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Evaporation time of droplets containing thiamethoxam and adjuvants sprayed on sugarcane leaves[1]

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ABSTRACT

The spread and evaporation time of droplets deposited on the target affect the application efficiency of pesticides. This study aimed at evaluating the evaporation time of droplets with different sizes, under different levels of relative air humidity, containing thiamethoxam and adjuvants sprayed on sugarcane leaves. Data were collected in a climate chamber with controlled conditions, where a digital microscope was set up to record the droplet images. The evaporation time was evaluated considering three relative air humidity rates (45 %, 60 % and 75 %). For each condition, a completely randomized experiment was installed with five replications, in a 5 x 6 factorial design consisting of five sprays (water, thiamethoxam, thiamethoxam + mineral oil, thiamethoxam + vegetable oil and thiamethoxam + spreader) and six droplet diameters (337 µm, 424 µm, 486 µm, 576 µm, 831 µm and 985 µm). The evaporation time is directly and linearly related to the droplet diameter, with larger diameters requiring a longer time to evaporate. The evaporation time of droplets is also influenced by relative air humidity and spray composition. Among the adjuvants tested, the mineral oil provides the lower evaporation time for all droplet sizes.

KEY-WORDS: *Saccharum officinarum* L.; pesticide; droplet diameter.

RESUMO

Tempo de evaporação de gotas contendo tiametoxam e adjuvantes em folhas de cana-de-açúcar

O espalhamento e o tempo de evaporação de gotas depositadas sobre o alvo afetam a eficiência de aplicações de produtos fitossanitários. Objetivou-se avaliar o tempo de evaporação de gotas de diferentes tamanhos, sob diferentes condições de umidade relativa do ar, contendo tiametoxam e adjuvantes, em folhas de cana-de-açúcar. A coleta de dados foi efetuada em câmara climática de condições controladas, utilizando-se microscópio digital para análise de imagens. O tempo de evaporação foi avaliado em três umidades relativas (45 %, 60 % e 75 %). Para cada umidade, conduziu-se um experimento em delineamento inteiramente casualizado, com cinco repetições, em esquema fatorial 5 x 6, sendo cinco caldas (água, tiametoxam, tiametoxam + óleo mineral, tiametoxam + óleo vegetal e tiametoxam + espalhante) e seis diâmetros de gotas (337 µm, 424 µm, 486 µm, 576 µm, 831 µm e 985 µm). O tempo de evaporação está direta e linearmente relacionado com o diâmetro da gota, sendo que gotas de maiores diâmetros necessitam de mais tempo para evaporarem. A umidade relativa do ar e a composição da calda influenciam na evaporação das gotas, na superfície vegetal avaliada. Dentre os adjuvantes testados, o óleo mineral é o que proporciona menor tempo de evaporação para todos os tamanhos de gota.

PALAVRAS-CHAVE: *Saccharum officinarum* L.; agrotóxico; diâmetro de gota.

INTRODUCTION

Insecticide application on sugarcane crop (*Saccharum officinarum* L.) is a fundamental tool for high yield systems.

Thiamethoxam belongs to the neonicotinoid chemical group and is one of the most important active ingredients for sugarcane. However, its use has been questioned due to problems related to the exposure of non-target organisms to environmental contamination, demanding studies regarding its application technology.

The efficiency of the chemical control is related to the effective deposit of the pesticide and consequently the absorption of the active ingredient, which in turn is connected to the spread and evaporation time of the droplets deposited on the target (Vilela & Antuniassi 2013). A portion of the droplets to be sprayed will reach the target and another portion will be carried away by the wind, fall on the soil or evaporate.

The coverage and evaporation time of the droplets deposited on the target, as well as the environmental conditions, are some of the

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factors that influence the absorption of the active ingredient. If any of these factors is not adequate at the moment of application, the control might be inefficient. Therefore, it is essential to know the spray composition, the droplet spectrum and the type of target to be reached, even for systemic products, such as thiamethoxam, which require equally good distribution along the canopy (Boller et al. 2007).

