXR 110015	7.7*	30.7*	168.1	164.4	3,637.6	3,554.2*
TTJ60	10.6*	32.7*	172.3	164.2	4,125.7	3,626.4*
Control	18.4	51.5	164.1	160.2	3,338.7	1,942.2
			M6410			
11002 BD	2.3*	22.4*	149.1	149.1*	3,665.5	3,328.7*
AIXR 110015	1.9*	23.7*	158.1*	158.1*	4,186.6*	3,104.2*
TTJ60	3.0*	20.7*	146.1	147.4*	4,430.4*	3,398.6*
Control	11.3	66.8	139.4	135.2	3,173.6	1,533,4
			M6210			
11002 BD	3.8*	30.8*	154.2*	157.0*	4,096.1*	3,041.7*
AIXR 110015	8.3*	19.2*	150.0	151.1	4,125.7*	2,986.1*
TTJ60	9.4*	34.3	152.9*	156.5*	4,321.1*	2,868.1*
Control	19.2	44.9	140.5	142.5	3,207.7	1,551.2

* - Means followed by an asterisk differ significantly from the control treatment at $p \leq 0.05$ according to Dunnett's test

Table 6. Area under the disease progress curve (AUDPC), 1,000-grain weight and yield in three soybean cultivars submitted to fungicide application with three spray-nozzles in the 2016/17 and 2017/18 growing seasons

Nozzle	Cultivar		
	SYN 1561	M6410	M6210
	2016/17 growing season		
	AUDPC		
11002 BD	6.3 aA	2.5 aA	4.3 aA
AIXR110015	7.7 aA	2.0 aA	8.9 aA
TTJ60	10.6 aA	3.1 aA	9.6 aA
	1,000-grain weight (g)		
11002 BD	169.5 aA	149.1 abB	154.2 aB
AIXR110015	168.1 aA	158.1 aAB	150.0 aB
TTJ60	172.3 aA	146.1 bB	152.9 aB
	Yield (kg ha^{-1})		
11002 BD	3,635.1 aA	3,665.5 aA	4,096.1 aA
AIXR110015	3,637.6 aA	4,186.5 aA	4,125.7 aA
TTJ60	4,125.7 aA	4,430.4 aA	4,321.1 aA
	2017/18 growing season		
	AUDPC		
11002 BD	33.2 aA	22.4 aA	30.8 aA
AIXR110015	30.7 aA	23.7 aA	19.2 aA
TTJ60	32.7 aA	20.7 aA	34.3 aA
	1,000-grain weight (g)		
11002 BD	166.8 aA	149.1 bB	157.0 aB
AIXR110015	164.4 aA	158.1 aAB	151.1 aB
TTJ60	164.2 aA	147.4 bB	156.5 aA
	Yield (kg ha^{-1})		
11002 BD	3664.5 aA	3328.7 aB	3041.7 aB
AIXR110015	3554.2 aA	3104.2 aB	2986.1 aB
TTJ60	3626.4 aA	3398.6 aA	2868.1 aB

Means followed by the same lowercase letter in the column (between nozzles) and uppercase letter in the row (between cultivars) do not differ according to Tukey's test at $p \leq 0.05$

Conclusions

1. The 11002BD and AIXR11005 nozzles provide better spray deposition in cultivars with lower leaf area indexes in the R1 soybean phenological stage.

2. Nozzles 11002BD, AIXR110015 and TTJ60 provide better management of Asian rust than that of the control treatment for the SYN 1561, M6410 and M6210 varieties, regardless of leaf area index.

3. The cultivar SYN1561 obtained the highest grain yield and leaf area index in the season with the highest rainfall, regardless of the spray nozzle.

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