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USE OF SURFACTANT WITH DIFFERENT VOLUMES OF FUNGICIDE APPLICATION IN SOYBEAN CULTURE

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KEYWORDS

leaf surface cover, *Phakopsora pachyrhizi*, application rate.

ABSTRACT

Application volume, adjuvants that act on the drop surface tension and droplet spectrum are the main factors affecting leaf surface coverage and the spray penetration droplets inside the canopy of the soybean crop, which may have an impact on fungicide efficiency, since those used in the handling of Asian-rust, including those that are absorbed by the plant, present a small displacement from the point of deposition. Thus, it was sought to determine the impacts on the use of the organosilicone surfactant compared to the changes in the spray volumes. For that, five spray volumes and the combination of two adjuvants were compared in randomized blocks with a factorial arrangement 5x2. Reductions in volume negatively impacted the number of drops cm^{-2} affecting the leaf surface cover which did not exceed 13% in the lower third, in the absence of the surfactant. Also, the reduction in the volume provided decreases in the control of Asian- rust, and the use of surfactant minimized the negative impacts of the disease, reflecting on the index of the leaf area which varied up to 6.5 times on changes in the spray volume, and up to 2.8 times against the use of the surfactant in relation to the mineral oil isolated. Grain yield was negatively affected as reductions in the spray volumes, occurred with less impact when the surfactant was used. Thus, coverage of the leaf surface and the number of drops cm^{-2} along the plant profile respond to the addition of the surfactant and to the increase of the spray volume, having relation with the control of soybean Asian-rust, and affecting the leaf area index and productivity.

INTRODUCTION

Asian soybean rust (ASR) caused by the fungus *Phakopsora pachyrhizi* is one of the most severe diseases affecting soybean cultivation, with damages varying from 10 to 90%, and damage being observed in order of 50% in Paraguay, 80% in Australia and 55% in Brazil (Reis et al., 2012). Still, the losses accounted for 21 billion dollars in Brazil between 2002 and 2013 (Godoy et al., 2016).

A number of management practices can and should be adopted to reduce ASR impacts. The restriction of soybean cultivation at certain seasons of the year, the elimination of volunteer plants and the elimination of intermediate hosts, allied to sowing at the beginning of the recommended season and the use of early-cycle cultivars (Godoy et al., 2016; Almeida et al., 2017), combined with changes in cultural practices such as plant arrangement and irrigation management (Madalosso et al., 2010; Holtz et al., 2014) besides the varietal resistance (Melo et al., 2015) and application of fungicides (Godoy et al., 2016) are integrated measures for the management of ASR, becoming relevant for the sustainability of the culture (Godoy et al., 2016, Langenbach et al., 2016, Kimati et al. , 2011).

The use of fungicides is one of the main strategies for ASR management, where control effectiveness depends on the fungicide efficiency, timing and applications frequency as well as the adjustment on application technology to the target and crop (Cunha & Silva, 2010). However, the results in terms of control are not always satisfactory since it starts in the lower third of the plant leaves. Thus, fungicide sprays must overcome the imposed barrier by the leaf mass to reach the target, as well as promote adequate coverage within the crop canopy (Debortoli et al., 2012; Tormen et al., 2012). In addition to aspects inherent to the deposition of the fungicide on the target, these have generally shown reductions in efficacy, given the selection pressure caused on the fungus resulting in control deficiencies (Schmitz et al., 2013; Reis et al., 2015; Godoy et al., 2016).

The coverage provided by fungicide application on the canopy, in general is poorly uniform especially in the lower third of the plant resulting in inefficient control

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(Prado et al., 2010; Cunha et al., 2011), since the deposition of drops in the median and lower third does not exceed 20%, giving rise to gradients up to three times in comparison between the upper and lower third of the plant (Villalba et al., 2009; Cunha et al., 2011).

Although the main fungicides used in the ASR management are classified as penetrating, that is, absorbed by the plant, most of them present loco-systemic action being transported at small distances from the point of deposition, so that for them to express their efficiency it is necessary the adequate distribution along the crop canopy, as well as on the foliar surface (Cunha et al., 2014; Reis et al., 2010). Due to the need for adequate foliar coverage, ASR control can be affected by application volumes, droplet size and the use of adjuvants that act on the sprinkling of droplets (Cunha et al., 2014).

The use of low-volume fungicide sprays, which appear as an alternative to increase the operational capacity of sprayers may adversely, affect the effectiveness of ASR control in certain situations (Cunha et al., 2008; Cunha et al., 2014), since the increase in the spray volume used has an effect on leaf cover (Cunha et al., 2006). However, spraying with larger volumes reduces the sprayed area per unit time, therefore becoming more and more common to reduce the spray volume in fungicide applications, even at the risk of reducing effectiveness.

The addition of surfactant adjuvants to the tank mixture can optimize the efficiency of the applications, since these can improve mainly the adherence and the spreading of the drops containing the fungicide on the target (Cunha et al., 2014), once reduces the surface tension of the solution and consequently the contact angle of the drops with the surfaces, increasing the coverage (Spanoghe et al., 2007; Prado et al., 2015). The oil-based adjuvants, associated with surfactants, have positive effects as wetting, spreading, penetrating, anti-evaporating, besides improving translocation, retention and adhesive effect (Chechetto et al., 2013; Prado et al., 2015). Thus, the combination of both surfactant and oil-based adjuvants appears as an alternative to optimize the fungicide effect.

The objective of this study was to determine the impacts of the use of organosilicone surfactant compared to the changes in the application volumes regarding to ASR control levels. In addition, it was sought to determine if the spray volume used and the use of surfactant interfere with the cover leaf surface and its relationship with ASR control with leaf area index (LAI) and grain yield.

MATERIAL AND METHODS

The study was conducted during the 2015/2016 season, at the experimental field of Passo Fundo University, Passo Fundo, RS, at an altitude of 687 m, latitude 28º 15'S and longitude 52º 24'W. The Nidera 5909 RR soybean cultivar was used with an indeterminate growth habit, semi erect with a branching potential, susceptible to ASR.

