

Quality of Phytosanitary Application in *Ricinus communis* L. Cultivation

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Abstract

One of the main challenges in castor bean (*Ricinus communis* L.) crop is controlling gray mold (*A. ricini*), a fungal disease. Most fungicides used are contact-based, and the plant's architecture complicates application efficiency. The objective of this research was to evaluate droplet deposition and spectrum in different parts of the castor plant canopy using various spray tips and flow rates. The experiment was conducted at the Instituto Mato-Grossense do Algodão (IMA) in Rondonópolis, MT, using a New Holland TL 75 tractor and a Jacto Columbia Cross sprayer. The results were in percentages and a 3-factor factor analysis was performed, where A (Tip) = 2 levels, B (Volume) = 3 levels and C (Position) = 3 levels with four replications, using Scott-Knott test and software Assistat. Treatments involved two hydraulic nozzles (JAC 80015 and JAC 8002), three flow rates (120, 150, and 180 L per ha⁻¹), and three plant positions (lower, middle, upper third). Data were analyzed using the “F” test and compared by the Scott-Knott test at a 5% significance level. The results showed that spray tips influenced VMD, NMD, and product concentration, with greater deposition and coverage observed in the upper third of the plant.

Keywords: application quality, flows, gray mold, plant position, pressures, spikes, target

1. Introduction

The castor bean plant (*Ricinus communis* L.) belongs to the *Euphorbiaceae* family and it is part of a large number of species native to the tropical region and is found in tropical latitudes. Its main commercial product is the oil extracted from its seeds, which contain 90% of ricinoleic fatty acid, which gives this byproduct some unique characteristics and allows its wide use in industry, thus making the castor bean a strategic crop for the production of biodiesel (Beltrão, Azevedo, Lima, Queiroz, & Queiroz, 2007; Silva, 2018).

Brazil led castor bean production between the 1960s and 1980s, with its productivity ranging from 800 to 1200 kg per ha⁻¹. However, currently, India and China are the largest producers in the world. In Brazil, the Northeast region concentrates 90% of national production, with the state of Bahia being the largest producer with an average of 1785 kg per ha⁻¹ (Ferreira & Melo, 2019).

Gray mold of castor bean, caused by *Amphobotrys ricini* (NF Buchw.) Hennebert, is one of the more economically important diseases of this crop due to the rapid and complete destruction of the bunches. This disease is present in practically all castor bean producing countries, and has been considered one of the limiting factors to the expansion of the crop in the center-west of Brazil. (Severino et al., 2012; Sá et al., 2015). Chemical control is used, but the quality of application is fundamental to the success of disease control (RAMOS et al., 2019).

In addition to knowing the nature of the chemical product, it is necessary to apply it in such a way as to ensure that the product reaches the target efficiently, minimizing losses and reducing environmental contamination (Cunha,

Teixeira, & Vieira, 2005). Often, part of the applied product is lost in the environment, mainly due to the poor quality of the application, whether by land or air, this being one of the greatest challenges of modern agriculture (Wang et al., 2023).

During crop development, there is an increase in leaf mass and plant architecture. Therefore, there is greater difficulty in covering the target and penetrating the droplets into the plant canopy, especially in the lower layers of the plants (Cunha, Moura, Silva Júnior, Zago, & Juliatti, 2008).

For high spraying efficiency, factors such as dosage, volume, spray deposition on the target and meteorological conditions (temperature, relative humidity, wind speed, time of application) are important in the process of applying phytosanitary products (Gentil-Sergent et al., 2021). Other factors such as spray tips aim for a homogeneous distribution and a spectrum of droplets with a more uniform size, allowing greater spraying efficiency (Kliopova, Baranauskaitė-Fedorova, Malinauskienė, & Staniškis, 2016; Yang, Zhu, & Wang, 2020), avoiding the risk of drift that results in low application efficiency on the crop (Wang et al., 2023).

The spray volume defined for application must be one that provides coverage of the plant and the minimum losses due to runoff to the soil (endodrift) and away from the desired target (exodrift) (Silva, Cunha, & Nomelini, 2014). Oliveira, Balan, Fonseca, & Saab (2012) reinforce in their work evaluating spray deposition that hydraulic nozzles that generate smaller drops provide greater coverage and penetration into the plant canopy. This occurs because they are produced with more kinetic energy and can reach the lowest and lower parts of the plants (Camara, Santos, Silva, & Ferreira, 2008).

Therefore, the objective of this research was to evaluate droplet deposition and spectrum in different parts of the castor plant canopy using various spray tips and flow rates.

