Acta Scientiarum. Agronomy
ISSN: 1807-8621
Editora da Universidade Estadual de Maringá - EDUEM

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de Souza, Diego Miranda; Raetano, Carlos Gilberto; Ferreira Moreira, Caio Alexandre; Oliveira de Freitas Bueno, Regiane Cristina; Carvalho, Marina Mouzinho
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Acta Scientiarum. Agronomy, vol. 41, 2019
Editora da Universidade Estadual de Maringá - EDUEM
Available in: http://www.redalyc.org/articulo.oa?id=303060470053
DOI: 10.4025/actasciagron.v41i1.42700

CROP PRODUCTION

Effects of news sowing arrangements and air assistance on fungicide spray distribution on soybean crop

Diego Miranda de Souza *
Universidade Estadual Paulista, Brazil
ORCID: http://orcid.org/0000-0002-4965-713X
Carlos Gilberto Raetano
Universidade Estadual Paulista, Brazil
Caio Alexandre Ferreira Moreira
Universidade Estadual Paulista, Brazil
Regiane Cristina Oliveira de Freitas Bueno
Universidade Estadual Paulista, Brazil
Marina Mouzinho Carvalho
Universidade Estadual Paulista, Brazil
ORCID: http://orcid.org/0000-0002-7855-2062

Acta Scientiarum. Agronomy, vol. 41, 2019

Editora da Universidade Estadual de Maringá - EDUEM

Received: 13 November 2017
Accepted: 19 March 2018

DOI: 10.4025/actasciagron.v41i1.42700

ABSTRACT. : The density and distribution of soybean plants can interfere in the plant growth stage and yield, as well as phytosanitary management of this crop. Thus, innovations in production systems must be followed by improvements in pesticide application technology. Therefore, this study aimed to evaluate the influence of soybean sowing arrangements on fungicide application technology, with or without air assistance in the spray boom, using qualitative and quantitative assessments of the spray deposits. In the experiments, a randomized block design with split plots was used. Four soybean sowing arrangements: Conventional (CO), Double row (DR), Narrow row (NR), and Crossed rows (CR) composed the main plots, and fungicide application technologies with air assistance (AA) and without air assistance (WA) in the spray boom composed the subplots, with four replications. For the assessment of spray deposits, Brilliant Blue tracer dye was used in the spray solution, and the spray coverage was evaluated using water-sensitive papers. The effects of different soybean sowing arrangements on deposits and spray coverage were limited. However, an increase in spray deposits on the lower part of the soybean plants was observed with air assistance in the spray boom.

Keywords: Glycine max, distribution of plants, air sleeve boom sprayer.

Introduction

The soybean is the most important commodity of agribusiness in Brazil. In the 2016/2017 growing season, it was estimated that 33.9 million hectares were used to grow this crop, producing more than 114 million tons (CONAB, 2017). Due to this importance, innovations in production systems are always necessary for the soybean crop. Based on this premise, variations in the spatial distribution of plants are a factor to be explored in soybean production.

New soybean sowing arrangements can provide better light penetration and better use of water and nutrients. The improvement in these parameters could result in an increase in the productivity of the soybean crop (Heiffig, Câmara, Marques, Pedroso, & Piedade, 2006; Petter et al., 2016; Souza, Teixeira, Reis, & Silva, 2016).

However, variations in the spatial distribution of soybean plants can influence the microclimate and thus have an effect on disease epidemiology (Madalosso, Domingues, Debortoli, Lenz, & Balardin, 2010). New sowing arrangements may also influence the pesticide spray deposition, because they can affect the deposition of pesticide sufficient to control the biological target, particularly in narrow sowing arrangements (Silva et al., 2009; Holtz, Couto, Oliveira, & Reis, 2014).