Five spray volumes (40, 70, 100, 130 and 160 L ha^{-1}) were combined with two adjuvants (Nimbus® (mineral oil) and Nimbus® plus Break Thru® (surfactant)), and the treatments were conducted in randomized blocks with three replicates arranged in a 5x2 factorial scheme. The experimental units measured 20 m in length and 5.85 m in width (13 rows spaced in 0.45 m), totaling 117 m^2.

The soybean sowing was carried out on December 7, 2015, in succession to wheat, in an area with soil type Red Latosol, with final population of 295,000 plants ha^{-1}. Fertilization, management of weeds and pests was carried out in accordance with the technical recommendations for the crop. Four fungicide applications were carried out using five different spray volumes combined with two adjuvants, been the mineral oil-based adjuvant used in the concentration of 256.8 g ha^{-1} and the surfactant at 0.1% volume.

The first fungicides application occurred in the V7 stage (Fehr et al., 1971), where the fungicides propiconazole + diphenoconazole (37.5 + 37.5 grams of active ingredient ha^{-1}) were used in combination with azoxystrobin + cyproconazole (60 + 24 grams of active ingredient ha^{-1}). In the second application (R1 stage - Fehr et al., 1971) and in the third application, 18 days after R1, it was used the fungicide mixture composed by azoxystrobin + benzovindiflupir (60 + 30 grams of active ingredient ha^{-1}). In the fourth application, 33 days after R1, the used fungicide was composed by mixture of azoxystrobin + cyproconazole (60 + 24 grams of active ingredient ha^{-1}).

The variations in the spray volumes ha^{-1} were due to the use of spray nozzles with different flow rates, calibrated for medium-sized droplet spraying, according to information cataloged by the manufacturer (Table 1). The applications were sprayed with a sprayer attached to the tractor using a sprayer bar with length of 6.0 m, with the nozzles spaced 0.50 m and kept 0.50 m above the crop canopy. In order to operate in favorable environmental conditions all applications were performed in the morning (Table 2).

TABLE 1. Spray volume (L ha^{-1}), spray nozzles, working pressure (kPa), application speed (km h^{-1}) and adjuvant used in each treatment, Passo Fundo - RS, 2018.

Treatment	Volume (L ha^{-1})	Nozzle	Pressure (kPa)	Velocity (km h^{-1})	Adjuvant
1 2	40	TT 11001	150	8.0	Mineral oil Mineral Oil and Surfactant
3 4	70	TT 110015	200	8.0	Mineral oil Mineral Oil and Surfactant
5 6	100	TT 110015	425	8.0	Mineral oil Mineral Oil and Surfactant
7 8	130	TT 11002	400	8.0	Mineral oil Mineral Oil and Surfactant
9 10	160	TT 110025	350	8.0	Mineral oil Mineral Oil and Surfactant
Control	Without fungicide application				

The number of drops cm^{-2}, the foliar surface coverage, the ASR severity, the LAI, the grain yield and the mass of one thousand grains (MTG) were evaluated. The MTG and the grain yield were evaluated in the six central rows, the others, in the adjacent rows.

TABLE 2. Averages of the environmental conditions observed during the applications. Passo Fundo - RS, 2018.

Environmental condition	Application 1	Application 2	Application 3	Application 4
Wind speed (km h^{-1})	7.1	5.9	6.9	6.4
Relative humidity (%)	59	61	68	57
Air temperature (ºC)	27.1	26.5	25.9	26.8

The number of drops cm^{-2} and the foliar surface cover were evaluated by hydro sensitive cards in the applications performed in R1 (Fehr et al., 1971) and R1 + 18 days where six cards were distributed in each plot in the lower, middle and upper third of the plant. After spraying, the cards were collected, scanned at 1200 dpi resolution and then read in CIR 1.5® software. From the six evaluated cards in each third and in each application, the arithmetic mean was done to determine the number of drops cm^{-2} and the leaf surface cover. In parallel to the evaluation of the number of drops cm^{-2} and cover of the leaf surface we evaluated the LAI and height of the plants, randomly collected in the experimental area including all treatments, aiming at characterizing plant height at the time of spraying.

The ASR severity was evaluated based on the affected leaf area, using as a reference the diagrammatic scale by Godoy et al. (2006). The evaluations started at the V7 stage and extended to R6 (Fehr et al., 1971), with intervals of 12 to 15 days where in each evaluation four plants were collected and evaluated all the developed leaves. The severity was quantified in the lower, middle and upper third of the plant. The ASR severity was integrated in the area under the disease progress curve (AUDPC), by means of the equation: $AUDPC = \Sigma [((y_1 + y_2)/2)* (t_2 - t_1)]$, where y_1 and y_2 are two consecutive evaluations performed at times t_1 and t_2. Based on the AUDPC of the treatment without the application of fungicide, the control of the disease was calculated, comparing the maximum AUDPC of the treatment without fungicides application in relation to those where the application occurred with the different spray volumes and with the different adjuvant combinations.

At the R6 stage (Fehr et al., 1971), six plants were collected in each experimental unit to determine the remaining leaf area of each plant through the leaf area integrator (LI-3100 Area Meter). From these plants, the arithmetic mean was determined and based on the established plant population was determined the LAI.

The harvest was carried out in 54 m^2 of each plot, considering the six central lines of each experimental unit through a harvester parcel (Wintersteiger, A-4910), after which the grains were processed. The moisture content and the weight, corrected to 13% moisture, were determined for grain yield (kg ha^{-1}) and one thousand grain mass (g). In one of the adjacent lines, six plants were collected where the vegetables were manually threshed and the grain mass of each third of the plant was evaluated and then compared in relation to the total grain mass of the plant. Thus, the percentage participation of each third (lower, middle and higher) was calculated in the yield of the plant. Knowing the participation of each third of the plant in the yield and with the possession of the plots grain yield, it was estimated the grains yield in each third of the plant proportionally.

We used the F test for analysis of variance and the Tukey test for comparison of means with the aid of the Assistat® software.