Adjuvants are products that alter the physicochemical characteristics of the spray, improving its application and reducing losses. However, different adjuvants do not act similarly and can promote either isolated or joint improvements. Some of these compounds have properties that can reduce losses due to evaporation (Yu et al. 2009b, Xu et al. 2010). Studies conducted by Zhu et al. (2008) show a reduction in the evaporation time, when the surfactant alkyl polyoxymethylene is combined with the imidacloprid and dinotefuran insecticides. On the other hand, the addition of a drift-reducing adjuvant has the opposite effect, increasing the evaporation time.

Another important factor in the deposition and maintenance of the liquid film on leaves is related to the droplet spectrum generated in the spray. The diameter of the droplets directly influences the coverage and therefore the biological efficacy of the product, since it impacts displacement (drift), penetration into the leaf and evaporation of the spray (Queiroz 2009, Xu et al. 2010). The fragmentation of the liquid into smaller droplets increases the surface exposed, what contributes to greater evaporation, mainly under low relative air humidity, since the speed of evaporation is greater in dryer environments (Xu et al. 2010).

The weather conditions have a direct relation to the success of the spraying. In the majority of cases, applications should be avoided when the relative air humidity is lower than 50 % and temperature is higher than 30 ºC. Ramsey et al. (2006) observed that the relative air humidity has a great effect on foliar pesticide applications, mainly on the cuticle of the plant and also on the evaporation and deposition of droplets. Zhu et al. (2008) evaluated the evaporation time of droplets deposited on non-lipophilic surfaces under different relative air humidity conditions, evidencing that a reduction of 30 % in relative air humidity caused an average reduction of 34 % in the evaporation time of droplets.

Considering the tropical weather conditions, studies on pesticide application technology which deal with aspects related to evaporation of droplets caused by different types of spray compositions, including the interactions with adjuvants, are still scarce and deserve attention. Spray compositions generate different behaviors in terms of evaporation time of droplets, being necessary to know the results from each spray, specifically for thiamethoxam.

Therefore, this study aimed at evaluating the evaporation time of droplets containing thiamethoxam associated with adjuvants after being deposited on sugarcane leaves, under different relative air humidity conditions.

MATERIAL AND METHODS

The assays were carried out at the Universidade Federal de Uberlândia, in Uberlândia, Minas Gerais State, Brazil, in 2014, and evaluations consisted of determining the evaporation time of droplets on lipophilic surfaces, corresponding to sugarcane leaves (*Saccharum officinarum* L., RB867515 cultivar), under three relative air humidity rates (45 %, 60 % and 75 %), based on the methodologies of Zhu et al. (2008) and Vilela & Antuniassi (2013).

For each humidity rate, a completely randomized experiment with five replications was conducted in a 5 x 6 factorial design, consisting of five spray compositions (water, insecticide, insecticide + mineral oil, insecticide + vegetable oil and insecticide + surfactant) and six droplet diameters (337 μm, 424 μm, 486 μm, 576 μm, 831 μm and 985 μm). The insecticide and adjuvants used, as well as their respective concentrations, are described at Table 1.

The sprays were individually prepared with distilled water, a few minutes before being used. Spray solutions were accommodated in a 100 mL volumetric balloon for agitation before utilization, in order to avoid incompatibility and instability problems, such as precipitation or separation of phases.

The evaporation time of droplets was recorded in a climate chamber (Quimis, Q315C21), where it was possible to control the temperature and relative air humidity conditions. All evaluations were carried out at 25 ºC.

For the data collection, an image capture analysis was adopted. This system was composed of a digital microscope (Dino-Lite, AM413ZT) positioned perpendicularly to the surface, where the droplets were deposited. This is a piece of equipment with capacity to magnify up to 200 times, with a resolution

Table 1. Evaluated products and their respective concentrations.