2. Method

2.1 Characterization of the Research

The were carried out at the experimental field of the Instituto Mato-Grossense do Algodão (IMA) in Rondonópolis, MT (Figure 1), with castor bean, hybrid AG IMA 110204, in an area of five ha. The application was carried out using a mechanized set consisting of a New Holland tractor, model TL 75, with 75 hp (55.16 kW) of power, and a Jacto trailed sprayer, model Columbia Cross, with a capacity of 2000 L and a spray bar of 18 m. The displacement speeds for volume modification were 8.5, 10.0, and 12.0 km per h⁻¹. The spacing between nozzles was 0.5 m and maintained at a distance of 0.5 m from the plant. The spray was applied vertically in relation to the soil surface.

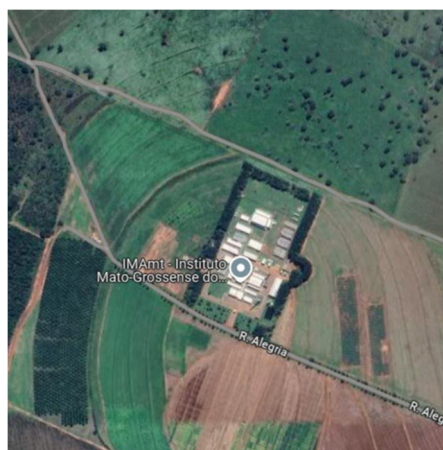


Figure 1. Experimental field of the Instituto Mato-Grossense do Algodão (IMA) in Rondonópolis, MT

At the time of application, the air temperature, relative humidity and wind speed were measured using a portable thermo-hygro-anemometer (ICEL brand, model HT-208), obtaining, respectively, average results of 30 °C, 50% and 1.65 km h⁻¹. The average height of the plants was 0.7329 m.

In the preparation of the spray solution, 0.36 g per L⁻¹ of wattrer of Brilliant Blue food coloring (FCF Blue Dye, Duas Rodas Industrial), internationally cataloged by Food, Drug & Cosmetic as FD&C Blue n° 1 and Break Thru adjuvant (1 mL per L⁻¹ of water) were used.

To study the deposition of the sprayed mixture, the tracer was quantified, forming a solution at a dose of 0.750 kg per ha⁻¹, according to the methodology adapted from Palladini, Raetano, & Velini (2005).

2.2 Research Factors

The results were in percentages and a 3-factor factor analysis was performed, where A (Tip) = 2 levels, B (Volume) = 3 levels and C (Position) = 3 levels with four replications. The treatments consisted of two Jacto brand hydraulic spray tips (JAC 80015 and JAC 8002 - conical jet), three volumes (120, 150 and 180 L per ha⁻¹) and three plant positions (lower, middle and upper third).

The droplet spectrum and spray solution deposition were evaluated. To obtain the droplet spectrum of each treatment, three water-sensitive paper labels per plot, measuring 76 x 26 mm, from the Syngenta brand, were used in the lower, middle and upper thirds, according to the height of the crop, using a metal rod placed in the middle of the crop line.

After application to each plot, the labels were collected and protected inside paper envelopes, duly identified and subsequently analyzed by the DropScope[®] software. The software evaluated the parameters of Volume Median Diameter of the drops (VMD), Numeric Mean Diameter of the drops (NMD), relative amplitude and coverage area.

To evaluate the deposition of the spray in the upper, middle and lower thirds of the castor bean plants, two leaves were randomly collected from each third of the plant, in three different plants per plot, respecting the useful area. The leaves were stored according to the corresponding third of each plot in plastic bags. They were then transported in a thermal box to the Agricultural Engineering laboratory of the State University of Goiás (UEG) at the Henrique Santilo Campus in Anápolis.

2.3 Concentrations of Brilliant Blue Food Color

A 100 mL of deionized water was used to remove the dye from the leaves collected in each plot. From this solution, the dye was quantified by absorbance in spectrophotometry, which consists of determining the concentration of a substance by measuring the relative absorption of light. For this, a Bioespectro spectrophotometer, model SP-220, with a tungsten lamp with halogen vapor and glass cuvettes with an optical path of 10 mm, at a wavelength of 630 nm for brilliant blue, was used.