RESULTS AND DISCUSSION

The analysis of variance for the number of drops cm^{-2} was only significant for the spray volumes. At the application of R1 the plants had an average height of 1.02 m and an average LAI of 4.98. In the application at R1 + 18 days, the average plant height was 1.18 m and the average LAI was 5.62.

The increase in the spray volume ha^{-1} provided an increase in the number of drops cm^{-2} throughout the plant profile, both in the application performed in R1 stage, Table 3, and in that performed in R1 + 18 days, Table 4, since in the passage from 40 to 160 L ha^{-1} there was an increase in approximately 2.1 times the number of drops cm^{-2}. The increase in the spray volume represented up to 33.9% more deposited drops in the plant when it went from 70 to 100 L ha^{-1} and was in the order of 20% when it was changed from 40 to 70 L ha^{-1} and from 100 to 130 L ha^{-1} in both evaluation moments. Even in the highest volumes there was an increase in the number of drops cm^{-2}, reaching 8.2% when the volume was increased from 130 to 160 L of ha^{-1} (Table 3 and Table 4).

TABLE 3. Number of drops cm^{-2} in R1 stage in the lower, middle and upper third of the plant, as a function of spray volume (L ha^{-1}) in the fungicide applications, Passo Fundo - RS, 2018.

Volume (L ha^{-1})	Number of drops cm^{-2}			
	Lower third	Middle third	Upper third	Average
40	6.6 e	33.0 e	113.8 d	51.1 e
70	13.0 d	42.6 d	133.5 c	63.0 d
100	21.6 c	52.8 c	172.2 b	82.2 c
130	29.8 b	63.3 b	212.3 a	101.8 b
160	37.3 a	74.1 a	220.6 a	110.6 a
Average	21.7	53.2	170.5	
C.V. (%)	15.8	13.5	14.2	12.7

Means followed by the same letter do not differ by Tukey test, 5% probability.

TABLE 4. Number of drops cm^{-2} in the R1 stage + 18 days in the lower, middle and upper third of the plant, as a function of spray volume (L ha^{-1}) in fungicide applications, Passo Fundo - RS, 2018.

Volume (L ha^{-1})	Number of drops cm^{-2}			
	Lower third	Middle third	Upper third	Average
40	5.4 e	32.1 e	122.7 d	53.4 e
70	10.8 d	40.4 d	136.3 c	62.6 d
100	20.1 c	54.5 c	183.5 b	86.1 c
130	27.5 b	62.1 b	224.1 a	104.6 b
160	35.2 a	72.6 a	230.6 a	112.7 a
Average	19.8	52.3	179.4	
C.V. (%)	10.2	14.7	12.3	11.8

Means followed by the same letter do not differ by Tukey test, 5% probability.

The deposition of drops cm^{-2}, considering the application performed in R1 and R1 + 18 days reduced along the canopy of the plant where on average, the lower third presented reduction 2.5 times in the number of drops cm^{-2} in relation to the middle third of the plant which presented 3.3 times less drops than the upper third, and the lower third compared to the upper one presented reduction of 8.5 times in the number of drops cm^{-2} (Table 3 and Table 4).

In the lower third of the plant, the increase in the spray volume increased the deposition of drops in the application of R1 (Table 3) and on R1 + 18 days (Table 4) which was 6.1 times higher when the spray volume changed from 40 to 160 L ha^{-1}, and variations of up to 98.1% were observed, especially when changed from 40 to 70 L ha^{-1} and 75.2% when used 100 L ha^{-1} in relation to 70 L ha^{-1}. The highest volume, 160 L ha^{-1} presented the highest number of drops cm^{-2}, being 26.5% higher than the volume of 130 L ha^{-1}. The reduction in the spray volume from 160 to 40 L ha^{-1} reduced the number of drops cm^{-2} in 55.6% in the middle third of the plant, considering the application of R1 (Table 3) and R1 + 18 days (Table 4) where the volume reduction from 100 to 70 L ha^{-1} and from 70 to 40 L ha^{-1} represented variations on the order of 22%, while the reduction on volume from 160 to 130 L ha^{-1} and from 130 to 100 L ha^{-1} represented a reduction of 14.5%.

In the upper third of the plant, in the application of R1 (Table 3) and R1 + 18 days (Table 4), the use of 130 or 160 L ha^{-1}, on average, showed no difference in the number of drops cm^{-2}, although the reduction in spray volume from 160 to 40 L ha^{-1} represented 47.6% decrease in the number of drops cm^{-2} with the greatest impacts observed when changed from 130 to 100 L ha^{-1} and from 100 to 70 L ha^{-1} which led to a reduction of 18.5 and 24.1% in drops number cm^{-2}.

When using thick drops the risk of drift can be reduced, however, it can also reduce the efficiency of the products, as well as impair the distribution of the products throughout the plant (Gandolfo et al., 2014). Thus, it is of utmost importance that the droplet size is small enough to allow adequate coverage of the target, and large enough to have sufficient durability to traverse the distance between the point of its emission and the target, in a given environmental condition (Cunha et al., 2014), so the use of medium-grade drops appears as an alternative to minimize drift risks without compromising the leaf surface cover.

The percentage of the leaf surface cover was influenced by the spray volume and the use of the surfactant. Regardless of the spray volume the surfactant added to the mineral oil provided greater coverage of the leaf surface in the application in R1, and in R1 + 18 days, Table 5. The addition of the surfactant to the tank mix was responsible for increments of up to 16.3% in the coverage which was influenced by up to 208.5% in relation to the increase in spray volume. The greatest contribution of surfactant occurred in the low volumes where its presence provided differences close to 46%, 26% and 20% when used 40, 70 and 100 L of ha^{-1}, respectively.

In the lower, middle and upper third, in both applications the use of surfactant was less responsive to the increase in spray volume showing greater relevance as lower is the used volume, Table 5. In the lower third, in the application performed in R1, to the increase volume from 40 to 70 L ha^{-1}, it presented increase of 89.5% in the coverage when in absence of the surfactant, but when it was present in the tank mixture, the obtained variation reached levels of 40.6%, as well as in the application performed in R1 + 18 days where the variation was on the order of 160.2% and 52.5%, when in the absence and presence of surfactant, respectively, associated with a change in the spray volume from 40 to 70 L ha^{-1}. The same behavior was observed in all the studied volumes, which shows that the surfactant is a component that added to the tank mixture can minimize the negative effects of the reduction on application volumes, regarding the cover of leaf surface, considering that the use of surfactant plus oil optimized leaf coverage, especially in volumes below 100 L ha^{-1} (Table 5).