Product	Concentration (commercial product)	Recommendation (manufacturer)	Concentration (% v/v; m/v^{+})
Thiamethoxam	250 g kg^{-1}	1,000 g ha^{-1}	0.40^{+}
Paraffinic mineral oil (aliphatic hydrocarbon)	428 g L^{-1}	0.50 L 100 L^{-1} mix	0.50
Vegetable oil (fatty acid esters)	930 g L^{-1}	0.50 L 100 L^{-1} mix	0.50
Surfactant (nonylphenol ethoxylate)	124.4 g L^{-1}	0.05 L 100 L^{-1} mix	0.05

of 1.3 mega pixels, through a USB interface. The software provided by the manufacturer (Dino Capture 2.0) allows obtaining images in real time.

The droplet sizes were 337 μm, 424 μm, 486 μm, 576 μm, 831 μm and 985 μm, which correspond to 0.02 μL, 0.04 μL, 0.06 μL, 0.1 μL, 0.3 μL and 0.5 μL of volume, respectively. The droplets were generated using a precision microsyringe adapted as a dispenser, with 0.5 μL of volumetric capacity and resolution of 0.01 μL (Hamilton, 7000.5C). The accuracy of the microsyringe was verified by weighing the droplets using a precision scale, as described by Vilela & Antuniassi (2013).

The evaporation time was computed as being the interval between the exact moment of the droplet deposition on sugarcane leaves and its complete extinction, calculated using the difference between the final and initial moments registered by the images captured by the digital microscope.

For statistical analysis, the assumptions of the data were initially tested using the SPSS software (SPSS 2008). The homogeneity of the variances and the normality of the residuals were verified by the Levene and Kolmogorov-Smirnov's tests, respectively. As the assumptions were not reached at 0.01, the data were transformed into $x^{0.5}$ and submitted to another analysis. The transformation corrected or improved at least one of the assumptions without harming the others. Afterwards, the same data were subjected to analysis of variance using the Sisvar software (Ferreira 2008). When significant differences were observed, the averages related to the sprays were compared among themselves using the Tukey's multiple comparison test, while the effect of droplet diameters was tested with a regression analysis, both at 0.05.

RESULTS AND DISCUSSION

There was observed a significant interaction ($p < 0.01$) between spray composition and droplet diameter, at 45 % relative air humidity (Table 2).

Water and thiamethoxam showed a similar evaporation time across droplet sizes, except at 486 μm and 576 μm. Thiamethoxam + vegetable oil and thiamethoxam + surfactant resulted in similar evaporation times when using droplets with smaller diameters (337 μm, 424 μm and 486 μm). On the other hand, thiamethoxam + mineral oil produced the shortest evaporation times for all droplets used.

Table 2. Evaporation time (s) of droplets from different spray compositions and diameters at 45 % relative air humidity (Uberlândia, Minas Gerais State, Brazil, 2015).

Spray	Droplet diameter (μm)					
	337	424	486	576	831	985
Water	34.60 a	48.00 a	25.00 b	99.60 a	156.00 b	226.00 a
Thiamethoxam	24.20 ab	39.60 ab	49.80 a	75.60 bc	144.60 b	244.00 a
Thiamethoxam + mineral oil	8.60 c	18.00 c	35.00 b	52.20 d	83.00 c	96.80 c
Thiamethoxam + vegetable oil	20.80 b	34.60 b	51.60 a	93.20 ab	152.80 b	195.80 b
Thiamethoxam + surfactant	22.60 b	36.60 ab	49.00 a	74.60 c	184.80 a	225.00 a
CV (%)	6.52					
F_{spray}	128.090**					
$F_{droplet}$	1,072.709**					
$F_{interaction}$	14.362**					

Averages followed by different letters in the column differ among themselves by the Tukey's test ($\alpha = 0.05$). F_{spray}, $F_{droplet}$ and $F_{interaction}$: values of F calculated for each spray, droplet diameter and interaction between spray and diameter, respectively. ** Significant at 0.01.

Some compounds have properties that can reduce loss due to evaporation. Studies conducted by Zhu et al. (2008) showed that a reduction in evaporation time occurred when a surfactant was added to the spray composition of an insecticide, as opposed to the addition of a drift reducing, which increased the evaporation time.

