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Use of the test bench for spray drift assessment under subtropical climate conditions[1]

Uso do test bench para avaliação da deriva de pulverização em condições climáticas subtropicais

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HIGHLIGHTS:
In regions with a subtropical climate, bench testing can be used to verify the drift potential.
High temperatures, low relative humidities, higher working pressures, and higher wind speeds lead to greater potential for drift.
Variations in the height of the spray boom did not show any changes in the drift potential.

ABSTRACT: As an alternative to the International Organization for Standardization (ISO) method 22866, a method for the field measurement of spray drift was developed in the Department of Agricultural, Forestry and Environmental Economics and Engineering of the University of Turin, Italy. This new method, termed “test bench,” can be applied for wind conditions beyond those covered in ISO 22866. The aim of this study was to quantify the drift potential of three nozzles at two working pressures and two sprayer boom heights using the test bench method, under subtropical climate conditions. The experiment was conducted at Bandeirantes, Paraná State, Brazil, from 2018 to 2019 in a completely randomized design with 12 treatments, wherein three nozzles were used at the minimum and maximum working pressures, and two boom heights were tested, with four replicates for each combination. The following nozzles were used: XR11002 (100 and 400 kPa), AIXR11002 (100 and 600 kPa), and ATR 2.0 (400 and 2000 kPa), operating at boom heights of 0.50 and 1.00 m. The test bench method allows for drift assessment under subtropical climate conditions, and the results revealed that changes in meteorological conditions, nozzles, and pressure are key factors affecting the drift potential of boom sprayers. Relative air humidity and working pressure were the most important determining factors of the drift potential of the nozzles, whereas boom height had no effect on drift potential.

Key words: spraying technologies, nozzles, agrometeorological conditions

RESUMO: Uma metodologia alternativa ao método da ISO 22866, para medir deriva em campo foi desenvolvida no Departamento de Agricultura, Silvicultura, e Economia e Engenharia Ambiental da Universidade de Turin, Itália. Este novo método, denominado de “test bench”, pode ser aplicado para condições de vento diferentes daquelas possíveis na ISO 22866. O objetivo deste estudo foi quantificar o potencial de deriva de três pontas de pulverização em duas pressões de trabalho e duas alturas da barra de pulverização utilizando o método test bench em condições de clima subtropical. O trabalho foi realizado em Bandeirantes, PR, entre 2018 e 2019 em delineamento inteiramente casualizado com 12 tratamentos, constituídos de três pontas de pulverização, as quais foram usadas nas pressões de trabalho mínima e máxima e duas alturas da barra de pulverização com quatro repetições. As pontas utilizadas foram XR11002 (100 e 400 kPa), AIXR11002 (100 e 600 kPa) e ATR 2.0 (400 e 2000 kPa), operando nas alturas da barra de pulverização de 0,50 e 1,00 m. O test bench possibilita avaliar a deriva nas condições climáticas subtropicais, evidenciando que as alterações nas condições meteorológicas, pontas e pressão são decisivas no potencial de deriva de pulverizadores de barra. A umidade relativa do ar e a pressão de trabalho foram os fatores mais determinantes no potencial de deriva das pontas de pulverização, enquanto a altura da barra de pulverização não influenciou no potencial de deriva.

Palavras-chave: tecnologias de pulverização, pontas de pulverização, condições agrometeorológicas

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Introduction

Spray drift is a complex process that is affected by various factors, including wind speed and direction (Kruger & Antuniassi, 2019; Wang et al., 2020), air temperature (Bish et al., 2019), relative air humidity (Maciel et al., 2017), physicochemical properties of the spray solution (Liu et al., 2021), the droplet spectrum (Vieira et al., 2018), and the development stage and sensitivity of the crop (Holterman et al., 2017).

Drift potential was quantified using laboratory and field methods. The standardized protocol, ISO 22866, is typically used for direct field drift measurements, but its application is complex and time-consuming (Gil et al., 2018).