Increase spray volume from 40 to 70 L ha^{-1} as well as from 130 to 160 L ha^{-1} with the use of mineral oil alone were not responsive in terms of increasing leaf surface coverage in the lower third of the plant in the application performed in R1, however, when these volumes were associated to surfactant they were significantly larger, especially the volume of 40 and 70 L ha^{-1} where there were variations of up to 2.8 times in coverage. However, in the application performed at R1 + 18 days there were direct responses in terms of volume increase and surfactant use, except when the volume was changed from 40 to 70 L ha^{-1} and only mineral oil was used (Table 5).

TABLE 5. Coverage of leaf surface (%) in the R1 stage and R1 stage + 18 days, in the lower, middle and upper third and average on the leaf cover in the plant, as a function of the spray volume (L ha^{-1}) and the combination of adjuvants in fungicide applications, Passo Fundo - RS, 2018.

Volume (L ha^{-1})	Application in R1		Application in R1 + 18 days	
	Mineral oil	Mineral Oil and Surfactant	Mineral oil	Mineral Oil and Surfactant
	* * * * * * * * * * Lower third * * * * * * * * *			
40	1.9 cB	5.3 cA	1.3 dB	4.6 eA
70	3.6 cB	7.5 bcA	3.5 dB	7.1 dA
100	6.9 bB	10.3 bA	7.0 cB	10.9 cA
130	10.2 aB	14.0 aA	9.8 bB	13.3 bA
160	12.7 aB	16.5 aA	13.0 aB	16.4 aA
C.V. (%)	14.6		10.3	
Volume	* * * * * * * * * * Middle third * * * * * * * * *			
40	5.2 eB	9.7 dA	4.9 eB	8.9 dA
70	8.9 dB	16.3 cA	8.5 dB	13.5 cA
100	14.3 cB	21.9 bA	13.6 cB	21.3 bA
130	22.0 bB	27.5 aA	21.5 bB	26.7 aA
160	26.0 aB	29.4 aA	24.7 aB	28.5 aA
C.V. (%)	10.2		15.8	
Volume	* * * * * * * * * * Upper third * * * * * * * * *			
40	44.4 dB	60.3 cA	45.3 dB	62.0 cA
70	64.6 cB	72.7 bA	65.3 cB	77.0 bA
100	76.2 bB	87.3 aA	81.1 bB	89.7 aA
130	83.7 aB	89.0 aA	83.2 aB	90.2 aA
160	87.4 aB	91.8 aA	89.7 aB	93.9 aA
C.V. (%)	13.1		12.4	
Volume	* * * * * * * * * * Overall average * * * * * * * * *			
40	17.2 eB	25.1 eA	17.2 eB	25.2 eA
70	25.7 dB	32.2 dA	25.8 dB	32.5 dA
100	32.7 cB	39.9 cA	33.9 cB	40.6 cA
130	38.6 bB	43.5 bA	38.2 bB	43.4 bA
160	42.0 aB	45.9 aA	42.3 aB	46.1 aA
C.V. (%)	12.4		12.3	

Means followed by the same capital letter in the row and lowercase in the column do not differ by Tukey test, 5% probability.

In the middle third of the plant, the applications performed at R1 and R1 + 18 days presented a similar behavior where increases in the spray volume associated with mineral oil, increased the leaf surface coverage, reaching values close to 25% coverage when used 160 L ha^{-1}, which reduced about 55% when it changed from 130 to 100 L ha^{-1}, as well as from 100 to 70 L ha^{-1} being the coverage reduction more abruptly when it changed from 70 to 40 L ha^{-1}, varying about 74% (Table 5). However, when the surfactant was added to the tank mix, similar coverage was obtained with the use of 130 or 160 ha^{-1}, and in this third of the plant, the use of surfactant in the spray volume of 40 and 70 L ha^{-1} provided an increase in coverage in the 85% range, reaching 52% when using 100 L ha^{-1} (Table 5).

In the upper third, Table 5, in both evaluations there were significant responses regarding the use of surfactant. Regardless of spray volume, when it was present, the coverage percentage was similar, using 100, 130 or 160 L ha^{-1}, as well as, in the absence of the surfactant, the obtained coverage with spray volumes of 130 or 160 L ha^{-1} show similar behavior. Although the effect on the imposed barrier by leaf mass in the upper plant extract is lower in relation to the medium and lower extracts, there were increases of up to 45% in the leaf surface cover in relation to volume increases and with the mineral oil use only, with the use of surfactant the increments were in the order of 20% where the volume of 40 L ha^{-1} showed a greater response, with variations reaching 36%, followed by the volumes of 70 and 100 L ha^{-1}, where there were responses on the order of 14%, in relation to the use of surfactant in the tank mixture (Table 5).

As for the spray volume, one of the ways to maximize the leaf surface cover, the growing increases studied demonstrate relevance, however, since certain limits tend to stagnate, so it is expected that the increased application volume provides an increase in the volume retained to some extent, from which the surface is no longer able to retain the liquid, and flowing occurs, which is not desirable (Cunha et al., 2008) so, volumes greater than 200 L ha^{-1} did not provide increases in ASR control and did not reflect on productivity (Cunha & Peres, 2010).

The AUDPC of the control, without fungicides application reached 1874 units along the plant canopy with 2003 units being computed in the lower third, 1667 units in the middle third and 1952 units of AUDPC in the upper third of the plant. The control AUDPC was significantly superior ($P <0.05$) than other treatments, indicating the ASR control, even with the lowest spray volumes.