After removing the dye from the leaves resulting from the deposit obtained in each treatment, the leaves were photographed to measure the leaf area (Equation 1). The camera used was a Sony Cyber-Shot model, with a resolution of 7.2 megapixels, at a height of 0.45 m. The leaf area was measured using the ImageJ software (Ferreira & Rasband, 2012).

$$LAI = (AF * ST) / 10\ 000 \quad (1)$$

in which:

LAI = leaf area index

AF = average leaf area of the evaluated soybean plants (m²)

ST = final plant stand per ha

In relation to the racemes, the volume was quantified using a beaker with a known volume of water (2 L) and then the racemes were added and their volume obtained by the difference in volumes according to Equation 2.

$$V_r = V_f - V_i \quad (2)$$

in which:

V_r = Volume of the racemes, in mm³

V_f = Volume obtained after introducing the racemes into 2 L of water, in mm³

V_i = Initial volume, in mm³

To obtain the deposit in the plant, the spectrophotometer calibration curve was performed using solutions with known concentrations of the dye, obtaining a regression equation in accordance with Figure 2.

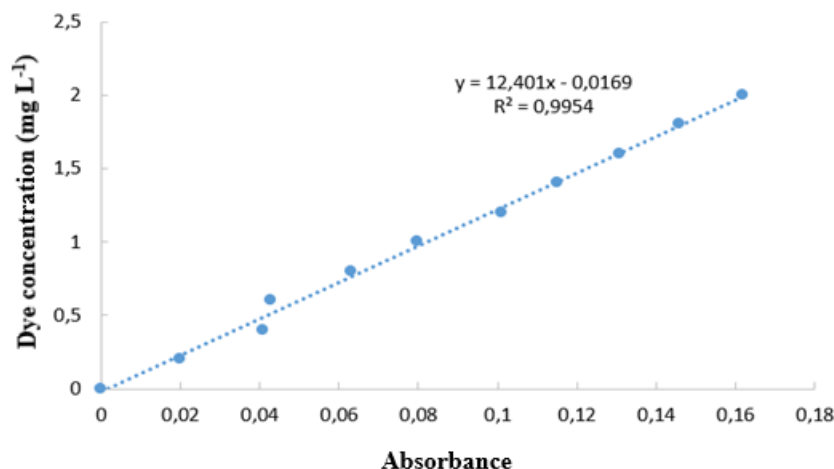


Figure 2. Calibration curve for known concentrations of Brilliant Blue Food Color (FD&C n° 1)

The absorbance data were transformed into concentration (mg per L⁻¹) and, using the initial concentration (mg per L⁻¹) and the dilution volume of the samples (100 mL), the volume retained in the lower, middle and upper thirds of the plants was determined according to Equation 3. From this result, it was divided by the value of the leaf area of the leaf sample, thus obtaining the quantity in μL per cm² of leaf.

$$C_i * V_i = C_f * V_f \quad (3)$$

in which:

C_i = initial concentration in the application solution (mg per L⁻¹)

V_i = volume retained by the target (mL)

C_f = concentration detected in optical density (mg per L⁻¹)

V_f = sample dilution volume of each leaf (mL)

2.4 Statistics

For the droplet spectrum and dye concentration, the data were subjected to the F test and when significant ($p < 0.01$ or $p < 0.05$), the treatment means or their interactions were compared by the Scott-Knott test at 5% probability. Subsequently, a correlation analysis between the factors was performed. ASSISTAT software version 7.7 Beta was used to perform all analyses (Silva & Azevedo, 2016).

3. Results

In the Table 1 contains a summary of the analysis of variance for the factors evaluated: tip model, application volume and position in the plant.

Table 1. Analysis of variance of the mean values of volume median droplet diameter (VMD) (μm), numeric mean droplet diameter (NMD) (μm), relative amplitude (R.A.), coverage area (C.A.) (%) and dye concentration (C) (mg L^{-1} per cm^{-2})

Variables	GL	Mean Square				
		VMD	NMD	R.A.	C.A.	C
Tip (T)	1	953.83 **	136.56 *	0.010 ^{ns}	6.78 ^{ns}	1.91x10 ⁻⁸ ^{ns}
Volume (V)	2	37.85 ^{ns}	15.39 ^{ns}	0.011 ^{ns}	7.11 ^{ns}	5.97x10 ⁻⁷ ^{ns}
Position (P)	2	114.15 *	108.11 ^{ns}	0.039 ^{ns}	192.81 **	2.00x10 ⁻⁶ *
T x V	2	2.81 ^{ns}	0.024 **	0.006 ^{ns}	3.82 ^{ns}	5.01x10 ⁻⁸ ^{ns}
T x P	2	126.69 *	47.5 ^{ns}	0.011 ^{ns}	9.06 ^{ns}	1.26x10 ⁻⁷ ^{ns}
V x P	4	68.10 *	66.67 ^{ns}	0.023 ^{ns}	2.63 ^{ns}	1.43x10 ⁻⁷ ^{ns}
T x V x P	4	37.99 ^{ns}	33.07 ^{ns}	0.011 ^{ns}	11.06 ^{ns}	1.19x10 ⁻⁷ ^{ns}
Residue	54	30.78	38.13	0.02	4.83	1.98x10 ⁻⁷
Total	71	-	-	-	-	-
CV (%)	-	6.86	9.22	23.34	42.22	83.00