Among pesticide application methods, spraying is the most commonly used. However, the difficulty of droplets in penetrating into the crop canopy is considered a limitation in the application (Cunha, Farnese, Olivet, & Villalba, 2011; Tormen et al., 2012; Cunha, Marques, & Alves, 2016). The adoption of a system that promotes droplet penetration into the soybean canopy is essential to reach internal biological targets, especially in more advanced growth stages of the crop (Cunha et al., 2011). Air assistance in the spray boom is among the techniques available that can enhance the deposition and coverage of the spray on the target (Christovam et al., 2010).

The integration of management techniques can promote an improvement in spray distribution into the canopy, making the application of pesticides more efficient. Therefore, the aim of this study was to evaluate the influence of different soybean sowing arrangements on the spray distribution of fungicide, with and without air assistance on a spray boom, using quantitative and qualitative methods for the spray assessment.

Material and methods

Location of the experiments

The experiments were conducted in two growing seasons at the São Paulo State University (Unesp), School of Agriculture, Botucatu, São Paulo State, Brazil, located at 724 meters above sea level, with the geographic coordinates 22°48' S and 48°25' E. The soil in the experimental area was classified as a red latosol, and it was cultivated with one plowing and two harrowing operations.

Sowing and crop characteristics

In the 2012/2013 growing season, the sowing occurred on November 22nd, 2012 with the 5D 688 variety [determinate growth type, RR technology (Roundup Ready®)] using a Semeato® seeder (model SHM 15/17). A fertilizer application was made to the soil at 320 kg per hectare with a 4-20-20 (N-P-K) formulation for all treatments, according to the soil analysis to production potential of 3,500 to 4,500 kg ha^{-1}.

In the 2014/2015growing season, the sowing occurred on October 29th, 2014 with the 5D 634 variety (indeterminate growth type and RR technology) using the same machine, and the fertilization was conducted at 200 kg ha^{-1} with the same fertilizer formulation. The population of soybean plants was 400 thousand plants per hectare, and the surplus was thinned after the third week of emergence in both seasons.

Treatments and experimental design

In the experiments, a randomized block design with split plots was used. Each experiment consisted of four sowing arrangements: Conventional (CO), with 0.40 m spacing between rows; Double row (DR), with two soybean lines spaced with "internal" spacing of 0.20 m and "externa" spacing of 0.40 m between rows (spacing of 0.20 m between rows); Narrow row (NR), with 0.20 m spacing between rows; and Crossed rows (CR), with the first sowing as CO and the second sowing perpendicular to the first (90°) main plots. The subplots consisted of two fungicide application technologies: with air assistance (AA) and without (WA) air assistance in the spray boom, and two parts of the plants: upper and lower, with four replications. The plots had dimensions of 6 x 6 m (length x width), and the useful area was 4 x 4 m in the central rows of the subplots.

Spraying

The spray evaluation of the R5.4 growth stage was performed on parts of the soybean plants to analyze two parameters: fungicide spray deposition and coverage. The timing of the spray, the grain filling period, was chosen to represent the maximum foliage and a period of occurrence of some of the main pests of the crop, such as Asian rust, white mold and bugs.

A sprayer Falcon Vortex® model mounted on the hydraulic system of a Massey Ferguson® tractor (model 296) and operated at a displacement speed of 1.25 m s^{-1} was used for spraying. The spray boom was equipped with a Jacto® AXI 11002 flat fan spray nozzle at 138 kPa working pressure. The sprayer calibration resulted in a volume rate of 150 L ha^{-1} and an average air speed under the boom of 6.1 m s^{-1}. The temperature, relative air humidity and wind speed were measured with a thermo-hygrometer (Lutron HT - 3003 model) and a digital anemometer (Lutron, model AM - 4201).

The spray solutions were prepared by adding trifloxystrobin and prothioconazole (Fox®) fungicide at a dose of 0.4 L ha^{-1}plus Brilliant Blue tracer dye at a dose of 0.0015 kg L^{-1} in distilled water (Cerqueira et al., 2012). According to Oliveira, Marubayashi, Gandolfo, and Alves (2017), the presence of the fungicide in the spray solution, together with the Brilliant Blue tracer, does not compromise the evaluation of the spray deposit. However, the authors highlight that removal of the marker from soybean leaves may be different in spray solutions of different compositions.