To overcome these limitations, researchers at the University of Turin (Department of Agricultural, Forestry and Environmental Economics and Engineering (DEIAFA)) developed a method termed "test bench" (Balsari et al., 2007), which was officially adopted by the International Organization for Standardization (ISO)/Final Draft International Standard (FDIS) 22369-3 (2011) as a reference for field measurements of spray drift. The test bench method is applicable for quantifying potential drift under temperate climate conditions with well-defined seasons; therefore, it is a simple and quick alternative for determining and classifying the drift potential of boom sprayers and warrants further investigation (Balsari et al., 2019), particularly in fields under subtropical climate conditions.

The aim of this study was to quantify the drift potential of three nozzles at two working pressures and two sprayer boom heights under subtropical climate conditions using the test bench method.

Material and Methods

The study was conducted from 2018 to 2019 at the laboratory of the Center for Research in Pesticide Application and Agricultural Machinery Technology (NITEC) at the State University of Northern Paraná, Paraná State, Brazil, located at 23° 06' 36" S and 50° 22' 03" W, at an altitude of 420 m. According to the Köppen climate classification, the climate type is Cfa, representing a humid, subtropical, mesothermal climate with hot summers and dry winters, with an average precipitation of 30 mm in the driest month and a low frequency of frosts (Reis et al., 2010), average precipitation between 1330-1600 mm, and an average air temperature of 20-22 °C (Alvares et al., 2013).

The study was performed in a completely randomized design with 12 treatment combinations to test three nozzles, two working pressures, and two boom heights, with four replicates for each combination. Each replicate was considered unique (an independent measurement), as the meteorological conditions changed constantly during the tests. The nozzles used in this study were the widely used XR11002® flat fan nozzles (100 and 400 kPa), AIXR11002® air-induction flat fan nozzles (100 and 600 kPa), and ATR 2.0® hollow cone nozzles (400 and 2000 kPa). The nozzles were used at the minimum and maximum working pressures and operated at boom heights of 0.50 and 1.00 m above the test bench. The tests were normalized at a speed of 1.53 m s^{-1}. The treatments, along with the characteristics and settings of the nozzles, are presented in Table 1.

The experiment was performed using a plot sprayer (Agrale 4100) with adaptations, such as a 50 L tank, a CJ 42A pressure gauge with a quick-release valve, a JP42 pump, 13 anti-drip nozzles, and a 7-m-long boom.

