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HOW DO THE DROPLET SPECTRUM UNIFORMITY AND SPRAY VOLUME OF FLAT-FAN NOZZLES INFLUENCE FUNGICIDE SPRAY DISTRIBUTION QUALITY IN SOYBEANS?

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KEYWORDS

application technology, coverage, deposits, drift, Span.

ABSTRACT

Droplet spectrum quality is essential to effectively control crop pests and diseases. This study aimed to characterize the droplet uniformity of the eight most popular flat-fan nozzles used by Brazilian farmers and relate it to their spraying quality. The method consisted of using a laser-diffraction-size analyser to determine droplet-size distribution for three fungicide spray solution compositions and at two flow rates. Our goal was to identify the nozzle models with the highest and lowest Span values for each fungicide spray solution. In the first stage, the results confirmed differences in uniformity and droplet size for both nozzle models and flow rates applied. However, these differences were not the same for both flow rates nor constant for all fungicide spray solution compositions. Through field experiments, we could understand how the combination of flow rate, nozzle model, and spray solution composition provides different results and application efficiencies. Based on our results, we can state that Span has an impact on the number of droplets prone to drift and quality of canopy coverage. Therefore, this droplet-quality parameter should be considered and displayed in nozzle catalogues to improve nozzle selection and sprayer configuration, thus enhancing application quality.

INTRODUCTION

Crop protection products are commonly sprayed in the field using hydraulic nozzles. However, when considering a single nozzle, droplet sizes vary widely, from very thick to very thin for a specific target (Costa et al., 2017). Very large droplets are prone to ricochet or run off from target surfaces, while very small droplets are very susceptible to evaporation or drift (Xue et al., 2021). In both cases, the biological effect of products is compromised, as deposit quality on plant surfaces decreases (Berger-Neto et al., 2017) and the risks of environmental contamination increase (Craig et al., 2014).

During droplet formation, several factors can play major roles in terms of droplet size uniformity such as nozzle model, flow rate, and spray solution composition (Craig et al., 2014; Sijs & Bonn, 2020). Some researchers have found that flow rates affect droplet uniformity (Nuyttens et al., 2013; Womac et al., 1997), with lower values achieving increased droplet uniformity. Still, a larger number of droplets of desirable size may not result in coverage as rich as increased flow rates (Courshee, 1967). Moreover, higher flow rates with larger droplets can be an advantage for drift reduction; however, it can increase runoff from treated surfaces (Almeida et al., 2016; Miranda-Fuentes et al., 2016).

Variations in liquid spray composition can also interfere with droplet uniformity (Calore et al., 2015; Sijs & Bonn, 2020). However, the complexity of spray solution combinations, aggravated by interactions with spray-nozzle orifice roughness and shape, generates diverse droplet spectra. In other words, for a given spray solution composition, droplet sizes may increase as a function of nozzle model, while for another it may decrease (Costa et al., 2017). When comparing nozzle models with and without air induction, this effect may be even higher (Jensen et al., 2013).

Soybean is a crop of great global importance given numerous ways of using its grains. During a season, several problems may compromise yield, thus crop protection

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products are usually needed. It is difficult for sprayed products to reach a target area in a suitable amount and distribution, thus increasing the importance of an appropriate application technology (Berk et al., 2016). The shielding effect of top canopy leaves on lower leaves decreases coverage thereof (Román et al., 2009). The ricochet effect of large droplets on upper leaves (Crick & Parkin, 2011), as well as drifting (Griesang et al., 2017) and shielding (Román et al., 2009) effects of small droplets, may hinder droplet penetration throughout the canopy strata. Therefore, the greater the uniformity of spray droplets, the greater the efficiency in reaching targets at the bottom of the canopy.

Although some studies have already assessed droplet uniformity (Carvalho et al., 2017; Ferguson et al., 2016a), its relationship with spraying quality and safety has not been deepened yet, especially by field experiments. Since this factor is significantly responsive, such information should be incorporated into spray nozzle catalogues by manufacturers.

Given the above, this study aimed to verify the influence of droplet uniformity and spray solution volume of fungicide with adjuvants on distribution quality throughout soybean canopy strata and its risk of drifting.