Considering the average of the thirds of the plant, Table 6, there was a reduction in the AUDPC as the spray volume ha^{-1} increased, especially when the increase in volume was associated with the surfactant, however, in the largest evaluated volume, 160 L ha^{-1}, the surfactant use did not provide reduction in AUDPC. The ASR control was about 40% higher when the volume of 40 L ha^{-1} was added the surfactant, and this difference was close to 23% when using 70 L ha^{-1}. The reduction in the spray volume from 160 to 40 L ha^{-1} showed reduction of 2.3 times in the ASR control when in the absence of the surfactant, since with its use in the tank mixture there was decrease close to 1.7 times on the disease control.

The greatest control differentials in the plant canopy were observed when the volume was reduced from 130 to 100 L ha^{-1} and from 100 to 70 L ha^{-1} resulting in control drops of around 18%, which came close to 27% when it was changed from 70 to 40 L ha^{-1} without the use of surfactant, since in the presence of this, the greatest reduction on control occurred when the volume was reduced from 70 to 40 L ha^{-1} reaching values close to 18%, Table 6.

In the lower, middle and upper third of the plant the reduction in the spray volume ha^{-1} had direct relationship with the increase of the AUDPC, especially when in the absence of the surfactant, however the use of mineral oil in an isolated manner combined with 160 L ha^{-1} did not impact on the amount of ASR, Table 6.

The highest AUDPC occurred in the lower third of the plant, Table 6, which represented control in the order of 10.5%, when 40 L ha^{-1} and mineral oil were used in the spraying, being this control close to 23% when the surfactant was added which increased the control in the order of 2.3 times, and this behavior was also observed in the volumes of 70 and 100 L ha^{-1} with variations close to 30 and 17%, respectively.

In the lower third of the plant, Table 6, the reduction in spray volume impacted in 6.8 times on ASR control when the volume was reduced from 160 to 40 L ha^{-1} in the absence of the surfactant, reducing the control up to 68% when it changed from 70 to 40 L of ha^{-1} which the reduction of the other volumes from 160 to 130, from 130 to 100, from 100 to 70 L ha^{-1} reached control reductions in order of 22%. When the surfactant was added to the spraying, the volume reduction from 160 to 40 L ha^{-1} represented drops of up to 3.1 times on disease control, however there was 45% reduction in the control from 70 to 40 L ha^{-1}.

In the middle third of the plant, Table 6, the use of 130 and 160 L ha^{-1} did not show significant differences on AUDPC, independent of the adjuvants combination, and in 160 L ha^{-1} volume, surfactant use showed no relevance for the reduction of AUDPC. In this third of the plant the impacts on AUDPC reached 3.1 times and 2.8 times, as the spray volume was reduced from 160 to 40 L ha^{-1} with the use of mineral oil or mineral oil plus surfactant, respectively. The control on soybean ASR was reduced by 70% compared to the higher volume in contrast to the lowest, in the absence of the surfactant remaining in the range of 50% when it was used. In the lower volumes, 40 and 70 L ha^{-1}, the surfactant optimized the ASR control up to 68 and 30%, respectively.

In the upper third of the plant, Table 6, the use of the surfactant showed no response in the ASR control when the volumes of 130 and 160 L ha^{-1} were sprayed, being the control in the range of 80 and 87%, respectively. However, for the other volumes, the control differences reached up to 17% being higher compared to the use of surfactant, especially in the lower volumes. When only mineral oil was used, the volumes of 40, 70 and 100 L ha^{-1} did not show differences in the control, whereas, with the use of surfactant, only the volume of 160 L of ha^{-1} showed greater disease control.

TABLE 6. Area under the disease progression curve (AUDPC - units) and soybean Asian-rust control (%) in the lower, middle, upper third and average of the plant, computed between V7 and R6, as a function of spray volume (L ha^{-1}) and the combination of adjuvants in fungicide applications, Passo Fundo - RS, 2018.

Volume (L ha^{-1})	AUDPC		ASR Control	
	Mineral oil	Mineral Oil and Surfactant	Mineral oil	Mineral Oil and Surfactant
*************** Average plant ***************				
40	1244.2 aA	993.7 aB	33.5 eB	46.9 eA
70	1003.1 bA	805.1 bB	46.4 dB	57.1 dA
100	823.4 cA	683.6 cB	56.1 cB	63.5 cA
130	566.1 dA	476.1 dB	69.8 bB	74.6 bA
160	414.7 eA	391.6 eA	77.8 aA	79.1 aA
C.V. (%)	13.6		12.3	
************** Lower third **************				
40	1791.5 aA	1529.6 aB	10.5 eB	23.6 dA
70	1342.2 bA	1138.1 bB	33 dB	43.2 cA
100	1106.7 cA	955.3 cB	44.7 cB	52.3 bA
130	838.2 dA	645.1 dB	58.1 bB	67.8 aA
160	567.1 eA	556.5 dA	71.7 aA	72.2 aA
C.V. (%)	14.2		14.7	
************** Middle third **************				
40	1289.3 aA	1030.4 aB	22.7 dB	38.2 dA
70	1047.5 bA	861.2 bB	37.2 cB	48.3 cA
100	841.6 cA	692.1 cB	49.5 bB	58.5 bA
130	486.3 dA	395.3 dB	70.8 aB	76.3 aA
160	417 dA	368.1 dA	75 aA	77.9 aA
C.V. (%)	15.2		14.1	
************** Upper third **************				
40	651.9 aA	421.2 aB	66.6 bB	78.4 bA
70	619.8 aA	416.1 bB	68.2 bB	78.7 bA
100	522.1 aA	403.6 cB	73.2 bB	79.3 bA
130	373.9 bA	387.8 dB	80.8 aA	80.1 bA
160	260.2 bA	250.6 dA	86.7 aA	87.2 aA
C.V. (%)	12.5		13.5	

Means followed by the same capital letter in the row and lowercase in the column do not differ by Tukey test, 5% probability.