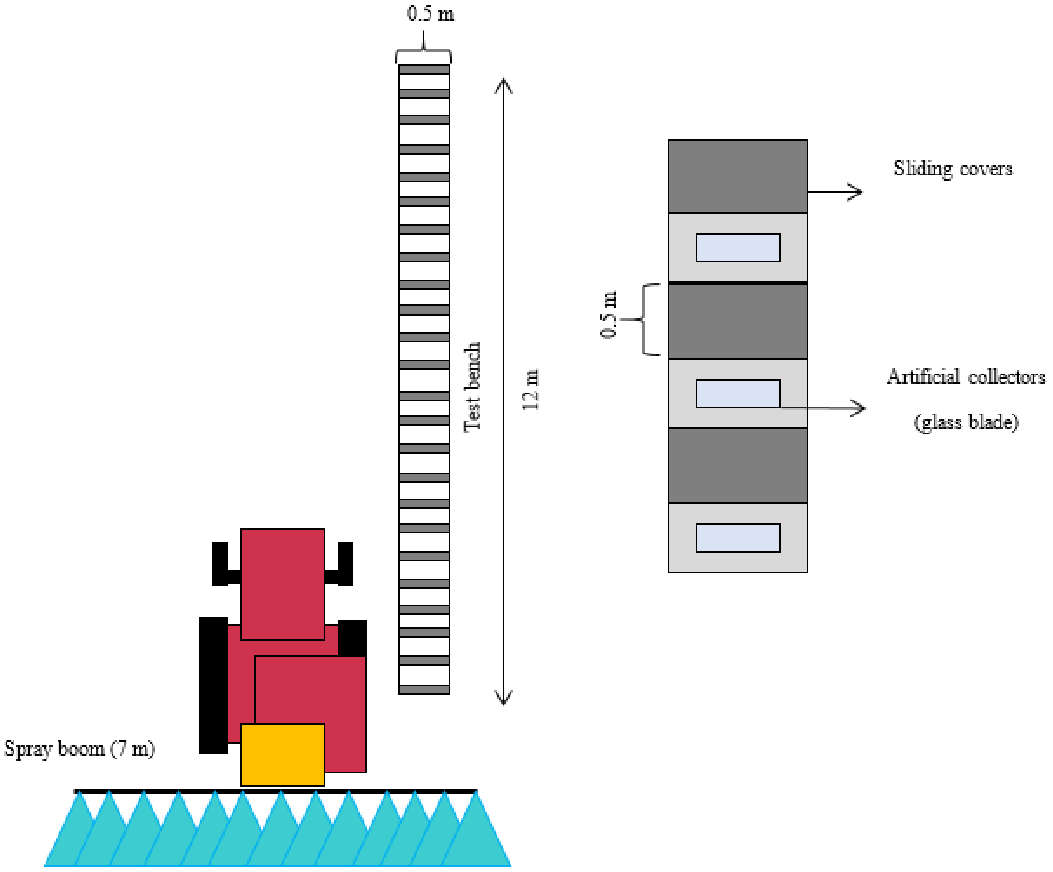
Samples were collected using a 12 × 0.5 m stainless steel test bench with spaces (slits) for collectors (0.10 × 0.20 m glass slides) at 0.5 m intervals (Figure 1). The 12-m-long stainless-steel test bench was placed at the center of the bar on the right side of the sprayer, 1.5 m from the tractor shaft, in alignment with the midpoint on the right side of the bar, maintaining a NW-SE position (Gil et al., 2014), and the wind direction was maintained in a range from 0° to 40° to the test bench. The collectors were placed 0.30 m above the ground, as recommended in ISO (2014). The height of the sprayer boom was adjusted prior to each treatment.

Each space (slit) on the test bench was equipped with a sliding cover to be able to cover and uncover the collectors as needed. Collectors were placed on top of the first and last sliding covers and remained uncovered throughout the experiment to determine the actual amount of spray that occurred during each independent measurement (Figures 2A and B).

Spraying was performed only on the right side of the bar on the test bench. The sprayed solution contained the marker Brilliant Blue (FCF-INS 133, 11%; Duas Rodas®) at a concentration of 6 g L^{-1}.

Table 1. Description of treatment combinations with different nozzles, working pressures, and sprayer boom heights

Treatment	Nozzle	Model	Pressure (kPa)	Boom height (m)	Flow rate (L min^{-1})	Application rate (L ha^{-1})
1	XR11002	Flat fan nozzle	100	0.5	0.46	100
2	XR11002		400	0.5	0.91	200
3	XR11002		100	1.0	0.46	100
4	XR11002		400	1.0	0.91	200
5	AIXR11002	Air-induction flat fan nozzle	100	0.5	0.46	100
6	AIXR11002		600	0.5	1.12	245
7	AIXR11002		100	1.0	0.46	100
8	AIXR11002		600	1.0	1.12	245
9	ATR 2.0	Hollow cone nozzle	400	0.5	0.65	141
10	ATR 2.0		2000	0.5	1.44	315
11	ATR 2.0		400	1.0	0.65	141
12	ATR 2.0		2000	1.0	1.44	315



The wind direction was maintained in the range of 0- 40° on the test bench

Figure 1. Schematic representation of the positions of the tractor, test bench, and collectors on the test bench during the experiments