MATERIAL AND METHODS

Eight conventional flat-fan nozzle models [TP110 and XR110 (TEEJET); F110 and VP110 (HYPRO PENTAIR); JSF110 and API110 (JACTO); BD110 (MAGNOJET); and LDB110 (KGF)] were tested in this study, as they are the most used in Brazilian farms. To do so, two spray volumes were used (75 and 150 L ha^{-1}), which were achieved by two flow rates (0.57 and 1.14 L min^{-1} [0.15 and 0.30 gpm]). Three spray solution compositions were also evaluated, namely: 1- fungicide alone (Elatus® WG, 300 g cp ha^{-1} - azoxystrobin 30%, benzovindiflupir 15%, other ingredients 55%, Syngenta Crop Protection Ltd.); 2- the fungicide + an adjuvant a (Nimbus®, 0.5% v v^{-1} - mineral oil 42.80% m v^{-1}, inert ingredients 43.55% m v^{-1}, Syngenta Crop Protection Ltda.); and 3- the fungicide plus an adjuvant b (Li-700 ®, 0.3% v v^{-1} - Mixture of Lecithin and Propionic Acid 71.28% m v^{-1}, inert ingredients 30.55% m v^{-1}, De Sangosse Agroquímica Ltda.).

Characterization of spray nozzles

First, all nozzle models were tested for droplet uniformity, at both flow rates and for the three spray solution compositions. The droplet uniformity was expressed as "Span", which is a measure of droplet size distribution. The Span was measured by a laser diffraction method using particle size analyser (Mastersizer S, version 2.19, Malvern Instruments Co.). In the equipment, an optical unit determines the droplet size of the sprayed spectrum by the trajectory deviation of the laser beam when reaching particles. The smaller the particle, the greater the degree of diffraction experienced by the ray of light (Etheridge et al., 1999). The nozzles with the highest and lowest Span values were selected for further field study. For this selection, the equipment was adjusted to evaluate droplet sizes from 0.5 to 900.0 mm (using a 300 mm lens).

The nozzles were positioned at 40 cm from the laser light beam. The spray was powered by compressed air, and pressure was maintained constant by precision pressure regulators. The nozzle was kept in a hanging motion, which allowed the analysis of droplets in the entire amplitude of the jet. In the Span determination test, the values DV0.1, VMD, and DV0.9 represented the droplet sizes for 10, 50, and 90% of the sprayed volume, according to the following equation: Span = (DV0.9-DV0.1) / VMD. The closer the Span is to zero, the more uniform the spray droplet sample.

Soybean field experiment

Field experiments were performed to determine the effects of droplet uniformity (Span), application volume, and solution composition on spray coverage and deposits throughout soybean canopy strata. The experimental areas are located on a gently sloping topography (about 5% slope), and sprays were carried out along the slope, between the coordinates 21°14'10" S and 48°17'15" W. The local climate is characterized as tropical, with winter and summer rains (*Cwa*), according to the Köppen classification.

The soybean cultivar AS 37391PRO (early cycle) was sown at 0.45-m row spacing and 22 plants per linear meter, with a final population of 450 thousand plants per hectare. At the time of spraying, plants had reached an average height of 1.2 m. The experiments were carried out in a fully randomized block design, with four replicates. The treatments were arranged in a 2×3×2 factorial scheme, with two application volumes (75 and 150 L ha^{-1}), three spray solution compositions (fungicide, fungicide + lecithin, fungicide + mineral oil), and two droplet-size uniformities (lowest and highest Span). Each experimental plot consisted of 9 10-m long soybean rows spaced 0.45 m apart, totalling 45.0 m^2 (Figure 1-A). For coverage and deposit evaluations, sprays were performed when the crop was at R.4 stage, 81 days after sowing (DAS).

Applications were performed with a quadricycle-mounted sprayer, equipped with a boom with six nozzles spaced 0.5 m apart, and a CO_2 constant pressurizing system. The spray boom was kept at a height of 0.5 m from the top of crop canopy. The applications were carried out at a speed of 9.0 km h^{-1} and working pressure of 275.79 kPa (40 psi), applying 75 and 150 L ha^{-1}. The atmospheric conditions at the time of spraying were sunny and cloudless, with temperatures between 26 and 34 °C, relative humidity between 56 and 74%, and wind speed between 0 and 6 km h^{-1}.

Spray coverage and deposit

Spray droplet coverage was evaluated using 50.76×22-mm water-sensitive papers (Syngenta Crop Protection AG - Basel, Switzerland) hang on rods at three heights, representing the lower, middle, and upper plant strata (15 cm below the top of each stratum) (Figure 1-B). To better represent each experimental unit, two rods spaced three meters apart were placed in the centre of each plot (Figure 1-A). The rods containing papers were positioned on the side of the plants, and the papers were arranged horizontally. After spraying, the papers were removed and scanned at 600 dpi. The percentage coverage of droplets on the water-sensitive papers was obtained from the processing of the digitized images, using the GOTAS® software (Chaim et al., 2005).