With the reduction in the spray volume, the coverage, the number of drops cm^{-2} and controlling ASR in all thirds of the plant were significantly affected, resulting in higher AUDPC, which shows that the magnitude of soybean protection to the disease varies according to the coverage and the penetration of drops provided by the application (Debortoli et al., 2012). In the spray volumes tested, the dependence on the organsilicone adjuvant was higher in relation to the reductions in the spray volume which compensated for the foliar surface cover, thus optimizing the disease control. However, in the volume of 160 L ha^{-1}, the use of organosilicone adjuvant was not determinant for the disease control, and did not differ in all thirds of the plant.

Spray techniques through hydraulic or centrifugal nozzles, with lower or higher application volume, offer low recovery of deposits and coverings in the middle and lower thirds of soybean plants causing low fungicide efficiency, and consequently low control levels (Boschini et al., 2008; Prado et al., 2010; Cunha et al., 2011).

The irregular distribution of the products in the lower canopy and inside the plant is one of the main causes of low efficiency on the ASR control (Boschini et al., 2008; Cunha et al., 2011; Cunha et al., 2016), thus, strategies are required to increase the deposition of spray droplets in this canopy stratum (Cunha et al., 2010; Cunha et al., 2011; Nascimento et al., 2013), in this way, techniques that allow a better distribution of the fungicide and the increase of the deposits in the middle and lower part can increase the fungicides efficiency in relation to ASR. Thus, ASR control can be increased with the use of larger spray volumes, changes in droplet size (use of lower spectrum drops when possible) and the use of adjuvants that increase the spread and cover on treated leaf surface (Carvalho et al, 2013, Cunha et al., 2014).

In developed research by Chechetto et al. (2014), it was observed that 70.7% of the interviewers use flat spray nozzles for the spraying of phytosanitary products, of which 31% use only one type of nozzle for all applications during the harvest with the majority of the interviewers use spray volume equal to or less than 100 L ha^{-1} for insecticide, herbicide and fungicide applications, where there is preference for applications at lower rates and the use of medium to fine droplets in applications in the State of Mato Grosso, Brazil.

The distribution on plant cover showed a lack of uniformity, independent of the spray volume and adjuvant, which was approximately five times higher in the upper third of the plant, compared to the lower third, resulting from the largest number of drops in this third of the plant. Regarding to the number of drops, the eight times gradient was observed in the comparison of the upper third in relation to the lower third.

The penetration of droplets into the canopy of the culture is a fundamental factor for the chemical control of diseases, especially those that initiate the infectious process in the low third leaves, such as the ASR. However, it was observed that the maximum coverage obtained was of the order of 12% when the mineral oil was used alone, increasing to 16% when the surfactant was added, in the spray volume at 160 L ha^{-1}, where not exceeded 37 drops cm^{-2}. The penetration and deposition of the active ingredient in leaves within the canopy is an essential condition for the effective control of the disease and, as the crop develops, reaching the lower layers of the canopy becomes increasingly difficult (Debortoli et al., 2012; Tormen et al., 2012).

In the tested volumes, the use of surfactant contributed to the maintenance of the remaining leaf area, except for the treatment with 160 L of ha^{-1}, where its use did not increase the LAI in R6 in relation to the use of the mineral oil in an isolated manner, Table 7. In the volume of 40 L ha^{-1} the use of the surfactant allowed the plant to maintain 184% more LAI at the end of the grain filling stage, whereas, with the volumes of 70 and 100 L ha^{-1} differentials were observed near to 92% and 43%, respectively, against the use of surfactant. The control, without application of fungicides, presented 0.18 units of LAI, being significantly inferior to the other treatments, indicating that the leaf area was maintained, even with the lowest spray volumes.

TABLE 7. Leaf area index (LAI) remaining in R6, as a function of spray volumes (L ha^{-1}) and the combination of adjuvants in fungicide applications, Passo Fundo - RS, Brazil, 2018.

Volume (L ha^{-1})	Adjuvant	
	Mineral oil	Mineral Oil and Surfactant
40	0.39 dB	1.11 cA
70	1.06 cB	2.04 bA
100	2.08 bB	2.98 aA
130	2.43 aB	3.07 aA
160	2.55 aA	2.97 aA
C.V. (%)	12.5	

Means followed by the same capital letter in the row and lowercase in the column do not differ by Tukey test, 5% probability.

The increase in the spray volume ha^{-1} had a positive impact on the LAI, however, up to certain limits, since the volumes of 130 and 160 L ha^{-1} do not show significant differences when used only with mineral oil as well as volumes of 100, 130 and 160 L ha^{-1} did not provide higher LAI in R6, when the surfactant was added (Table 7).

The reduction in volume ha^{-1} resulted in LAI reductions close to 85%, when it went from 160 to 40 L ha^{-1}, being more abrupt in the reduction from 100 to 70 and later with the change from 70 to 40 L ha^{-1}, where there was reduction of 49 and 63% on LAI, respectively, when spraying was performed with mineral oil only. When the surfactant was present in the tank mixture, the contrast of the higher and lower volume used presented variations of approximately 62%, with LAI reduced into the smallest volume. The highest variation occurred when changed from 70 to 40 L ha^{-1} reaching about 45%, followed by a reduction from 100 to 70 L ha^{-1} where the remaining LAI reduced by approximately 32% (Table 7).

The grain yield obtained in the treatment without the fungicide application reached 1,971.1 kg ha^{-1} with mass of one thousand grains of 101.45 g, showing to be significantly inferior ($P <0.05$) to the other treatments, indicating the partial preservation of the grain yield potential, compared to the ASR control, even with the lower spray volumes. The participation of thirds in the yield and grain yield in each of the evaluated thirds, lower, middle and higher, showed significance ($P <0.05$) for the interaction among spray volumes and adjuvants.

The yield of grains and the mass of 1000 grains, Table 8, were reduced when reductions occurred in the spray volume of the sprays, the reductions being less accentuated when was added surfactant in the tank mixture. The grain yield was reduced by 25% when the spray volume was changed from 160 to 40 L ha^{-1} using mineral oil in an isolated manner from 3,971.8 kg ha^{-1} to 3,005.5 kg ha^{-1} and reductions observed in the order of 8 and 12% when the volume was reduced from 100 to 70 and later from 70 to 40 L ha^{-1}, respectively, representing about 420 and 362 kg ha^{-1}, for the cited volumes.