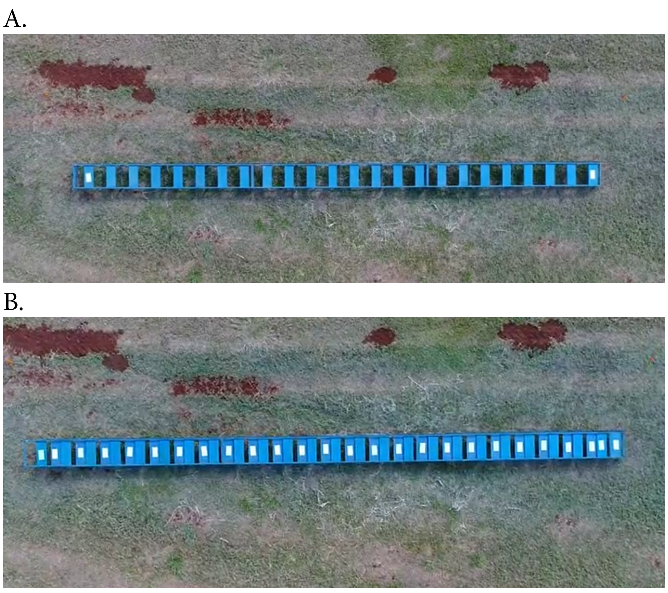


Figure 2. Test benches with all collectors covered, except for the first and last, for the entire duration (A), and test benches with collectors uncovered (opened) to collect spray (B)

The spray travelled 20 m before reaching the test bench, and another 20 m past the edge of the test bench, resulting in a total spray length of 52 m. After the spray passed over the edge of the test bench and reached a point exactly 2 m beyond the last covered collector, the glass plates were uncovered to collect any droplets suspended in the air. Droplets were collected 60 s after the system was opened.

To quantify the deposited droplets, glass plates were placed in dry plastic jars with lids, washed with 70 mL of distilled water, and shaken to remove all the colored marker. The solution was then placed in a 100 mL plastic container, and absorbance was determined using a spectrophotometer (630 nm wavelength) (model 600 S; Femto®).

By constructing a standard curve (with 18 known concentrations of the mixture and their respective absorbance values), a linear equation (y = b + ax) was used to calculate the concentration of the dye (mg L^{-1}) as a function of the absorbance of each sample. From the concentration values, the volume of the mixture collected at the targets (in μL) was calculated using Eq. 1.

$$V_i = \frac{C_f \cdot V_f}{C_i} \times 1000 \qquad (1)$$

where:

V_i - volume collected at the target (μL);

C_i - concentration of the dye in the mixture (6 g L^{-1});

C_f - concentration of the dye (mg L^{-1}) detected by the spectrophotometer, which was calculated using a linear equation; and,

V_f - volume of water used to wash the target (70 mL).

The volume collected at the target was divided by the area of the target (cm^2) to determine the deposited volume per unit area (μL cm^{-2}), which is termed the effective and/or absolute deposition.

The drift potential (DP) was calculated using the individual volumes collected at the targets using Eq. 2:

$$DP(\%) = \sum_{n=0}^{24} \frac{D_i}{SDR} \times 100 \qquad (2)$$

where:

DP (%) - drift potential;
Di - individual volume collected at each target (μL);
n - number of collectors (24); and,
SDR - spray deposition reference (μL cm^{-2}).

During the experiment, wind speed and direction, temperature, and relative humidity of the air were determined and recorded continuously (every second) using the Arduino programming language, with a weather station positioned 5 m to the side of the test bench and at a height of 2.0 m from the soil surface.

The relations between meteorological variables (relative air humidity, air temperature, and wind speed) and spray factors (boom height, nozzles, and working pressure) and DP were assessed by multivariate analysis of hierarchical clustering (joining)). To this end, data standardization was adopted so that the attributes would contribute with similar weights toward calculating the coefficient of dissimilarity between them. The Euclidean distance (dAB) was selected as the measure of dissimilarity, because lower values indicate more-similar results between the different treatments. Ward's method was used as the grouping strategy, wherein groups are formed by seeking to minimize the sum of the differences between the elements of each group and the mean value of the group, thereby minimizing the standard deviation between the data of each group formed.

Results and Discussion

Table 2 outlines the treatments, which are clustered according to meteorological conditions, boom height, pressure, drift potential, and nozzle type in each experimental replicate. Groups 3 and 4 showed the highest drift potential (DP), with a mean DP of 154.2% (Group 3) and 133.2% (Group 4) for the ATR 2.0 hollow cone nozzle at a pressure of 2000 kPa.

