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DEPOSITION OF SPRAYED DROPS IN SOYBEAN IN FUNCTION OF SOWING SPACING

Antonio Luiz Viegas Neto[1*], Cristiano Márcio Alves de Souza[2], Paulo Eduardo Degrande[2], Izidro dos Santos Lima Júnior[1]

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ABSTRACT – To reach all parts of the plants can be a difficult achievement faced by the drops in several crops. Strategies in crop management such as an increment in the plant spacing can contribute to the spray application's success. This study aimed to evaluate the droplets deposition in soybean, using three different spray nozzles and application rate, in two soybean rows spacing. The experimental design used was the randomized blocks, with treatments arranged in a split-plot scheme. The plots were the interrow spacing (0.45 and 0.76 m), the subplots were the spray nozzles (JA-2 and Magno 11002 BD), and the sub-subplots were the application rate (120, 200 and 280 L ha^{-1}). Droplets coverage was evaluated in the upper, middle and lower thirds of soybean plants. Water-sensitive papers were installed in the adaxial part of plant leaves to analyze the spray technology and evaluated using E-Sprinkle® software. Spraying was performed in plants at the R5.3 soybean stage. This experiment evaluated the following parameters: the volume median diameter, the density of droplets per cm^2, the droplet coverage area, and the droplet percentage less than 150 µm. The increase in the soybean row spacing combined with the spray volume increase provided greater droplet coverage in the middle third in soybean crop. The Magno 11002 BD droplet nozzle provided the higher droplet coverage in the row spacing of 0.76 m. The spray rate of 280 L ha^{-1} provided the highest density of droplets per cm^2 in the lower third and greater coverage in the middle-third.
Keywords: *Glycine max* (L.) Merr., spray nozzle, spray volume, spray technology.

DEPOSIÇÃO DE GOTAS PULVERIZADAS NA SOJA EM FUNÇÃO DOS ESPAÇAMENTOS DE SEMEADURA

RESUMO - Em diversos cultivos há a dificuldade de as gotas pulverizadas atingirem todas as partes da planta, estratégias no manejo como o aumento do espaçamento entrelinhas podem contribuir para o sucesso na aplicação. O objetivo do presente trabalho foi avaliar a deposição de gotas pulverizadas na cultura da soja, utilizando diferentes pontas de pulverização e volumes de aplicação em dois espaçamentos entrelinhas de semeadura. O delineamento experimental utilizado foi blocos ao acaso, com tratamentos arranjados em esquema de parcelas sub-subdivididas. As parcelas foram os espaçamentos entrelinhas (0,45 e 0,76 m), as subparcelas as pontas de pulverização (JA-2 e Magno 11002 BD) e as sub-subparcelas os volumes de aplicação (120, 200 e 280 L ha^{-1}). As avaliações de deposição de gotas foram feitas no terço superior, médio e inferior das plantas de soja. Para a análise de deposição de gotas foram instalados papéis hidrossensíveis, alocados na parte adaxial das folhas, sendo avaliados no programa E-Sprinkle®. As aplicações ocorreram com as plantas no estágio R5.3. Foram determinados: o diâmetro mediano volumétrico, a densidade de gotas, a área coberta e a porcentagem de gotas menor que 150 µm. O aumento no espaçamento entrelinhas, aliado ao aumento no volume de aplicação, proporcionou uma maior deposição das gotas pulverizadas no terço médio da cultura da soja. A ponta Magno 11002 BD proporcionou maior área coberta no espaçamento de 0,76 m. O volume de calda de 280 L ha^{-1} resultou em maior densidade de gotas no terço inferior e maior área coberta no terço médio.
Palavras-chave: *Glycine max* (L.) Merr., tecnologia de aplicação, bico de pulverização, volume de calda.

INTRODUCTION

The coverage of the soybean canopy produced by the droplets during the spraying process in the application of phytosanitary products is not uniform, mainly in the lower part of the plant, resulting in inefficient control, even with the use of systemic and, or mesostemic pesticides (CUNHA et al., 2014).

Canopy coverage by phytosanitary products in medium-sized plants such as soybeans, corn and cotton is generally low, especially in the lower part of the plant close to the soil, resulting in a reduction in the application efficiency, even with the use of systemic products. It is necessary to study strategies that increase spray droplets' deposition at the lower part of the plant canopy (MACIEL et al., 2018).