Water droplets emulsified with oil evaporated more slowly, as oils reduce the evaporation of water (Kissmann 1998). However, it must be considered that the process of evaporation on the surface is more complex than evaporation in the air, because it also involves droplet spread. Mineral oil reduces the surface tension, what increases the wetted area, making the droplets more exposed to evaporation. Lower surface tension enlarges the contact area with the leaf, increasing the evaporation rate.

In general, the greater the lifespan of the droplet the better is the condition for absorption of the active ingredient. After the evaporation of the droplets fixed on the foliar surface, there might be no more absorption of the product applied (Ramsey et al. 2005). After evaporation, crystals containing the active ingredient can be formed, preventing its absorption (Yu et al. 2009b, Xu et al. 2011). By increasing the evaporation time, the pesticide efficacy can be improved (Ramsey et al. 2006). Nevertheless, the product runoff needs to be evaluated (Yu et al. 2009a), mainly when higher carrier volumes are used.

Similarly, a significant interaction ($p < 0.01$) between spray composition and droplet diameter was also observed at 60 % relative air humidity (Table 3). Furthermore, the evaporation times of all the sprays rose in relation to the 45 % relative air humidity. This was already expected, as there is more water in environments with higher air humidity. Thus, the equilibrium point between the liquid and gaseous phases is closer, representing a smaller tendency for liquids to pass into the gaseous phase.

For 424 μm and 486 μm droplet diameters, similar evaporation times across all sprays, including water, were observed, except for thiamethoxam + mineral oil. For the other diameters, the sprays containing adjuvants reduced the evaporation time of the droplets, when compared to water, except for the surfactant applied at 985 μm. Again, droplets from the thiamethoxam + mineral oil evaporated more quickly, ranging between 14 s and 165 s. This result can be explained by the lower surface tension provided by the solution with mineral oil.

The greatest evaporation times were observed under higher humidity conditions (75 %), when compared to the other levels of air humidity tested (Table 4). At 75 % relative air humidity, the droplets evaporated more slowly, due to the humidity being closer to their saturation point. In some cases, the evaporation times at 75 % were almost three times higher than at 45 %.

In general, pesticide applications under higher relative air humidity conditions are recommended, due to the fact that it improves the efficiency of the application by keeping the droplet in contact with the target for a longer time (Yu et al. 2009c).

The evaporation pattern of the sprays at 75 % relative air humidity remained similar to the lower humidity levels (Table 4). At the smallest diameter (337 μm), only the spray with surfactant

Table 3. Evaporation time (s) of droplets from different spray compositions and diameters at 60 % relative air humidity (Uberlândia, Minas Gerais State, Brazil, 2015).

Spray	Droplet diameter (μm)					
	337	424	486	576	831	985
Water	49.80 a	63.60 a	95.00 a	173.00 a	345.20 a	418.00 a
Thiamethoxam	28.80 b	52.00 a	74.80 a	127.80 b	293.20 b	380.00 ab
Thiamethoxam + mineral oil	14.00 c	28.20 b	47.80 b	72.00 c	137.00 d	165.00 c
Thiamethoxam + vegetable oil	28.60 b	48.00 a	72.20 a	111.60 b	241.00 c	347.20 b
Thiamethoxam + surfactant	33.00 ab	50.00 a	82.20 a	117.60 b	253.00 bc	406.20 a
CV (%)	7.03					
F_{spray}	149.762**					
$F_{droplet}$	1,094.496**					
$F_{interaction}$	8.297**					

Averages followed by different letters in the column differ among themselves by the Tukey's test ($\alpha = 0.05$). F_{spray}, $F_{droplet}$ and $F_{interaction}$: values of F calculated for each spray, droplet diameter and interaction between spray and diameter, respectively. ** Significant at 0.01.

resulted in an evaporation time similar to the water and the insecticide thiamethoxam alone. When the diameter was increased to 424 µm and 486 µm, all the adjuvants, except for the mineral oil, produced droplets that evaporated at a similar rate, when compared to droplets containing only water and insecticide. When using larger droplet diameters (831 µm and 985 µm), all the sprays, including adjuvants and the insecticide alone, produced droplets that evaporated in less time, if compared to only water. The difference may result from the increased contact area on the leaf, due to the lower surface tension of the thiamethoxam solution. Thus, as observed for the humidity rates of 45 % and 60 %, thiamethoxam + mineral oil produced droplets with the shortest evaporation time.