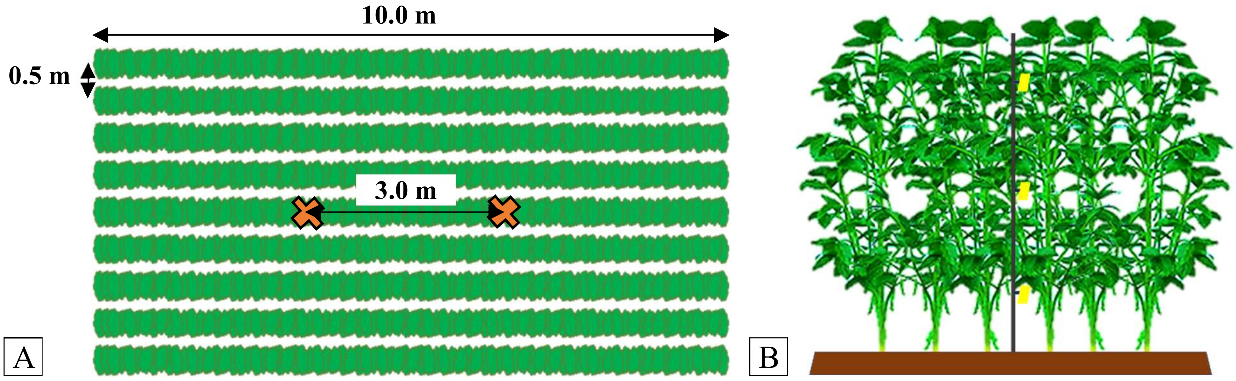


FIGURE 1. Scheme of the plot size and distances between samples (A), and locations of the hydrosensitive papers throughout the soybean canopy strata.

For spray deposition evaluation, manganese sulphate (31% Mn; Oxiquímica Agrociência Ltda.) was added at the concentrations of 5 and 10 g L^{-1} for the spray volumes of 150 and 75 L ha^{-1}, respectively. To do so, some changes in the equipment configuration were required to quantify the contents of marker in all samples. After 15-min application, when droplets were already dried out, 10 leaflets were collected from each canopy stratum. These samples were conditioned in plastic containers and taken to the laboratory, wherein they received 250 mL HCl 0.2 N solution (Qhemis, by Hexis Distributor) for 2 hours to extract Mn ion from leaf surface. The Mn concentration in the wash solution was determined by atomic absorption spectrophotometer (Thermo scientific, iCE 3000 Series). To determine Mn concentration per leaf area unit, leaf area was measured using an area meter LI-3100C (LI-COR®). The concentrations of Mn obtained from the spectrophotometer readings were related to the measured leaf areas, resulting in the spray volume accumulated per unit area (μL cm^{-2}).

Statistical analysis

Data were subjected to a multivariate analysis using the Statistica® v. 7.0 software. To do so, the data were initially standardized so that attributes contributed with the same weight in calculating the coefficient of similarity between the objects. The standardization adopted consisted of subtracting from the value of each observation the average value of the variable to which it belongs, followed by dividing the result by the standard deviation of the variable's dataset. After data standardisation, a principal component analysis (PCA) and classification analysis were performed.

For the droplet uniformity of each nozzle model, VMD, Span, and V100 data were subjected to analysis of variance (ANOVA). The means of each treatment were compared by the Tukey's test at a 5% probability, using the AGROSTAT® software.

For the field experiments, spray coverage and deposit data were also subjected to ANOVA and their means compared by the Tukey's test at a 5% probability, also using the AGROSTAT® software. Coverage and deposit variables were compared within each crop stratum.

RESULTS AND DISCUSSION

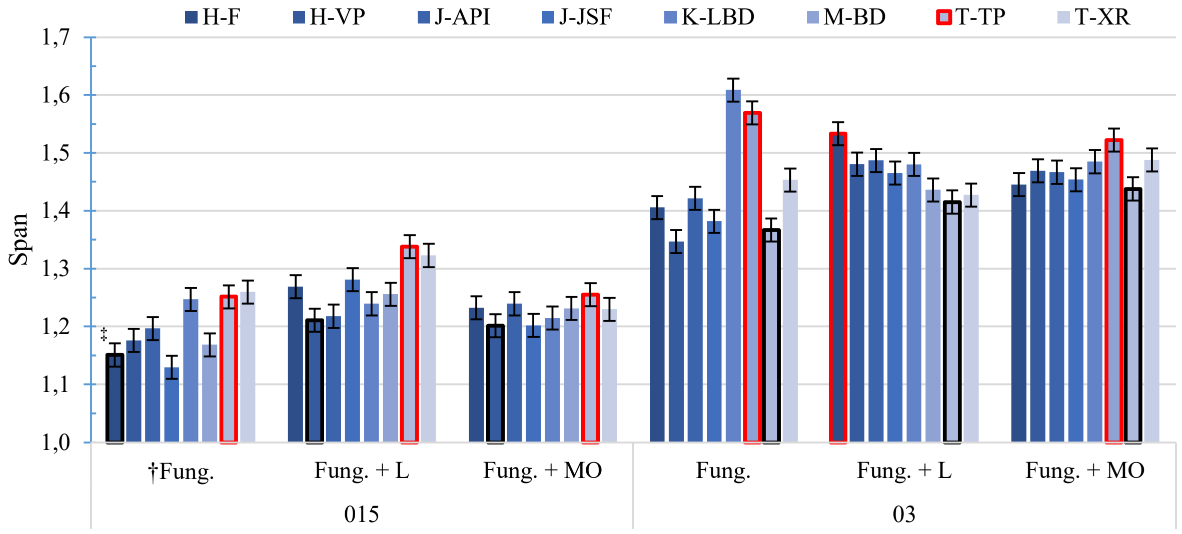
The results presented here consider the nozzle models that provided the highest and lowest Span values for each flow rate (0.57 and 1.14 L min^{-1}) and spray solution composition (Fungicide, Fungicide + Lecithin, Fungicide + Mineral Oil) as a function of their effect on coverage and deposit throughout soybean canopy.