Results of clustering analysis are shown in Figure 3. Group 1 included the treatment using the ATR 2.0 hollow cone nozzle with the lowest DP (27.6%) and the lowest working pressure (400 kPa).

Group 3 included the treatment conducted using ATR 2.0, which had the highest DP (154.2%) and the highest working pressure (2000 kPa). These results can be explained by the interference of agrometeorological and spraying conditions, as highlighted by the results for Groups 1 and 3 (Figure 3). In a study assessing the effects of meteorological conditions, Balsari et al. (2007) observed that the amount of spray droplets collected on plates was significantly lower at the highest temperatures and lowest relative air humidities.

Group 2 included treatments with XR11002 and AIXR11002 nozzles, both at a spray pressure of 100 kPa. The mean DP of this group was 42.9%, with relative air humidity of 61.5%, temperature of 31.2 °C, and wind speed of 0.4 m s^{-1}. The wind speed was low in this group because 33.3% of all replicates recorded wind speeds of zero. Even at a high temperature, the DP of Group 2 was lower than that of the other groups (excluding Group 1) because the AIXR11002 nozzles (100 kPa), which were used most often in Group 2 (in 66.7% of treatments), generated coarse to extremely coarse droplets, whereas the XR11002 tip (100 kPa) produced medium-coarse droplets, and the RH remained high (61.5%).

Meteorological variables were the determining factors for the formation of Group 2. The lowest DP was 20.3% and the highest was 60.3%, indicating a large range of this variable. The average wind direction recorded in Group 2 was not as uniform as that recorded in Group 1, and this factor affected the average DP. The performance of spray-drift-reducing technologies is generally determined through multiple replicate tests performed under similar conditions and subsequent pair-wise comparisons (Grella et al., 2019), and such tests are not easily replicated (Wang et al., 2022). The bench test makes it possible to optimize the operational time in field drift validation tests, which can minimize variations between replicate measurements for the same treatment.

A prior field analysis of the factors affecting drift and correlation analysis of the variables (relative air humidity, air temperature, and wind speed) revealed that low wind speeds and high relative air humidities decreased the amount of deposited droplets (Nuyttens et al., 2006). These authors further reported that, considering the correlation between air temperature and relative air humidity, a lower air temperature would also result in fewer deviations owing to the cumulative effect of relative air humidity.

Although Groups 3 and 4 had the same peak and working nozzle pressures, they were not combined owing to differences in the meteorological conditions. In Group 3, the mean temperature was 38.9 °C and the mean RH was 40.2%. In contrast, in Group 4, the mean temperature was 35 °C and the mean RH was 54.6%. An increase in temperature typically corresponds to a decrease in RH, which may indicate strong atmospheric instability, leading to losses due to convection in the atmosphere (Nuyttens, 2007).

When studying the evaporation potential of a sprayed liquid under different psychometric conditions, Maciel et al. (2017) found that relative air humidity had a stronger effect than air temperature on the evaporation potential. Evaporation has an indirect relationship with humidity and is directly related to the temperature.

Among the meteorological conditions that affect drift, wind is considered to be the most important because it directly affects the mass of the droplets produced by spraying. Groups 3 and 4 exhibited different wind speed values of 6.0 and 1.8 m s^{-1}, respectively. Wang et al. (2020) reported that the amount of drift increases with increasing wind speed.

The highest DP values were recorded in Groups 3 and 4, in which the highest working pressure (2000 kPa) was applied, indicating that increasing the pressure decreased the droplet size and increased the proportion of fine droplets. Droplet spectrum is also influenced by interactions between the physicochemical properties of the spray solution; however,