GL Degrees of Freedom; *Significant at 5% probability by Scott-Knott test; **Significant at 1% probability by Scott-Knott test; ^{ns} Not Significant.

It was found that for the different levels of the spray nozzle factor, there was a significant difference only for the variable of the VMD and NMD. For the application position in the plant, the VMD, the coverage area and the dye concentration were significant. Only the interaction between tip x position obtained significance among those evaluated, occurring in the VMD variable. This behavior shows that the factors changed more within their levels than in their interactions, with only the VMD being affected when two factors were evaluated simultaneously (Table 1).

The spray nozzle influenced the dye concentration (Table 2). This can be explained by the VMD and NMD values obtained by each of them. Higher VMD and NMD values were found for the JAC 80015 tip, which differed from the JAC 8002 tip. These values are within the expected range because, according to the catalog of the respective tips (JACTO, 2024), the drops remain with a diameter classified as VF (very fine), and the different volumes changed these average values and, consequently, the VMD and NMD values of each tip.

Table 2. Means of VMD (μm), NMD (μm), coverage (%) and dye concentration (mg per L^{-1}) for the different tips and positions in the plant canopy

	VDM	NMD	Coverage	Concentration
JAC 80015	84.55 a	68.35 a	-	0.0046 a
JAC 8002	77.27 b	65.59 b	-	0.0028 b
Average	80.91	66.97	-	0.0037
Superior	83.42 a	-	8.35 a	0.00089 a
Average	79.76 b	-	4.42 b	0.00036 b
Lower	79.54 b	-	2.85c	0.00034 b
Average	80,90	-	5.21	0.00053

Averages followed by the same letter in the column do not differ from each other by the Scott-Knott test at 5% probability.

VMD values were altered by the presence of smaller droplets that have less weight and greater buoyancy, breaking away from natural obstacles and reaching their targets in the lower thirds of the plants.

Table 3 shows the average values of the interaction between the spray tips and the position of the plant for the

VMD values. The value found for this variable was found with the JAC 8002 tip, which differed in the lower and middle thirds of the plant, while in the upper third there were higher values. Larger droplets weigh more and are less subject to wind drift, thus depositing in the upper third of the plant, while smaller droplets, through the action of the wind, can break away from obstacles and reach the lower thirds.

Table 3. Breakdown of the interaction between tips and label position on the plant for the mean VMD values (μm)

		VMD		
		Lower	Average	Superior
Tips	JAC 80015	85.74 Aa	82.72 Aa	85.16 Aa
	JAC 8002	73.34 Ba	76.8 Ba	81.66 Ab
	Average	79.54	79.76	83.41
		NMD		
Volumes	120	81.28 aA	75.31 bB	82.50 aA
	150	76.68 bA	81.81 aA	83.96 aA
	180	80.64 aA	82.17 aA	83.80 aA
	Average	79.53	79.76	83.42
		Volumes (L ha^{-1})		
		120	150	180
Tips	JAC 80015	67.40 aA	68.82 aA	68.83 aA
	JAC 8002	64.70 aA	66.07 aA	66.01 aA
	Average	66.05	67.44	67.42

Averages followed by the same uppercase letter in the column and lowercase letter in the row do not differ statistically from each other, according to the Scott-Knott test, at 5% probability.

For NMD, when comparing the flow rates with the positions in the plant, it was found that only at the flow rate of 120 L ha^{-1} was there a difference for the middle third of the plant. When comparing the application volumes with the evaluated tips, it was found that even with the F Test being significant, for the Scott-Knott test there was no difference in the interactions, which should be in the sublevels of the variables presented (Table 2).

4. Discussion

There is greater difficulty in reaching the lower part of castor bean plants after their growth and vegetative development (Tormen et al., 2012). However, Raetano (2007) states that another important factor is that more pathogenic organisms begin their infection in the lower third of the plant, where, normally, the crop is less protected by applications of phytosanitary products. Some authors observed that fungicide deposition on the target increased as the spray volume increased, but no significant differences were found in droplet density between the spray volumes deposited in the upper parts of the canopy (Cunha et al., 2008; Prado et al., 2015).