Nozzle selection according to Span value

Nozzles used in the field experiment were selected based on droplet size uniformity and low inter-sample variability for each group of nozzle models. Thus, the highest and lowest Span values verified for nozzle models were selected for each flow rate and each spray solution composition.

For the lowest flow rate, the nozzle models Hypro F (fungicide only) and Hypro VP (the other spray compositions) resulted in the lowest Span values, which represented more uniformity of droplets (Figure 1), while the model Teejet TP resulted in the highest Span values.

For the highest flow rate, the model Teejet TP resulted in the lowest Span values for all spray solution compositions, while the highest Span values were obtained by the model Hypro VP for the lecithin-based spray solution and by the model Magnojet BD for the other spray compositions. At times these models showed no significant differences from the others; therefore, the frequency of occurrence was the criterion used.



†Fung. (fungicide only), Fung. + L (fungicide plus lecithin-based adjuvant), and Fung. + MO (fungicide plus mineral oil adjuvant). ‡LSD (Least Significant Difference) represents Span differences for each spray solution composition at each flow rate tested. Graphic columns circled in black and red represent the lowest and highest Span values for the field tests. CV (%) = 2.60.

FIGURE 2. Droplet characterization by Span for each nozzle model and spray solution composition used.

The most significant Span variations were observed between flow rates, followed by nozzle models, and finally by spray solution compositions. For flow rates, the lowest Span values were provided by the lowest flow rate (overall mean for Span: 015 = 1.23, 03 = 1.46 - F = 4689.34 **). Among the spray solution compositions (F = 53.48 **), the fungicide sprayed alone showed the lowest Span (1.32), with the others not differing significantly from each other (1.35 for Fung. + L and 1.36 for Fung. + MO). However, Span value amplitude for fungicide plus mineral oil was lower than the other solution compositions; therefore, nozzle model influenced less than spray solution composition.

Nozzle model also influenced Span regardless of the flow rate. The models with the most uniform droplets for the flow 015 had different results from the flow 03. The models with the lowest Span values for flow 015 showed the highest Span values for flow 03 (Teejet TP). Thus, nozzle models with similar technology for droplet formation showed differences in droplet uniformity.

Obtaining differences in flow rate for the same nozzle model and pressure by just changing the nominal nozzle flow rate means spraying jets of different thicknesses. The higher the flow rate, the thicker the flat jet will be. This occurs because by the time the jet exits the nozzle orifice, it shocks the air around the nozzle, and such friction has lower interaction for thicker flat jets, as it has greater resistance for liquid shearing and droplet formation (Lin & Reitz, 1998). Moreover, the physical-chemical properties of spray solutions have great influence on droplet sizes, resulting in different Span values. Therefore, tank mixtures with different adjuvants may often result in significant droplet spectrum variations (Costa et al., 2017; Griesang et al., 2017). On the other hand, spray solution compositions act directly on liquid sheet length from the nozzle orifice to the starting point of droplet formation, especially for nozzles like those used in this experiment (conventional flat fan nozzles). In general, the longer the liquid sheet length, the finer the formed droplets will be (Altieri & Cryer, 2018). This phenomenon is a result of some chemical-physical properties in liquids, such as surface tension and viscosity. The higher the liquid viscosity, the lower the disturbing effect of air friction, resulting in thicker droplets (Zhang & Xiong, 2021).