As the droplet diameter factor was significant within spray composition at the three relative air humidities, a regression analysis was performed (Figures 1, 2 and 3). For all the sprays, a good

Table 4. Evaporation time (s) of droplets from different spray compositions and droplet diameters at 75 % relative air humidity (Uberlândia, Minas Gerais State, Brazil, 2015).

Spray	Droplet diameter (µm)					
	337	424	486	576	831	985
Water	61.60 a	75.60 a	113.80 a	246.60 a	534.60 a	610.00 a
Thiamethoxam	40.20 abc	85.20 a	131.60 a	222.60 a	396.80 b	528.20 b
Thiamethoxam + mineral oil	23.80 c	33.00 b	48.60 b	80.00 c	156.60 d	158.60 d
Thiamethoxam + vegetable oil	30.80 bc	77.80 a	99.00 a	143.60 b	348.80 bc	431.00 c
Thiamethoxam + surfactant	43.60 ab	83.80 a	124.80 a	144.20 b	335.60 c	465.20 bc
CV (%)	7.03					
F_{spray}	235.194**					
$F_{droplet}$	1,017.343**					
$F_{interaction}$	16.762**					

Averages followed by different letters in the column differ among themselves by the Tukey's test ($\alpha = 0.05$). F_{spray}, $F_{droplet}$ and $F_{interaction}$: values of F calculated for each spray, droplet diameter and interaction between spray and diameter, respectively. ** Significant at 0.01.