The success of the application and the result of the control are directly related to selecting the nozzles, adjusting the spray volume, operational parameters,

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[1] Federal Institution of Science and Technology of Mato Grosso do Sul, Ponta Porã *campus*. Rodovia BR-463, km 14, s/n. CEP 79909-000 Caixa Postal 287 | Ponta Porã, MS, Brazil. Email: antonio.viegas@ifms.edu.br. *Corresponding author.
[2] Federal University of Grande Dourados (UFGD), Agriculture Science Faculty (FCA). Rodovia Dourados-Itahum km 12, Bairro Aeroporto, Caixa Postal 533, CEP 7984-970, Dourados, MS, Brazil.

environmental conditions, and time of application (MACIEL et al., 2016). The diversity of spray nozzles on the market allows the application of the most varied volumes and patterns of drops, however, the correct choice will be responsible for the success of the application (NASCIMENTO et al., 2009) and its quality.

The spray nozzle and the working pressure interfere with the size of the spray droplets in optimal conditions. Small diameter droplets provide a higher density of droplets deposited on the target (ALVARENGA et al., 2014). For the same application volume, smaller and constant drops can be considered biologically more effective than larger drops (SIKKEMA et al., 2008), but this may depend on the weather conditions at the time of application and the biological target. Cultural practices can provide an arrangement of plants that result in a better penetration condition in applying phytosanitary products over the canopy of the plants, resulting in better efficiency of the application. To achieve a greater deposition of droplets, reaching the lower layers of the soybean canopy also depends on the architectural characteristics of the cultivar used. Cultivars with a higher leaf area index (LAI) and more lateral branches allow a faster closing of the rows, resulting in an obstacle for the passage of the drops to the lower layers of the canopy (TORMEN et al., 2012).

Madalosso et al. (2010), in work with row spacing of soybean crop to control Asian rust, found that the increase in the row spacing improved the efficiency of fungicides on the target, which can be explained by the characteristics of the maximized application technology such as greater exposure of leaves from the middle and lower thirds to penetration and droplet coverage. In soybean production systems with larger row spacing, the leaves are better distributed along the plant's main stem, favoring the deposition of drops in the lower third mainly (HOLTZ et al., 2014). That is why it is interesting to seek more efficient agronomic practices to increase the quality of the application of phytosanitary products.

The objective of this work was to evaluate the deposition of droplets sprayed on the soybean crop, using spray nozzles and spray volumes in two sowing rows spacings.

MATERIAL AND METHODS

The study was carried out on the Experimental Farm of the Federal University of Grande Dourados (FAECA/UFGD), municipality of Dourados (MS). The region's climate is classified as *Cwa* type: humid mesothermal, with an accumulated average annual rainfall of 1,427 mm (FIETZ; FISCH, 2006).

For planting, a seeder-fertilizer, model Solografic DIRECTA 4000, was used with nine sowing rows spaced 0.45 m apart, pulled by an AWD tractor, with a nominal power of 125 hp (91.9 kW) at 2,300 rpm.

The experimental design used was in randomized blocks, with four replications, where the treatments were arranged in a split-plot scheme, in which the plots were the spacing between rows (0.45 and 0.76 m), the subplots consisting at the spray nozzles (JA-2 and Magno 11002 BD) and the sub-subplots characterized the spray volumes (120, 200 and 280 L ha^{-1}).

The JA-2 tip (ceramic tip, empty conical jet, 80°spray angle) and the Magno 11002 BD tip (ceramic tip, simple flat jet, 110° spray angle) were used. To carry out the spraying, a hydraulic trailed sprayer with a tank capacity of 2,000 L and bars of 12 m of operational width, model Ecoranger 2000, pump with a flow rate of 125 L min^{-1}, working at a speed of 4.0 km h^{-1}, was used for the volumes of 200 and 280 L ha^{-1} and 6.4 km h^{-1} for the volume of 120 L ha^{-1}. The spray nozzles were spaced every 50 cm along the bar, with an average target height of 50 cm. Flow adjustments were made by adjusting the sprayer's working pressure, using pressures of 413, 432 and 923 kPa for the JA-2 nozzle and 182, 201 and 400 kPa for the Magno 11002 BD nozzle, in order to obtain the desired spray volumes.

The experimental area was tilled in the conventional system, using a plowing and two harrowings, and sowing was performed using the cultivar Campo Mourão RR and fertilization of 400 kg ha^{-1} of the formulated 00-20-20 + micro. The seeds were inoculated with *Bradyrhizobium japonicum estirpe* strain 5079, at a dose of 300 mL per 100 kg of seed. Sowing was carried out with 12 and 21 seeds linear m^{-1} for the row spacing of 0.45 and 0.76 m, respectively, planting depth of 5 cm, plant population of 240,000 plants ha^{-1}. The cultural treatments followed the technical recommendations for the cultivation of soybean in the region (EMBRAPA, 2011).