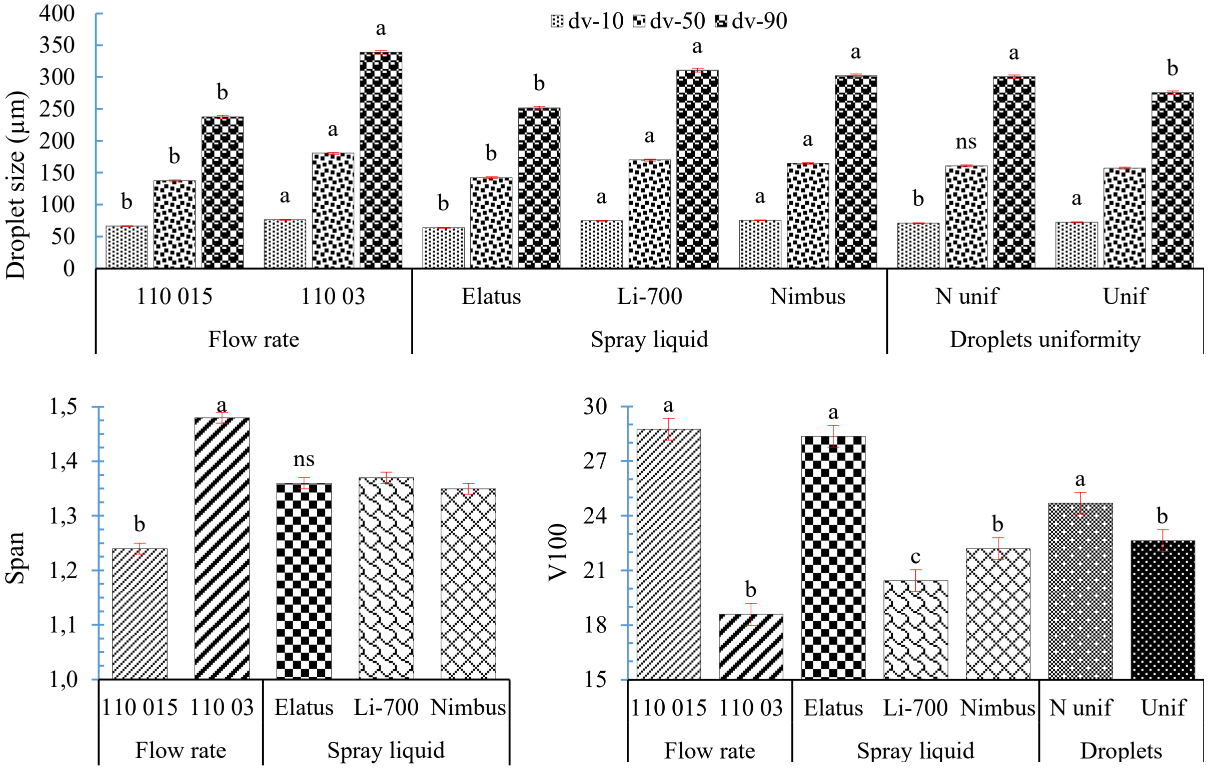
Besides that, nozzle models may also significantly affect the properties of droplet spectra (e.g., Span values), regardless of their technology. This is because the material the nozzles are made from can affect the manufacturing process and thus affect flow rate, spray pattern, and droplet spectrum (Kooij et al., 2018).

With respect to droplet formation technology, nozzle models may be air induction, conventional flat jet, and hollow cone. Such differences often generate different droplet spectra (Costa et al., 2017; Dorr et al., 2013; Garcerá et al., 2017) and large differences in droplet sizes, of which much larger droplets are often produced by air-induction nozzles and smaller ones by hollow-cone ones. Other important effects are also verified on volume distribution pattern, which is commonly more predictable in flat-fan than in hollow-cone nozzles (Hassen & Sidik, 2019; Negrisoli et al., 2021).

The Span values of the nozzle models tested ranged from 1.18 at a flow rate of 015 to 1.57 at a flow rate of 03, both with fungicide-only spray solution (Figure 1). This range is in line with what was suggested at the beginning of the study that different qualities of droplet spectrum are produced in field applications. This is because larger Span values imply a greater discrepancy in droplet size for the VMD of the sample (Al Heidary et al., 2014). Thus, droplets larger than the desired size may promote losses by runoff or poor product distribution over the sprayed area, concentrating within small areas where they are deposited (Butler-Ellis & Tuck, 1999; Decaro et al., 2016; Yu et al., 2009). On the other hand, finer droplets may result in losses by drift and evaporation on the path to their target (Ferguson et al., 2016b; Griesang et al., 2017).

Characterization of droplets in size, uniformity, and drift susceptibility

Droplet sizes are characterized by the parameters dv-10, VMD, and dv-90. In this sense, flow rate was a factor that resulted in the largest differences (Figure 3). There are differences in Span values, especially related to the two flow rates. All factors tested had influence on the parameter V100, with the highest effect provided by flow rate, followed by spray composition and droplet uniformity.