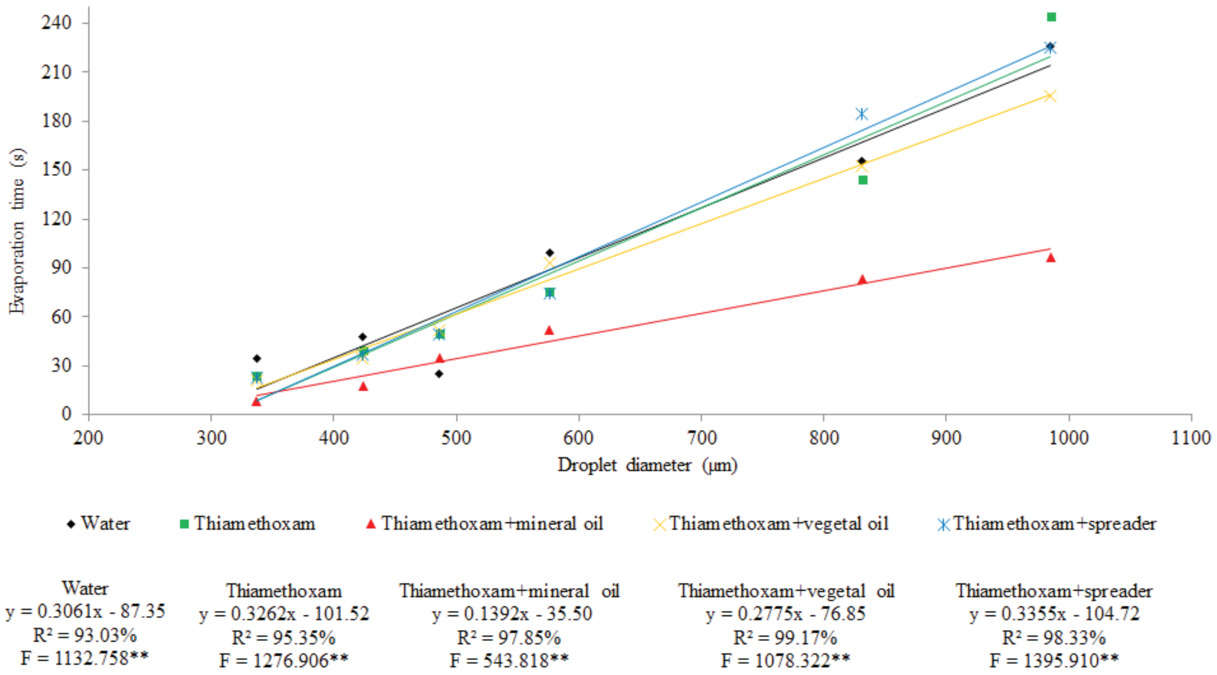

Figure 1. Evaporation time (s) according to the diameter of droplets for different spray compositions at 45 % relative air humidity (Uberlândia, Minas Gerais State, Brazil, 2015). ** Significant at 0.01.

adjustment was obtained with linear models, with coefficients of determination ranging from 93 % to 99 %. The evaporation time increased as the diameter of the droplets became larger. This was already expected, as droplets with greater volume need longer time to completely evaporate.

For all the relative air humidity conditions evaluated, thiamethoxam + mineral oil produced the lower increase rate of evaporation time as the droplet diameter was increased. For water at 45 % relative air humidity, an increment of 100 µm on droplet diameter increased the evaporation time by 31 s. On the other

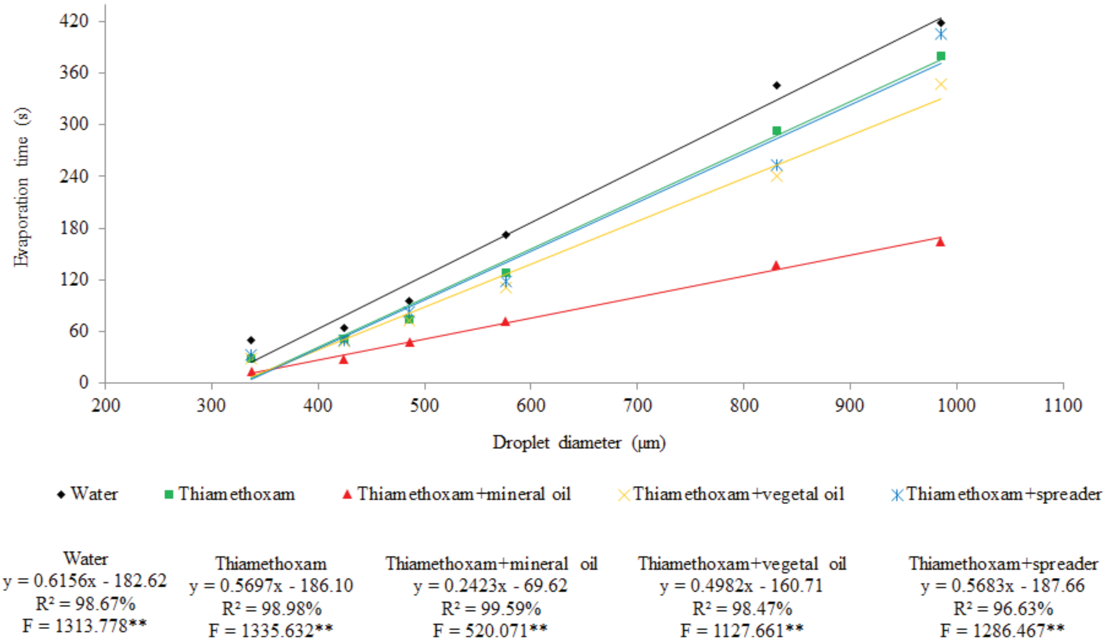

Figure 2. Evaporation time (s) according to the diameter of droplets for different spray compositions at 60 % relative air humidity (Uberlândia, Minas Gerais State, Brazil, 2015). ** Significant at 0.01.