In a research carried out by Negrisoni et al. (2019), analyzing the deposition of the spray mixture using different types of tips with different jets, it was concluded that in the middle and lower extracts of the soybean plant there was a reduction in the deposition when reducing the volume of the mixture. The VDM values in different positions of the plant are also related to the coverage and concentration of the dye, since drops smaller than $100 \mu\text{m}$ are subject to drift (Maciel, Teixeira, Fernandes, Zolnier, & Cecon, 2018; Ahmad et al., 2020).

The coverage had higher values in the upper part of the plant and lower in the lower part (Table 2). This fact is explained by the jet emitted by the sprayer coming from the top to the bottom of the plant. The leaf area interfered so that the drops arriving at the top of the plant had difficulty penetrating the canopy and settling in the lower layers. In a research carried out by Sousa Júnior et al. (2017), studying the application in coffee plants, they observed that, in the innermost parts of the plant, there was a reduction in the percentage of coverage, and the authors also highlighted the difficulty of penetration of the drops altered by the leaf area present in coffee plants. Negrisoni et al. (2019), evaluating different spray tips in soybean crops, found that in the upper extract there was no difference in the deposition of the spray regardless of the shape of the jets, in agreement with the present study.

As the application coverage was greater in the upper part of the plant, the concentration affected by the spray tips according to their VDM and NMD followed this trend, that is, in the upper part there was a greater concentration in the middle and lower parts of the canopy, no statistical differences were observed. The leaf area to be crossed to reach the middle and lower layers are obstacles considered in several studies, such as in tomatoes in protected environments (Sánchez-Hermosilla, Pérez, Rincón, & Carvajal, 2013; Llop et al., 2015b), where in these cases, in extreme situations, the relative deposition of product was only 6.8% in the lower regions (Braekman et al., 2010). This behavior highlights the importance of developing equipment that provides better penetration of the product inside the canopy, in order to contribute mainly to the control of pests and diseases in these locations (Sánchez-Hermosilla, Rincón, Pérez, Agüera, & Carvajal, 2011; Llop et al., 2015a).

Vitória and Campanharo (2016) state that droplets with VDM values smaller than 100 μm are more subject to drift. Quirino, Teixeira, Fernandes, & Ferreira (2013) report that droplets with diameters larger than 400 μm are considered very thick. According to Baesso, Teixeira, Ruas, & Baesso (2014), thick droplets larger than 400 μm are less influenced by the wind and, therefore, are less problematic to reach the target. This trend corroborates the results found in this study, since the VDM was lower in the middle and upper thirds of the plant. Bayer et al. (2012) demonstrated that low values of Numerical Mean Diameter (NMD) are closely related to drift, since dividing the droplet diameter arithmetically, this parameter demonstrates that large quantities of fine droplets were generated, reiterating that the greater the NMD of the droplets generated by spray nozzles, the lower the percentage of droplets with a size of 100 microns, consequently the lower their drift.

An assertive choice of tips and application volumes is necessary so that the applied product reaches specific parts of the plant canopy. According to Raetano (2019), the decision-making for choosing the correct application technology, such as droplet spectrum, spray tip model and spray volume, must be initially considered based on the mode of action of the phytosanitary product and the type of target to be reached.

Thus, the present study identified that under the conditions of this experiment, the JAC 80015 tip presented higher values of VDM, NMD and coverage. Also, the application volume only changed the NMD of the JAC 80015 nozzle, and the applied volume did not present a difference in the VDM in the upper and lower parts of the crop. Regarding the application position in the plant, the upper third presented the highest average values of VDM, coverage and product concentration.

5. Conclusions

The JAC 80015 and JAC 8002 tips significantly influence DMV, DMN and product deposition in castor bean crops. The application volume only changed the DMN when the droplet spectrum was verified in the middle third of the plant.

Regarding the application position in the plant, the upper third showed the highest average values for DMV, coverage and product concentration.

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Authors contributions

Prof. Cristiane F. Lisboa was responsible for data collection, statistical analysis, writing the original manuscript and reviewing the translation. Prof. Túlio de A. Machado was responsible for writing the original manuscript and reviewing the final manuscript. Prof. Elton F. dos Reis, Prof. Lilian L. Costa, Camilla S. da Silva, Prof. Ana Paula de F. Coelho and Mr Jefferson de S. Patriarca were responsible for reviewing the final manuscript. And MSc Ailyn de O. Vilela was responsible for translation of the original article and review of the final article.

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