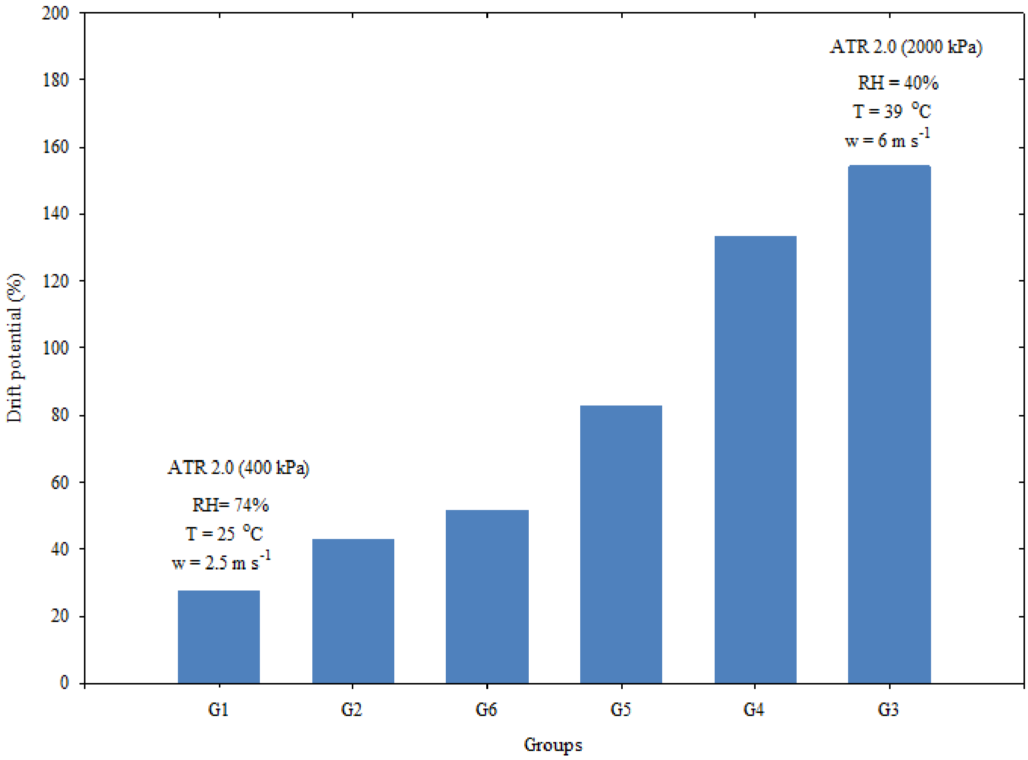
Table 2. Treatments/replicates, clustered by the study variables