For the analysis of droplets deposition were used water-sensitive papers (Novartis Biociência SA), which are semi-rigid papers, with a layer composed of bromophenol blue, reflecting yellow, which becomes blue when in contact with water, due to pH change from 2.8 to 4.6 (NASCIMENTO et al., 2013). The papers were placed in the adaxial part of the leaves.

The application was carried out with soybeans in stage R5.3 (FEHR; CAVINESS, 1977). The plants were 0.85 ± 0.06 m high and were equally divided into three parts in the vertical direction (upper, middle and lower). The hydrosensitive papers were fixed to the leaves' adaxial part with the aid of a stapler, being perpendicular to the spraying, and three repetitions were collected for each third of the plant. The average relative humidity of the air at application was 55%, the wind speed was 2.5 km h^{-1}, and the average temperature was 28ºC.

Immediately after spraying, the papers were removed from the leaves and stored in a wooden box with blue silica gel to prevent the environment's humidity from interfering with the results. These were scanned with a resolution of 600 dpi in Bitmap format and subsequently evaluated in the image analysis program E-Sprinkle®. The following were determined: the volume median diameter (VMD), the density of droplets (droplets cm^{-2}), the covered area (%), and the percentage of droplets less than 150 µm.

The data were submitted to Analysis of Variance. When the F values were significant ($p < 0.05$), comparisons between means were made using the test of Tukey at a 5% probability of error. The SISVAR software (FERREIRA, 2011) was used in the statistical analyses.

RESULTS AND DISCUSSION

The spray volume of 280 L ha^{-1} provided a lower VMD in the upper-third and a higher percentage of area covered in the plants' upper and middle thirds. In the lower third, this volume resulted in a higher density of droplets. The percentage of droplets less than 150 µm increased as it was evaluated from the upper to the lower third in the crop canopy. As it penetrated into the plant canopy, the percentage of droplets less than 150 µm increased (Table 1). As estimated in the classification reference chart of the ASABE/ANSI/ASAE S-572.1 standard (ASABE, 2009), very fine drops are those smaller than 145 µm. They can reach the lower part of the soybean plant canopy in greater quantity, although they have characteristics that can increase the drift if the weather conditions are not favorable at the time of application (CUNHA et al., 2017). The percentage of covered area was greater than 30% in the upper third, and the percentage of drops less than 150 µm was less than 30%. There were no obstacles for droplets to reach the target at the plant's upper part, regardless of the spray volume.

TABLE 1 - Means of the volume median diameter (VMD, µm), percentage of droplets <150 µm, density of drops (drops cm^{-2}), and covered area (%), obtained in the upper, middle and lower thirds for the different spray volume.

Spray volume (L ha^{-1})	VMD	Droplets <150 µm	Droplet density (droplets cm^{-2})	Covered area (%)
		Upper-third		
120	269.1 a*	28.0 a	634.4 a	34.9 c
200	236.4 b	22.1 ab	789.3 a	48.6 b
280	206.1 c	13.2 b	676.0 a	64.4 a
CV(%)	38.3	35.2	24.9	26.8
		Middle-third		
120	234.7 a	54.7 ab	426.3 a	14.8 b
200	159.3 b	58.7 a	447.6 a	15.4 b
280	158.2 b	40.7 b	665.1 a	30.9 a
CV(%)	33.9	38.7	33.4	32.5
		Lower-third		
120	131.4 a	74.7 a	215.7 b	6.2 a
200	118.9 a	81.2 a	174.8 b	4.0 a
280	126.6 a	81.0 a	338.8 a	8.6 a
CV(%)	17.9	22.8	35.8	33.2

*Means followed by the same letters in the columns do not differ statistically from each other by the test of Tukey at 5% error probability.

In general, it is expected that the increase in the spray volume will increase the coverage of the target to a certain extent, after which the surface no longer retains the liquid, therefore runoff will occur, which is not desirable (CUNHA; PEREIRA, 2009). It is interesting to reduce the application volumes to increase the operational capacity and decrease the amount of water used, but the reduction in volume results in less deposition of the sprayed drops, which can occasionally decrease the application's quality.

It can be seen in the interaction between row spacing and spray nozzle that the Magno 11002 BD nozzle, in the lower third, with a spacing of 0.76 m, resulted in the highest percentage of covered area and the lowest percentage of drops <150 µm (Tables 2 and 3). It is probably that the greater row spacing caused a smaller physical barrier of the soybean canopy, favoring the deposition of the drops.