Same lowercase letters in the column within each analysed parameter do not differ from each other by the Tukey's test at a significance level of 5%. Flow rate for the model 110 015 = 0.57 L min^{-1} and for the model 110 03 = 1.14 L min^{-1}. VMD = Volumetric Median Diameter; Span = Coefficient of Uniformity; V100 = Volume percentage of droplets smaller than 100 micrometres; dv-10 = diameter representing the 10% smallest droplets; dv-90 = diameter representing the 10% largest droplets. Coefficient of Variation (%): VMD = 2.04; dv-10 = 2.53; dv-90 = 2.31; Span = 2.00; V100 = 5.92.

FIGURE 3. Characterization of the droplet spectrum as a function of application volume, spray solution composition, and droplet uniformity.

When considering the VMD, the flow rate 03 resulted in larger droplets. This is because spray nozzles with higher nominal flows have larger orifices for liquid passage and jet formation, which naturally results in larger droplets (Ferguson et al., 2016c). Regarding the spray solution composition, the largest droplets were produced for the solution containing Li-700 adjuvant, followed by that with Nimbus, which, in turn, differed from that with no adjuvant, which had the lowest VMD. This occurs because the addition of some adjuvants is responsive to specific nozzle models (Hilz & Vermeer, 2013; Knowles, 2008). Moreover, as spray nozzle model is one of the most important tools for drift mitigation, it has been the subject of several studies, mainly those on reduction of accumulated volume of fine droplets (Dorr et al., 2013; Gil et al., 2014; Griesang et al., 2017).

For the Span parameter, the nozzle models with higher flow rates resulted in less uniform droplets. This shows that the increase in VMD found for larger flow rates is not exclusively related to the progressive increase in size of all the droplets in the spectrum, but mainly due to the higher dv-90 values, increasing the contrast with dv-10, thus worsening the results of Span.

The percentage of volume represented by very fine droplets (V100) was lower for the flow rate 03. Considering the factor spray solution composition, the highest values were verified for that composed solely of fungicide, differing from those with adjuvants. For the different droplet uniformities, there were significant responses in the volume percentage of droplets smaller than 100 µm, with lower values for more uniform droplets. Volume reductions for droplets smaller than 100 µm are of great importance to the safety of applications, as very fine droplets are the most likely to contaminate neighbouring areas due to drift predisposition (Damak et al., 2016; Gil et al., 2014). Thus, the uniformity of spray droplet sizes is an important factor in reducing losses by drift and enables safer applications (Matthews et al., 2014).

Considering the interaction observed between flow rate and droplet uniformity (Table 1) in the first part of our study, treatments with uniform droplets for the flow rate 015 showed significantly lower VMD (4.3%) and, even so, resulted in a lower volume percentage of droplets susceptible to drift (6.7%). For the flow rate 03, no difference was recorded for VMD, but again a significant reduction was recorded in drift-sensitive drops (10.8%).

TABLE 1. Interaction between nozzle flow rate and droplet uniformity (Span).

	VMD		Span		V100	
	110 015	110 03	110 015	110 03	110 015	110 03
N unif	140.42^{aB}	181.08^{nsA}	1.32^{aB}	1.57^{aA}	29.75^{aA}	19.65^{aB}
Unif	134.38^{bB}	180.25^{A}	1.17^{bB}	1.39^{bA}	27.76^{bA}	17.53^{bB}
dms	2.682		0.023		1.161	

Same lowercase letters in the column and uppercase in the row within each analysed parameter do not differ by the Tukey's test at a significance level of 5%. VMD = Volumetric Median Diameter; Span = Coefficient of Uniformity; V100 = Volume percentage of droplets smaller than 100 micrometres.

Regarding spray solution composition and droplet uniformity (Table 4), the spray solution composed of Li-700 adjuvant had significantly higher VMD for the non-uniform droplets, which can be explained by an increase in dv-90 (Table 2). Both uniform and non-uniform groups showed droplets lower than the VMD for the spray composed only of Elatus (without adjuvants). The addition of adjuvants into spray solutions can influence droplet sizes, increasing VMD and reducing drift and evaporation losses (Ferguson et al., 2014; Griesang et al., 2017).

Relevant results were also obtained for the parameter V100, with the highest values for the group of non-uniform droplets and only fungicide application. This means that, for this case, droplet uniformity plays an important role in the safety of application since droplets with the same VMD, but from a nozzle producing more uniform droplets, have a smaller volume of fine droplets (Table 2).

TABLE 2. Interaction between spray solution composition and droplet uniformity.