Treatment/ Replicate	Height (m)	RH (%)	Temperature (°C)	Wind speed (m s^{-1})	Pressure (kPa)	DP (%)	Nozzle type
Group 1 (ATR 200 and 400 kPa) at 0.5 and 1.0 m boom height)							
11/3	1.0	63.8	28.8	3.8	400	33.5	ATR 2.0
11/2	1.0	68.1	27.6	3.2	400	31.7	ATR 2.0
11/1	1.0	71.7	26.4	2.6	400	32.2	ATR 2.0
9/4	0.5	77.1	24.7	1.7	400	22.2	ATR 2.0
9/3	0.5	77.9	24.4	1.8	400	28.4	ATR 2.0
9/2	0.5	79.1	23.8	1.9	400	22.5	ATR 2.0
9/1	0.5	80.0	23.4	2.5	400	22.7	ATR 2.0
Mean		74	25.6	2.5		27.6	
Group 2 (XR11002 and AIXR11002 at 100 kPa and 0.5 and 1.0 m boom height)							
5/3	0.5	60.7	30.4	0.3	100	35.8	AIXR11002
5/2	0.5	61.4	30.6	1.3	100	51.2	AIXR11002
5/4	0.5	62.7	30.1	0.0	100	32.4	AIXR11002
5/1	0.5	61.7	30.4	0.1	100	42.3	AIXR11002
7/4	1.0	60.3	30.8	0.1	100	57.4	AIXR11002
7/2	1.0	62.2	30.9	0.1	100	40.6	AIXR11002
3/4	1.0	59.3	32.3	1.1	100	60.3	XR11002
7/3	1.0	60.3	30.7	0.0	100	35.4	AIXR11002
7/1	1.0	61.8	31.0	0.1	100	48.0	AIXR11002
3/2	1.0	64.2	31.8	0.6	100	52.6	XR11002
3/3	1.0	63.3	31.8	0.8	100	31.8	XR11002
3/1	1.0	60.4	33.2	0.0	100	20.3	XR11002
Mean		61.5	31.2	0.4		42.9	
Group 3 (ATR at 2000 kPa and 1.0 m boom height)							
12/2	1.0	40.0	38.7	6.6	2000	244.0	ATR 2.0
12/4	1.0	40.1	39.1	5.9	2000	116.5	ATR 2.0
12/3	1.0	40.7	38.6	6.1	2000	144.8	ATR 2.0
12/1	1.0	39.9	38.9	5.5	2000	111.3	ATR 2.0
Mean		40.2	38.9	6.0		154.2	
Group 4 (ATR at 2000 kPa and 0.5 m boom height)							
10/4	0.5	47.8	37.6	2.3	2000	131.6	ATR 2.0
10/2	0.5	57.7	33.8	1.5	2000	98.5	ATR 2.0
10/3	0.5	55.7	34.5	1.5	2000	176.3	ATR 2.0
10/1	0.5	57.3	34.0	1.6	2000	126.2	ATR 2.0
Mean		54.6	35.0	1.8		133.2	
Group 5 (AIXR11002 at 600 kPa with 1.0 m boom height and XR11002 at 100 and 400 kPa with 0.5 m boom height)							
8/4	1.0	44.1	38.1	1.8	600	67.0	AIXR11002
2/4	0.5	44.5	39.0	1.9	400	112.4	XR11002
2/3	0.5	52.1	34.8	1.5	400	73.8	XR11002
8/1	1.0	32.9	44.4	2.8	600	64.1	AIXR11002
2/2	0.5	48.9	36.9	6.9	400	127.4	XR11002
1/4	0.5	39.4	40.8	8.7	100	62.9	XR11002
2/1	0.5	41.0	40.7	3.3	400	85.0	XR11002
1/3	0.5	39.1	42.4	3.1	100	75.3	XR11002
1/2	0.5	40.5	40.8	5.3	100	76.8	XR11002
Mean		42.5	39.8	3.9		82.7	
Group 6 (XR11002 and ATR at 400 kPa with 1.0 m boom height and AIXR11002 at 600 kPa with 0.5 m boom height)							
11/4	1.0	58.4	30.3	6.2	400	31.3	ATR 2.0
4/3	1.0	54.8	34.8	4.8	400	28.4	XR11002
4/2	1.0	58.9	33.3	5.1	400	41.4	XR11002
8/3	1.0	48.2	35.7	3.3	600	66.5	AIXR11002
8/2	1.0	48.9	35.8	4.3	600	65.5	AIXR11002
4/4	1.0	51.7	36.4	4.7	400	67.3	XR11002
4/1	1.0	58.7	33.3	3.4	400	48.1	XR11002
6/2	0.5	49.9	34.3	5.8	600	49.2	AIXR11002
6/4	0.5	43.8	37.9	4.4	600	50.5	AIXR11002
6/3	0.5	50.4	34.1	5.3	600	49.6	AIXR11002
6/1	0.5	46.9	35.2	4.7	600	48.7	AIXR11002
1/1	0.5	50.0	26.9	2.9	100	72.6	XR11002
Mean		51.7	34.0	4.6		51.6	

Height - Boom height; RH - Relative air humidity; Wind speed - Average wind speed; DP - Drift potential

it is primarily affected by the nozzle and its working pressure (Sijs & Bonn, 2020).

According to Xue et al. (2021), atmospheric conditions cause a significant loss of small droplets through evaporation because spray droplets continue to exchange mass and heat with the atmosphere during their spatial motion, leading to a reduction in droplet diameter and loss of product mass. Spatial droplet evaporation is controlled by diffusion and is mainly



RH - Relative air humidity; T - Air temperature; w - Wind speed; G - Group

Figure 3. Drift potential of the groups measured in the field using the test bench method

affected by droplet diameter, atmospheric temperature, and relative air humidity.