The highest percentage of drops <150 µm was obtained using the JA-2 nozzle. According to the manufacturers, the JA-2 nozzle produces very fine droplets, while the Magno 11002 BD produces medium to fine drops. In the lower third at the 0.76 m spacing, the Magno 11002 BD nozzle resulted in a higher percentage of covered area, while no difference was observed between the nozzles at the 0.45 m spacing. Cunha et al. (2008) evaluated the deposition promoted by different nozzles in the soybean crop and found greater coverage of the lower part of the canopy when nozzles with smaller droplet sizes were used. Smith et al. (2000) also show the advantages associated with the use of drops of smaller diameter concerning the coverage of the target by the application of pesticides. In both studies, the row spacing used was 0.45 m, but as observed in Table 3, the spacing increase resulted in a greater penetration of the droplets sprayed into the crop canopy.

TABLE 2 - Means of the droplet percentage (<150 µm) obtained in the upper, middle and lower thirds, for different spacing between rows and spray nozzles.

Row spacing	Spray nozzle	
	JA-2	Magno 11002 BD
	Upper-third	
0.45 m	26.5 Aa*	13.2 Aa
0.76 m	27.9 Aa	16.8 Aa
	Middle-third	
0.45 m	56.7 Ba	42.7 Ab
0.76 m	72.0 Aa	34.1 Ab
	Lower-third	
0.45 m	67.9 Ba	69.9 Aa
0.76 m	81.0 Aa	57.1 Bb

*Means followed by the same letters, for each assessment, uppercase in the columns and lowercase in the rows are not statistically different from each other, by the test of Tukey, at 5% error probability.

TABLE 3 - Means of covered area percentage (%) obtained in the upper, middle and lower third for different spacing between rows and spray nozzles.

Row spacing	Spray nozzle	
	JA-2	Magno 11002 BD
	Upper-third	
0.45 m	47.2 Aa*	55.8 Aa
0.76 m	44.7 Aa	49.5 Aa
	Middle-third	
0.45 m	21.0 Aa	20.7 Aa
0.76 m	15.2 Bb	24.6 Aa
	Lower-third	
0.45 m	5.9 Aa	4.3 Ba
0.76 m	4.6 Ab	10.3 Aa

*Means followed by the same letters, for each assessment, uppercase in the columns and lowercase in the rows are not statistically different from each other, by the test of Tukey at 5% error probability.

The interaction between row spacing and spray volume in the middle third showed that, in the 0.45-m spacing, the volume of 280 L ha^{-1} provided greater droplet density, and in the 0.76-m spacing and the volume of 200 L ha^{-1} did not differ from the volume of 280 L ha^{-1} (Table 4). The use of the 0.45-m spacing resulted in a greater row closure (HEIFFIG et al., 2006), indicating that the increase in the row spacing can assist in penetrating the sprayed drops.

Understanding the factors inherent to the application, such as application volume and spray nozzle for the most diverse situations, is undoubtedly important (OLIVEIRA et al., 2012). According to Holtz et al. (2014), in arrangements with larger row spacing, the leaves are better distributed along the main stem of the plant, while, in reduced spacing, most leaves are arranged at the upper part of the plant in search of the greatest amount of solar radiation, causing a barrier during applications.

TABLE 4 - Means of droplet density (droplet cm^{2}) obtained on the upper, middle and lower third for the different row spacing and spray volume.

Row spacing	Spray volume (L ha^{-1})		
	120	200	280
	Upper third		
0.45 m	584.4 Aa*	806.3 Aa	616.5 Aa
0.76 m	684.5 Aa	772.4 Aa	735.5 Aa
	Middle third		
0.45 m	477.5 Ab	345.0 Bb	729.8 Aa
0.76 m	375.1 Ab	550.3 Aab	600.5 Aa
	Lowe third		
0.45 m	212.5 Aa	197.9 Aa	311.9 Aa
0.76 m	218.9 Aa	251.8 Aa	365.6 Aa

*Means followed by the same letters, for each assessment, uppercase in the columns and lowercase in the rows are not statistically different from each other, by the test of Tukey at 5% error probability.

Tormen et al. (2012) obtained a higher percentage of drop deposition in the lower and middle thirds in two soybean cultivars when applied at the R1 stage compared to R4, probably due to architectural differences and canopy closure, at the time of application. Strategies to increase the spray volume using 0.45 m row spacing or increase the row at sowing result in greater penetration of the droplets sprayed in the canopy of the soybean crop, thus improving the pesticide application quality.

CONCLUSIONS

The increase in the row spacing combined with the increase in the spray volume provided a greater deposition of the droplets sprayed in the middle third of the soybean crop. The Magno 11002 BD nozzle provided a larger covered area at the 0.76-m spacing. In turn, the spray volume of 280 L ha^{-1} resulted in a higher density of droplets in the lower third and a greater covered area in the middle third.

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