The weather conditions at the time of spraying were within acceptable limits (Raetano, 2011), with temperatures below 30°C, relative air humidity above 60% and wind speeds of 0.83 to 1.94 m s^{-1}.

Evaluations

To quantify spray deposits, a modified method proposed by Bauer and Raetano (2000) was used. After spraying, ten leaflets from the upper part of the plants were individually collected and packed in plastic bags. These leaflets were the most exposed to the spraying. Ten other leaflets were collected from the lower part of the plant. The samples were taken to the laboratory and washed with 40 mL of distilled water to remove the tracer dye. After the tracer extraction, the area of each leaflet was measured by a leaf area meter LICOR (LI - 3100 model). The solution obtained after washing was placed in plastic bottles and stored under refrigeration (8 ± 3°C) for 12 hours. The deposits were quantified with a Shimadzu UV 1601 PC spectrophotometer at the 630-nm wave length. Thus, the absorbance values of the samples were made into a concentration (mg L^{-1}).

Based on the values of the dye concentration identified in each sample (Cf), it was possible to obtain the volume captured by the target (Vi). For this, the following equation was used (E1): , where: Vi = volume captured by the target (mL), Cf = dye concentration detected in the spectrophotometer (mg L^{-1}), Vf = dilution volume of the sample (mL), and Ci = dye concentration in the spray solution (mg L^{-1}). At the end, the volume retained from each leaflet in mL (milliliters) was transformed to μL (microliters) to better present the data, and it was subsequently divided by its respective leaf area (μL cm^{-2}).

For the qualitative assessment, water-sensitive papers (26 x 76 mm) were distributed on a wood stem with two bases for fixation. The stem was adjusted so that the water-sensitive papers remained at the same height level with the upper and lower parts of the soybean plants. A 600-dpi resolution scanner was used to scan the images of water-sensitive papers, and the spray coverage was analyzed by Gotas® software (Chaim, Camargo-Neto, & Visoli, 2012).

The productivity was evaluated in both growing seasons, and the yields of the plots that did not received fungicide spray were also presented to illustrate the differences between the sowing arrangements without the fungicide effect. To estimative the yield, 2 m^2 per plot was harvested, and the average yield per hectare was calculated.

Data analyses

The quantitative data of the spray deposit (deposition), spray coverage (qualitative data of spray) and crop yield were submitted to a variance analysis (F-test), and the means of the treatments were compared by a T-test (LSD) at the 5% probability level. All the data analyses were performed using the Sisvar® version 5.6 statistical software (Ferreira, 2011).

To illustrate the relationship between the absence and presence of air assistance in the spray boom, the ratio between the mean values of deposits was calculated (Ratio = presence / absence). Thus, if the ratio is equal at one, the average values of spray deposits are equivalent, and if the ratio is higher than one, there is a greater increase provided by the air assistance in relation to the absence of the technology.

Results and discussion

In the 2012/2013 and 2014/2015 growing seasons, the spray deposit levels were very similar in different sowing arrangements (season 12/13: $P_{value} = 0.2026^{ns}$; season 14/15: $P_{value} = 0.0802^{ns}$), especially in the leaflets from the lower parts of the soybean plants. Differences between spray deposits from the upper and lower parts of the plant were also observed (season 12/13: $P_{value} = 0.0001^{*}$; season 14/15: $P_{value} = 0.0000^{*}$), regard less of the sowing arrangement used (Table 1).

The experiment exhibited a clear inequality in the vertical distribution of spray deposition on soybean plants. In the 2012/2013 season, the conventional sowing arrangement (CO) provided a deposit amount 10 times smaller in the lower part of the plant when compared to those values obtained from the upper part of the plants when spraying without air assistance (WA).