Yield declines were minimized as the surfactant was used, and in the volume of 40 L ha^{-1}, yield differentials were observed in the order of 14%, compared to surfactant which reached 11% and 9% with the volumes of 70 and 100 L ha^{-1}, respectively. In the volumes of 130 and 160 L ha^{-1}, the use of the surfactant did not optimize the soybean yield compared to the oil use, as well as its use there was no significant difference between the volumes of 100, 130 and 160 L ha^{-1}, whereas, with the isolated use of the mineral oil, the volumes of 130 and 160 L ha^{-1} showed no differences in yield, Table 8.

TABLE 8. Grain yield (kg ha^{-1}) and mass of one thousand grains (g) according to the spray volume (L ha^{-1}) and the combination of adjuvants in the fungicide applications, Passo Fundo - RS, 2018.

Volume (L ha^{-1})	Yield (kg ha^{-1})		Mass of one thousand grains (g)	
	Mineral oil	Mineral Oil and Surfactant	Mineral oil	Mineral Oil and Surfactant
40	3,005.5 dB	3,409.3 cA	140.6 dB	145.4 cA
70	3,424.8 cB	3,816.6 bA	144.6 cB	146.9 bcA
100	3,733.9 bB	4,069.1 aA	146.4 bcB	150.9 aA
130	3,955.6 aA	4,078.1 aA	149.5 aA	150.3 aA
160	3,971.8 aA	4,025.2 aA	149.2 aA	149.6 aA
C.V. (%)	11.9		10.8	

Means followed by the same capital letter in the row and lowercase in the column do not differ by Tukey test, 5% probability.

The thousand grains mass, Table 8, presented similar behavior to the grain yield, where with the isolated use of mineral oil, the volumes of 130 and 160 L ha^{-1} did not show significant differences, as well as the volumes of 100, 130 and 160 L ha^{-1} showed similar behavior when sprayed with the presence of surfactant. In the lower evaluated volumes, the use of surfactant contributed to increases in one thousand grains mass up to 3%, especially in the volume of 40 L ha^{-1}.

Regarding to grain yield distribution it was observed that the lower third of the plant contributed between 5.7% and 18.9% of the yield, while in the middle third the contribution was between 26.3% and 45.1% and the upper third was responsible for 36.2% to 67.9% of the yield, as shown in Table 9. As there were reductions in the spray volume ha^{-1}, independent of the adjuvants, the lower and middle portions of the plant had a lower contribution on the final yield, so the upper third of the plant acquired greater importance on this variable, as the spray volume increased, there was greater equivalence on distribution throughout the plant.

Productivity damages are a reflection of a set of effects that ASR causes on soybean, such as early defoliation, leaf area reduction and reduction of dry mass accumulation (Kumidini et al., 2008), since the greater the severity of the disease, the larger the number of uredinia per unit area, thus the greater interference in the leaf metabolism and the greater the loss of water, with reflex on the longevity of the leaflets (Garcés-Fiallos & Forcelini, 2013; Twizeyimana et al., 2011), Thus, the use of fungicides, aiming to control the disease, reduces the damage resulting in larger leaf area during grain filling which directly influences yield components (Godoy et al., 2009; Godoy et al. 2016).

Fungicide applications with different spray volume may result in different levels of ASR control, especially when grown in cultivars with different architectures (Madalosso et al., 2010. Still, with the reduction of water for the same active ingredient amount, less dilution occurs, demanding greater precision in the application. Therefore, the reduction of the volume ha^{-1} brings risks directly linked to the control efficiency of the fungicide and its residual (Madalosso et al., 2010).

TABLE 9. Participation in yield (%) and grain yield (kg ha^{-1}) of the lower, middle and upper third of the plant, as a function of the spray volume (L ha^{-1}) and the combination of adjuvants in fungicide applications, Passo Fundo - RS, 2018.

*************** Lower third ***************				
Volume (L ha^{-1})	Yield Participation (%)		Yield (kg ha^{-1})	
	Mineral oil	Mineral oil and Surfactant	Mineral oil	Mineral oil and Surfactant
40	5.7 dB	7.5 dA	172.1 dB	255.7 dA
70	9.5 cB	12.1 cA	326.5 cB	462.9 cA
100	14.3 bB	15.9 bA	535.1 bB	647.4 bA
130	18.0 aB	18.9 aA	713.4 aB	773.5 aA
160	18.4 aA	18.8 aA	730.5 aA	755.5 aA
C.V. (%)	13.5		13.9	

*************** Middle third ***************				
Volume (L ha^{-1})	Yield Participation (%)		Yield (kg ha^{-1})	
	Mineral oil	Mineral oil and Surfactant	Mineral oil	Mineral oil and Surfactant
40	26.3 dB	30.5 dA	792.6 dB	1,040.9 cA
70	34.4 cB	37.5 cA	1,178.1 cB	1,430.3 bA
100	41.0 bA	42.4 bA	1,532.3 bB	1,725.6 aA
130	43.2 abA	44.4 abA	1,708.4 aB	1,810.5 aA
160	44.7 aA	45.1 aA	1,775.7 aA	1,814.1 aA
C.V. (%)	12.5		12.7	

*************** Upper third ***************					
Volume (L ha^{-1})	Yield Participation (%)		Yield (kg ha^{-1})		
	Mineral oil	Mineral oil and Surfactant	Mineral oil	Mineral oil and Surfactant	Average
40	67.9 aA	61.9 aB	2,040.7	2,112.7	2,076.7 a
70	56.1 bA	50.4 bB	1,920.2	1,923.4	1,921.8 b
100	44.6 cA	41.7 cB	1,666.5	1,696.2	1,681.4 c
130	38.8 dA	36.6 dB	1,533.8	1,494.2	1,514.0 d
160	36.9 dA	36.2 dA	1,465.7	1,455.7	1,460.7 d
C.V. (%)	12.4		13.5		

Means followed by the same capital letter in the row and lowercase in the column do not differ by Tukey test, 5% probability.