	VMD			Span			V100		
	Elatus	Li-700	Nimbus	Elatus	Li-700	Nimbus	Elatus	Li-700	Nimbus
N unif	142.6^{nsC}	173.75^{aA}	165.8^{nsB}	1.47^{aA}	1.45^{aA}	1.41^{aB}	30.25^{aA}	21.10^{nsB}	22.75^{nsB}
Unif	141.6^{B}	166.63^{bA}	163.6^{A}	1.25^{bB}	1.29^{bA}	1.30^{bA}	26.49^{bA}	19.79^{C}	21.65^{B}
lsd	column	3.28	LINE 3.96	column	0.028	LINE 0.03	column	1.41	LINE 1.71

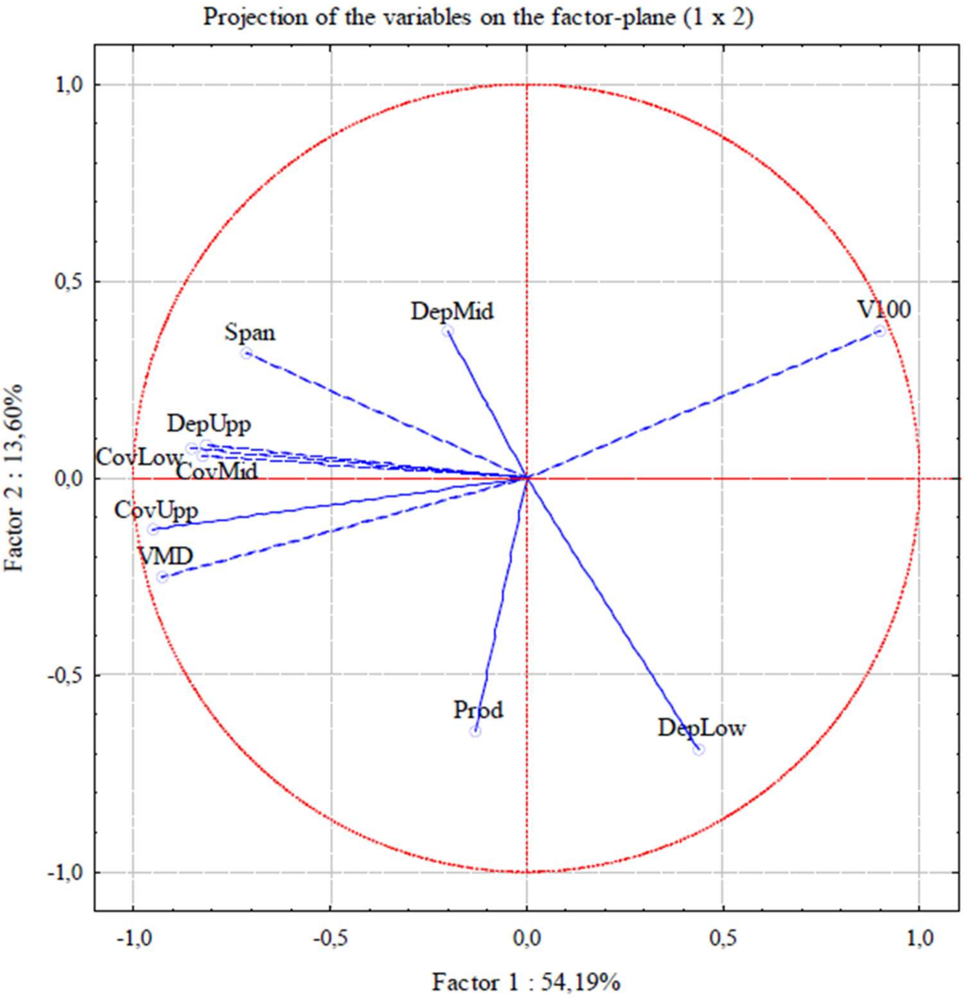
Same lowercase letters in the column and uppercase in the row within each analysed parameter do not differ from each other by the Tukey's test at a significance level of 5%.

Our results highlight that Span is an essential information for planning safe agricultural sprays. However, instead of Span (droplet uniformity), the most commonly information made available in commercial labels is VMD. In turn, knowing only this parameter can disguise the risk of drift, which decreases application efficiency under adverse weather conditions (Nuyttens et al., 2005). Thus, as drifts can be managed by knowing the Span, it can be used to improve selection of nozzle models throughout a crop season. This information, combined with a careful combination of sprayer configuration (boom height and working pressure) and selection of products (pesticide and adjuvants), can improve application efficiency, and pose less human and environmental risks during sprays (Wolf, 2013).

Spray coverage and deposition

Sprays were carried out in three soybean crop areas to evaluate the effect of droplet uniformity provided by all nozzle models in the field. Multivariate analysis by principal component (PCA) showed that the two most important factors together accounted for more than 54% of the results reached (Figure 3). In the main factor, a negative relationship was found between the parameter V100 and the group composed of VMD, Span, and coverage in the upper and middle thirds of the crop canopy (Figure 1). Thus, smaller droplets (VMD) resulted in larger V100, which can be easily lost by drift and evaporation; therefore, it is an important factor to be considered to maintain spray efficiency and safety (Gil & Sinfort, 2005; Griesang et al., 2017).