Additionally, this inequality in spray deposit distribution was observed by other authors using tracers or artificial targets (Bauer, Almeida, Marques, Rossi, & Pereira, 2008; Farinha, Martins, Costa, & Domingos, 2009). Despite some differences between spray deposits on the leaflets from upper part of the plants, the deposit levels were still higher in the tops of the plants. Thus, the amount of pesticide that comes into contact with the lower parts of the plants is minimal and irregular.

Our experiments also show that the spray deposits with AA, in the upper part of the soybean plants, were consistently lower than WA, probably as a consequence of the additional energy provided by the air assistance, which resulted in moving spray droplets into the canopy. The ratio between the presence and absence of air assistance in each part of the plant illustrates the lower amount of spray deposit with AA technology when the upper parts of the plants were analyzed (ratio < 1). However, in the lower part, increases in the spray deposits with AA spraying are evident (ratio > 1), regardless of the sowing arrangement (Table 1).

Thus, it is possible to observe that there is a reduction in the heterogeneity of the spray distribution with air assistance in the spray boom, which was also observed by Aguiar Júnior et al. (2011).The increase in spray deposit levels at the lower parts of the plant have been observed by other authors, such as Christovam et al. (2010). Bauer and Raetano

(2000) found benefits of this technology, such as drift reduction and lower heterogeneity in the vertical distribution of spray deposits in soybean.

On the other hand, the increment of the spray deposit in the lower parts of the plants was not observed in the same proportion in both seasons (season 12/13: Pvalue = 0.0223*; season 14/15: Pvalue = 0.2474ns) (Table 1). The AA spray can influence the deposit levels more when compared at the WA spray due to factors such as air speed in the spray boom, crop features, the growth type of varieties and climate conditions (Raetano, 2011).

Table 1

Average spray deposit (μl) in sowing arrangements and the ratio of the presence (AA) and absence (WA) of air assistance in the spray boom in the 2012/2013 and 2014/2015 growing seasons, Botucatu, São Paulo, Brazil.

Sowing arrangements	DOW 5D 688 variety, season 2012/2013					
	Upper part			Lower part		
	WA	AA	Ratio	WA	AA	Ratio
Conventional	$0.342^{aB\beta}$	$0.209^{aA\beta}$	0.61	$0.032^{aA\alpha}$	$0.040^{aA\alpha}$	1.25
Double row	$0.357^{aB\beta}$	$0.217^{abA\beta}$	0.61	$0.018^{aA\alpha}$	$0.031^{aA\alpha}$	1.72
Narrow row	$0.363^{aB\beta}$	$0.324^{bA\beta}$	0.89	$0.010^{aA\alpha}$	$0.013^{aA\alpha}$	1.30
Crossed	$0.444^{aB\beta}$	$0.301^{abA\beta}$	0.68	$0.012^{aA\alpha}$	$0.075^{aA\alpha}$	6.25
$F_{Sowing\ arrangements}$: 1.59; P = 0.2026^{ns}/ $F_{Air\ assistance}$: 5.55; P = 0.0223*/ $F_{Part\ of\ plant}$: 220.52; P = 0.0001* / $F_{Sowing\ arrangements\ x\ Air\ assistance\ xPart\ of\ plant}$: 0.726; P = 0.5279^{ns}						
	DOW 5D 634 variety, season 2014/2015					
Sowing arrangements	Upper part			Lowerpart		
	WA	AA	Ratio	WA	AA	Ratio
Conventional	$0.779^{bA\beta}$	$0.589^{abA\beta}$	0.76	$0.174^{aA\alpha}$	$0.265^{aA\alpha}$	1.52
Double row	$0.466^{aA\alpha}$	$0.682^{bB\beta}$	1.46	$0.284^{aA\alpha}$	$0.180^{aA\alpha}$	0.63
Narrow row	$0.712^{bA\beta}$	$0.663^{abA\beta}$	0.93	$0.198^{aA\alpha}$	$0.188^{aA\alpha}$	0.95
Crossed	$0.765^{bB\beta}$	$0.449^{aA\beta}$	0.59	$0.128^{aA\alpha}$	$0.136^{aA\alpha}$	1.06
$F_{Sowing\ arrangements}$: 3.130; P = 0.0802^{ns}/ $F_{Air\ assistance}$: 1.381; P = 0.2474^{ns}/ $F_{Part\ of\ plant}$: 139.813; P = 0.0000* / $F_{Sowing\ arrangements\ x\ Air\ assistance\ x\ Part\ of\ plant}$: 3.866; P = 0.168^{ns}						