In Groups 5 and 6, pressures of 100 kPa, 400 kPa, and 600 kPa were applied in an alternating fashion. In Group 5, the XR11002 and AIXR11002 nozzles were used, with the XR11002 nozzles being used predominantly (for 77.7% of measurements), at a mean RH of 42.5%, a mean air temperature of 39.8 °C, wind speed of 14.1 m s^{-1}, and DP of 82.7%. In Group 6, the most-commonly used nozzle tip was the AIXR11002 (50%), followed by the XR11002 (41.66%) and the ATR 2.0 (8.33%). The mean meteorological conditions in Group 6 were as follows: 51.7% RH, 34 °C, 16.5 m s^{-1} wind speed, and 51.6% DP.

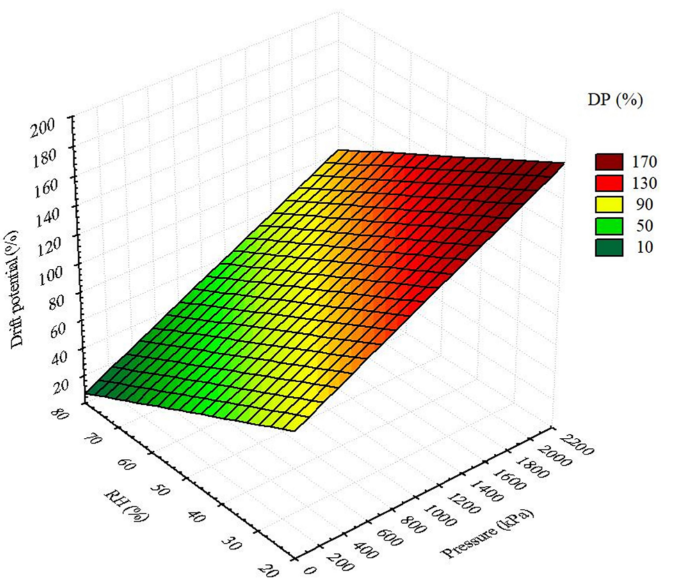
In field tests, meteorological conditions may cause variations in drift measurements, in particular temperature and humidity, which affect the evaporation rate and atmospheric stability of droplets. Wind speeds above 5 m s^{-1} may hamper such measurements (Donkersley & Nuyttens, 2011).

The DP increased with increasing spray pressure and decreased with increasing RH, as indicated by the correlation analysis. For this reason, multiple linear regression analysis was performed, resulting in fitted models for DP as a function of pressure (DP = 36.17 + 0.052*P), where all estimated coefficients were significant (F = 0.07; $p \leq 0.01$) with $R^2 = 0.58$.

According to the fitted models, spray pressure alone accounted for 58% of the variation in DP (%), and relative air humidity accounted for 11%, together accounting for 69% of the variation in DP (F = 0.32; $p \leq 0.05$). Combining these factors produced the fitted model DP = 115.22 + 0.044*P - 1.35*RH ($R^2 = 0.69$), wherein all estimated coefficients were significant ($p \leq 0.01$). An increase in pressure results in an increase in the percentage of droplets smaller than 100 μm in diameter, which are known as drift-sensitive droplets (Antuniassi et al., 2021).

Figure 4 shows the response surface of DP as a function of nozzle pressure and relative air humidity. Higher pressures and lower relative air humidities resulted in higher DP values.

DP (%) = 115.22 + 0.044 + P - 1.35 * RH



DP - Drift potential; P - Pressure; RH - Relative air humidity

Figure 4. Response surface of drift potential as a function of pressure and relative air humidity

Conclusions

1. The test bench method enables spray drift measurements on the field under subtropical climate conditions, and results indicated that meteorological conditions, nozzles, and working pressure are key factors that affect the drift potential of boom sprayers.

2. The relative air humidity and working pressure were the most-important factors in determining the drift potential of the ATR 2.0, XR11002, and AIXR11002 nozzles, whereas boom height had no effect on drift potential.

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