On the other hand, VMD values were directly related to the percentage of coverage in the upper third of the crop, with larger droplets resulting in greater coverage. Increases in coverage provided by smaller droplets are generally expected from a same spray volume. This is because smaller droplets result in a much larger number of droplets, and thus increase surface coverage potential (Almeida et al., 2016; Ferguson et al., 2016c; Zaidan et al., 2012). In this study, the larger droplets were obtained by the highest sprayed volumes (Table 2), contributing to an increased coverage (Courshee, 1967; Román et al., 2009).



VMD = Volumetric Median Diameter; Cov = Coverage; Dep = Deposit; Upp = Upper third; Mid = Middle third; Low = Lower third; Span = Coefficient of Uniformity; V100 = Volume percentage of droplets smaller than 100 micrometres.

FIGURE 4. Projection of the variables in the plane defined by the two principal components of the multivariate analysis.

Considering the deposits in the lower third of the canopy, smaller application volumes resulted in larger deposits. Yet for the Span in the lower third, more uniform droplets also resulted in larger deposits (Table 3). The lower volume is formed by smaller droplets, which can explain increased penetration and deposits reaching the leaves at the lower third of the canopy (Wolf & Daggupati, 2006). As for the Span, more uniform droplets have a lower volume of finer droplets but higher of large droplets, which can ricochet and runoff from leaf surfaces (Damak et al., 2016; Dong et al., 2015).

The volume of spray applied affected only coverage but not deposit for the three heights tested. This was due to the double concentration of tracer at lower flow rates. The upper canopy layer had higher deposits and coverage. This can be easily explained by the trajectory of droplets, which leave the sprayer and are first intercepted by the upper crop leaves. Thus, only droplets that pass through this first obstacle can reach the lower parts of the crop canopy.

TABLE 3. Spray coverage on water-sensitive papers and deposits on soybean leaves as a function of sprayed volume, spray solution composition, and droplet uniformity at three strata of the crop canopy.

		Deposit (µl cm^{-2})			Coverage (%)		
		Lower	Middle	Upper	Lower	Middle	Upper
Volume	75 L/ha	0.39 ^{a}	0.52 ^{ns}	1.02 ^{b}	0.43 ^{b}	2.20 ^{b}	14.40 ^{b}
	150 L/ha	0.33 ^{b}	0.54	1.20 ^{a}	0.74 ^{a}	4.34 ^{a}	26.18 ^{a}
	dms (column)	0.05	0.11	0.13	0.125	0.7	1.57
Spray solution composition	Elatus	0.35 ^{ns}	0.56 ^{ns}	1.09 ^{ns}	0.61 ^{ab}	3.18 ^{ns}	17.75 ^{b}
	Li-700	0.38	0.49	1.20	0.68 ^{a}	3.52	22.24 ^{a}
	Nimbus	0.36	0.53	1.04	0.46 ^{b}	3.11	20.89 ^{a}
	dms (column)	0.07	0.17	0.19	0.18	1.04	2.32
Droplet Uniformity	N unif	0.33 ^{b}	0.53 ^{ns}	1.13 ^{ns}	0.56 ^{ns}	3.11 ^{ns}	20.38 ^{ns}
	Unif	0.40 ^{a}	0.52	1.09	0.60	3.43	20.20
	dms (column)	0.05	0.11	0.13	0.12	0.70	1.57
	CV (%)	23.8	23.5	19.3	36.7	36.7	13.2

Same lowercase letters in the column within each analysed parameter do not differ from each other by the Tukey's test at a significance level of 5%.

The application of 150 L ha^{-1} increased coverage in the three thirds of the crop canopy compared to 75 L ha^{-1}. In the upper third, such a difference was more evident than in the other thirds. This fact is explained by the larger number of larger droplets (Figure 2) intercepted by external leaves. The application of lecithin-based spray solution promoted higher coverage in the lower and upper thirds, which may be related to droplet spreading provided by the chemical properties of the adjuvant (Decaro JR et al., 2015).

CONCLUSIONS

Our results show that Span influences drift risks and coverage uniformity on crop canopy. Therefore, it is a quality parameter that should be considered and displayed in nozzle catalogues to improve nozzle selection and sprayer configuration for safe and efficient field applications.

Although the quality of droplets varies with the nozzle model, some models may achieve good results for one flow rate but not for other flow rates. More uniform droplets (lower Span values) enhance application quality (coverage and deposits throughout canopy strata).

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