Averages followed by the same letters in each comparison level did not differ by T-test (LSD) (p < 0.05). Lowercase letters compare the spray deposition between the sowing arrangements at each level of air assistance and in each part of the plant. Upper case letters compare the spray deposition with and without air assistance in each sowing arrangement and in each part of the plant. Greek letters compare the spray deposition between the parts of the plant at each level of air assistance and in each sowing arrangement.

The difference between the values of spray deposits obtained in each season can be related with the growth type of the soybean varieties. Thus, the positioning of the soybean leaflets on a determined growth type variety (season 14/15) may have benefited the spray deposition in the lower part of the plant, and in particular, this may have attenuated the effect of the air assistance on the spray deposition on the leaves of this part of the plant.

The variation in spray coverage percentage in the sowing arrangements is very similar to that observed in spray deposit values, especially when the spraying occurred in the same season (14/15). The change in sowing arrangements did not result in increases in the spray coverage (season 14/15: P_{value} = 0.1653^{ns}). On the other hand, the use of the artificial targets showed the increment of spray deposits provided by the air assistance in spray boom in the lower part of the soybean plants (ratio > 1), although the analysis of variance between the absence and presence of the air assistance was not significant (P = 0.0908^{ns}) (Table 2).

Based on an analysis of spray distribution on water-sensitive papers, Tormen et al. (2012) observed a greater influence of soybean variety in spray deposits when the plants were at the R1 phenological stage and the R4 stage. The spray deposition in the middle and lower parts of the plants was similar. Therefore, it is likely that the interference of each sowing arrangement on the spray coverage in the lower part of the plant was limited by the vegetation architecture in the R5.4 phenological stage at the time of the application.

It is important to know the performance of spraying at different soybean growth stages because targets that are difficult to control, such as stink bugs and some caterpillars, are present at these critical developmental stages of soybean plants (Farinha et al., 2009; Madalosso et al., 2010; Tormen et al., 2012; Roese, Melo, & Goulart, 2012).

Table 2

Average spray coverage (%) on water-sensitive paper in sowing arrangements and the ratio of the presence (AA) and absence (WA) of air assistance in the spray boom with the DOW 5D 634 variety and in the 2014/2015 growing season, Botucatu, São Paulo, Brazil.

Sowing arrangements	DOW 5D 634 variety, season 2014/2015					
	Upper part			Lower part		
	WA	AA	Ratio	WA	AA	Ratio
Conventional	$25.54^{abB\beta}$	$12.19^{aA\alpha}$	0.48	$1.27^{aA\alpha}$	$2.94^{aA\alpha}$	2.31
Double row	$33.71^{bA\beta}$	$26.19^{bA\beta}$	0.78	$2.47^{aA\alpha}$	$6.61^{aA\alpha}$	2.67
Narrow row	$30.52^{abB\beta}$	$17.32^{abA\beta}$	0.57	$1.29^{aA\alpha}$	$4.63^{aA\alpha}$	3.60
Crossed	$19.62^{aA\beta}$	$13.61^{aA\alpha}$	0.69	$1.07^{aA\alpha}$	$4.07^{aA\alpha}$	3.82
$F_{Sowing\ arrangements}$: 2.139; P = 0.1653^{ns}/ $F_{Air\ assistance}$: 3.014; P = 0.0908^{ns} / $F_{Part\ of\ plant}$: 92.076; P = 0.0000* / $F_{Sowing\ arrangements\ x\ Air\ assistance\ x\ Part\ of\ plant}$: 0.176; P = 0.9119^{ns}						

Averages followed by the same letters in each comparison level did not differ by T-test (LSD) ($p < 0.05$). Lowercase letters compare the spray coverage between the sowing arrangements at each level of air assistance and in each part of the plant. Upper case letters compare the spray coverage with and without air assistance in each sowing arrangement and in each part of the plant. Greek letters compare the spray coverage between the parts of the plant at each level of air assistance and in each sowing arrangement.