In the lower third of the plant, Table 9, the increases in the spray volume with isolated use of mineral oil, increased by 3.2 times the participation of that third on the final yield, whereas when surfactant was added to the tank mixture, the increases in yield are in the range of 2.5-times, since the impacts on volume reduction were minimized by the surfactant, especially in the 40 and 70 L ha^1 which allowed increases of approximately 31 and 27%, respectively, in the yield. However, in the volumes of 130 and 160 L ha^{-1}, no differences were observed in terms of participation in the yield when the mineral oil was used alone or in association with the surfactant.

The grain yield observed in the lower third, Table 9, ranged about 4.3 times and 2.9 times, when the mineral oil was used alone or when it was added to the surfactant, respectively. The increase in spray volume from 40 to 70, from 70 to 100 and from 100 to 130 L ha^{-1}, represented about 89%, 64% and 33% more yield in the lower third of the plant when the mineral oil was used alone, however, as the surfactant was added to the tank mixture there were less abrupt variations on yield, being 81%, 39% and 19% for that volume increases. Also, in 40 L ha^{-1} volume, the use of the surfactant in the tank mixture, in relation to the isolated use of the mineral oil, represented 48% more yield in the lower third, whereas for the volume of 70 L ha^{-1} the differential reached around 42%, being 21% for the volume of 100 L ha^{-1}.

In the middle third of the plant, Table 9, the use of the surfactant together with mineral oil in the spray volumes from 100 L ha^{-1} did not contribute to increase the participation of that third in the yield of grains, which was between 41 and 45%. However, in the smaller volumes 40 and 70 L ha^{-1}, there were increases close to 16 and 9%, respectively. The increase in the spray volume from 40 to 70 L ha^{-1} and later from 70 to 100 L ha^{-1} led to increases of 30% and 19%, respectively on the participation of the middle third in the yield in the absence of the surfactant being the differentials close to 22% and 13% when the surfactant was used, in the referred volumes.

The middle third of the plant had variations in yield between 792.6 and 1814.1 kg ha^{-1} due to the combination of adjuvants and variations in the spray volume, Table 9. In the absence of the surfactant, the increase in the spray volume represented the increase in yield in the order of 2.3 times, where the greatest contributions occurred with the increase in the volume of 40 L ha^{-1} to 70 L ha^{-1} with an increase close to 49% and in the change from 70 to 100 L ha^{-1}, reaching levels close to 30%. As the surfactant was used, the differentials in volume increases were attenuated, since, in contrast, the differences observed in relation to the lowest and the highest tested volume reached 1.7 times, with levels of 37% and 20%, ranging from 40 to 70 L ha^{-1} and from 70 to 100 L ha^{-1}, respectively. In the higher spray volume evaluated there was no increase in yield when using surfactant.

The upper third of the plant, Table 9, showed interaction between the spray volume and the combination of adjuvants as regard to the participation of the upper third in the yield, however, the yield of grains was significant only for the spray volumes.

As the spray volume ha^{-1} increased there was a higher participation of the lower and middle thirds in the yield of grains, thus, with the lower volumes sprayed there was the smallest participation in the yield. Thus, in the 40, 70 and 100 L ha^{-1} volumes there was higher concentration of yield in the upper third of the plant reaching about 68% when pulverized 40 L ha^{-1} combined with mineral oil. The use of surfactant reduced the influence of the upper third in the yield compared to the better distribution in the other parts of the plant, and the same behavior was observed for spray volume, that, as they increased, minimized the importance and supremacy of the third on yield, which was better distributed throughout the plant.

As the leaf surface coverage and the number of drops cm^{-2} were reduced, there was an increase in ASR severity, resulting in higher AUDPC, and lower disease control, directly affecting the remaining LAI in R6, as well as thousand grains mass and grain yield in all strata of the plant, interfering with the participation of thirds in yield.

In the spray volumes evaluated, the surfactant utilization shown to be feasible, increasing the leaf surface coverage, reducing AUDPC, maximizing ASR control, collaborating for the maintenance of LAI and positively impacting grain yield, especially in the volumes of 40, 70, 100 and 130 L ha^{-1}, as solutions containing organosilicone surfactant promote spreading increments, maximizing adherence and penetration of phytosanitary products (Iost & Raetano, 2010; Zyl et al., 2010; Cunha et al., 2011, Garcia et al., 2016). Thus, the surfactant addition to the tank mixture optimizes the coverage with reflection on the ASR severity, however, does not impact on the amount of the agrochemical deposit (Prado et al., 2015).

Due to the alteration of the sensitivity of *P. pachyrhizi* to specific fungicides site (demethylation inhibitor, quinone outside inhibitors and succinate dehydrogenase inhibitors) and since fungicides with new mechanisms of action are not available, multisite fungicides (mancozeb, chlorothalonil, copper sulphate, among others) were used in the management of ASR, in formulated mixtures or tank mixtures with those of specific site, in order to increase the control efficiency, as well as to mitigate the resistance risks of the fungus (Juliatti et al., 2017; Godoy et al., 2016, Silva et al., 2015, Gullino et al., 2010). The fungicides with multisite action interfere in several cellular functions, being classified as immobile and acting as a protective surface barrier to infection, so they are non-penetrating or immobile, and when applied to the aerial parts they are not absorbed and therefore are not translocated, remaining on the surface of the plant where they were deposited (Reis et al., 2010).

Due to the characteristic of the multisite fungicides the leaf surface cover has great importance on the efficiency control of the ASR. Thus, increases in spray volume, as well as the use of surfactant can optimize the management of the disease, since the increase in spray volume, besides increasing leaf cover, provides greater deposition on the middle and lower third of the plant, as well as the use of surfactant, provides increases in leaf cover, especially with reduced spray volumes.

CONCLUSIONS

The greater dependence of the surfactant occurs in the low spray volumes where it provides increases in the leaf surface cover, optimizing the control of the Asian-rust, maximizing the index of leaf area, and the grains yield. The applications with greater spray volume do not require the use of surfactant without compromising the coverage, optimizing the density of droplets throughout the plant, reflecting on the control of the Asian-rust in the maintenance of the leaf area index, and in the grain yield.

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