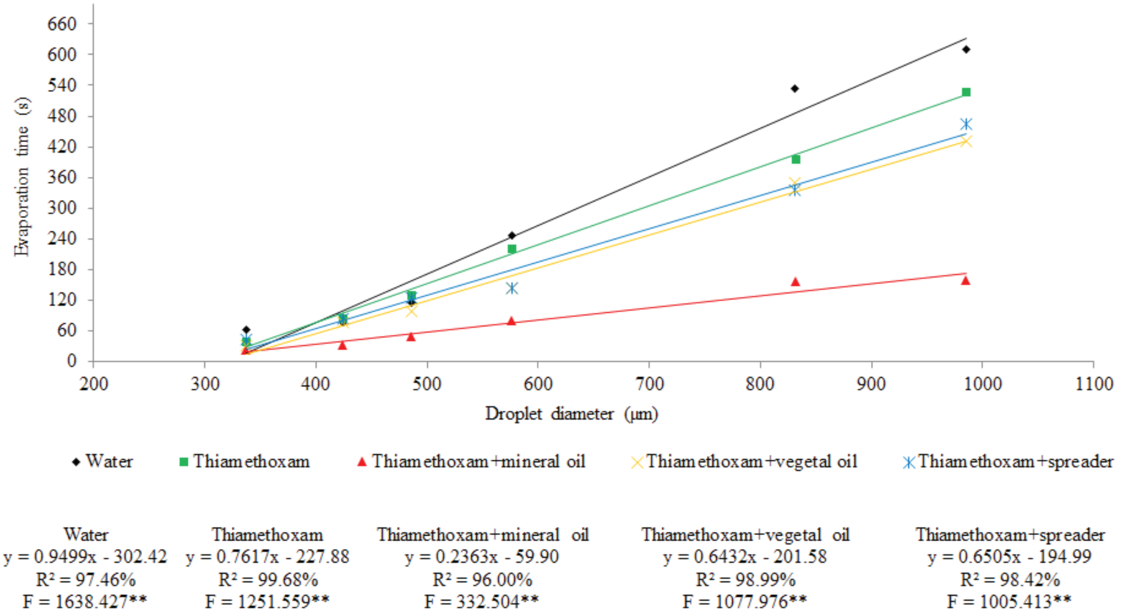

Figure 3. Evaporation time (s) according to the diameter of droplets for different spray compositions at 75 % relative air humidity (Uberlândia, Minas Gerais State, Brazil, 2014). ** Significant at 0.01.

hand, for the thiamethoxam + mineral oil, this same increment resulted in only 14 s.

As observed in this study, Vilela & Antuniassi (2013), evaluating the droplet evaporation of sprays containing the fungicide azoxystrobin + cyproconazole associated with adjuvants, observed that the droplet evaporation was also affected by relative air humidity and use of adjuvants. They also concluded that mineral oil resulted in less sensibility to variations of humidity. This could possibly be related to the spread factor of the droplet on the foliar surface. The reduction in surface tension increases the contact area between the droplet and the target, what facilitates the conditions to evaporation. Furthermore, another point to be considered is that mineral oil is not pure. It has only 42.8 % of mineral oil in its respective commercial product formulation, while the other 57.2 % are composed by inert substances not described by the manufacturer. These ingredients could also have contributed to the results observed.

The formulation of each emulsifiable oil varied greatly among the commercial products, since the manufacturing companies do not indicate the type of compound used as emulsifier on the label of the product; they only describe the proportion used. It is known that the type of emulsifier determines some of the physicochemical characteristics of the spray, such as superficial tension (Queiroz et al. 2008).

CONCLUSIONS

1. The relative air humidity and spray composition influence the evaporation time of droplets on the surface of sugarcane leaves.
2. The evaporation time is directly related to the droplet diameter, as larger droplets need more time to evaporate.
3. The mineral oil adjuvant associated with thiamethoxam decreases the evaporation time of the droplets on sugarcane leaves. Thus, the mineral oil may modify the absorption rate and therefore the efficiency of thiamethoxam.

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