The average yield in the sowing arrangements was similar in the two growing seasons (Table 3). Increments in the yield are not always are repeated in the literature, especially when the same population of plants is maintained (Petter et al., 2016).

The similar productivity among soybean sowing arrangements further showed the importance of other benefits that a new system may add. However, in particular, the phytosanitary control carried out through spraying had a limited impact of the alteration of soybean sowing arrangements.

In the 2012/2013 growing season, there were increases in yield when fungicide was used, regardless the presence of air assistance in the spray boom. Because of the absence of epidemic in the 2014/2015 growing season, it was not evidenced, but the yield in the CO arrangement with AA was higher that with WA.

Table 3
Average yield (kg/ha) in sowing arrangements with the presence (AA) and absence (WA) of air assistance in the spray boom and absence of fungicide (WF) for the growing seasons of 2012/2013 and 2014/2015, Botucatu, São Paulo, Brazil.

Sowing arrangements	DOW 5D 688 variety and the 2012/2013 season		
	AA	WA	WF
Conventional	3367.01^{aAB}	3547.21^{aB}	2876.20^{aA}
Double row	3659.71^{aB}	3578.08^{aB}	2861.26^{aA}
Narrow row	3838.92^{aB}	3538.25^{aAB}	3014.58^{aA}
Crossed	3950.42^{aB}	3802.08^{aB}	3107.17^{aA}
$F_{Sowing\ arrangements}$: 1.57; p = 0.2144^{ns}/ $F_{Application\ technology\ of\ fungicide}$: 14.88; p < 0.0001* / $F_{Sowing\ arrangements\ x\ Air\ assistance\ x\ Part\ of\ plant}$: 0.288^{ns}; p = 0.9386			
Sowing arrangements	DOW 5D 634 variety and the 2014/2015 season		
	AA	WA	WF
Conventional	3200.37^{aB}	2410.10^{aAB}	1881.11^{aA}
Double row	2748.60^{aA}	2657.42^{aA}	2659.34^{aA}
Narrow row	2239.10^{aA}	2112.29^{aA}	2085.64^{aA}
Crossed	2276.31^{aA}	2283.84^{aA}	2183.10^{aA}
$F_{Sowing\ arrangements}$: 1.20; P = 0.3643^{ns}/ $F_{Application\ technology\ of\ fungicide}$: 1.229; p = 0.3104^{ns} / $F_{Sowing\ arrangements\ x\ Air\ assistance\ x\ Part\ of\ plant}$:0.659; P = 0.6826^{ns}			

Averages followed by the same letters in each comparison level did not differ by T-test (LSD) (p < 0.05).Lowercase letters compare the yield between the sowing arrangements at each level of air assistance and the part of the plant. Upper case letters compare the yield with and without air assistance in each sowing arrangement and in each part of the plant.

Conclusion

There was no interference by the sowing arrangements in the fungicide spray deposits in soybean plants.

The heterogeneity in the vertical spray distribution on soybean plants, with greater deposit levels at the upper parts of the plants and smaller spray deposits at the lower parts of the plants, was not affected by sowing arrangements.

Air assistance increased the spray deposits and spray coverage at the lower part of the plants, but the beneficial effect of this technology can be associated with the agronomical characteristics of the crop at the timing of application and operational conditions.

There was no interference from sowing arrangements on soybean yield in two different growing seasons.

Acknowledgements

The authors thank the Coordination for the Improvement of Higher Level - or Education- Personnel - CAPES for the financial support. The authors also thank the FEPE and AGRIMIP for their support in the execution of the experiments.

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Author notes

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Author for correspondence. E-mail: diego-agronomia@hotmail.com