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Sprayed liquid loss due to evaporation in different psychrometric conditions

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ABSTRACT

Low relative humidity and high air temperature are favorable conditions for droplet evaporation, and this may cause financial losses for the farmer due to poor pest control, and also cause environmental contamination. Thus, the aim of this work was to evaluate the effect of temperature and relative humidity on pesticides spraying, and to estimate the spraying losses by evaporation depending on air psychrometric conditions. The experiment was carried out inside of a climate chamber to control the temperature and relative humidity, and thus to obtain different vapor pressure deficits. This study used the nozzle Lurmark LD11002 operating at the pressure of 300 kPa and the liquid was tap water. The loss by evaporation was studied in a completely randomized design with twenty vapor pressure deficits and three replications. Even obeying the recommendations of climatic conditions for pesticides application, there are losses of liquid due to evaporation. For the nozzle LD 11002 and working pressure of 300 kPa, the loss of pesticides due to evaporation can reach about 27% under weather conditions characterized by low wind velocity, high air temperature and low relative humidity.

Key words: application technology; droplet evaporation; evaporation losses; spraying

Perda de líquido pulverizado por evaporação em diferentes condições psicrométricas

RESUMO

Baixas umidades relativas e altas temperaturas do ar são condições propícias à evaporação de gotas, e esta, além de causar grande prejuízo ao agricultor devido a um deficiente controle fitossanitário, também pode contaminar o ambiente. Deste modo, objetivou-se com este trabalho avaliar os efeitos da temperatura e umidade relativa na pulverização de agrotóxicos e estimar a perda da pulverização por evaporação em função das condições psicrométricas do ar. O experimento foi realizado dentro de uma câmara climática para controle da temperatura e umidade relativa e, assim, obtenção de diferentes déficits de pressão de saturação de vapor d’água no ar (DPV). Este estudo utilizou uma ponta Lurmark LD11002 operando na pressão de 300 kPa e o líquido foi água. A perda estimada de líquido por evaporação foi montada em delineamento inteiramente casualizado com vinte déficits de pressão de vapor e três repetições. Mesmo obedecendo às condições climáticas recomendadas para uma aplicação de agrotóxicos segura, houve perda de líquido pulverizado por evaporação. Para a ponta LD 11002 e pressão de trabalho de 300 kPa, a perda de agrotóxicos por evaporação pode alcançar aproximadamente 27% sob condições meteorológicas caracterizadas por baixa velocidade do vento, alta temperatura e baixa umidade relativa do ar.

Palavras-chave: tecnologia de aplicação; evaporação de gotas; perdas por evaporação; pulverização

Introduction

Droplets evaporation may cause financial losses for the farmer due to poor phytosanitary control, and it also may contaminate the environment and bring serious problems to the society.

Air conditions with low relative humidity and high temperatures make droplets evaporate in still air, losing all the diluent and creating very small particles of concentrated chemical which may be carried over much longer distances by air flows and contaminate the environment (Matthews, 2000; Tobi et al., 2011). So it is important to choose the best moment to spray at the field to avoid contaminations.

A greater droplet deposition on the target may be achieved in the morning time comparing to the afternoon time, when relative humidity and temperature are less favorable to pesticides application (Nascimento et al., 2012). However, due to Brazil's continental dimension the ideal time for spraying, considering the psychrometric conditions, varies for each agricultural region (Alvarenga et al., 2013). Thus, the ideal moment to spray must have air psychrometric conditions with air temperature between 15 and 30 °C and minimum air relative humidity of 55%. It should be also observed the wind speed, and it must be in the range from 3 to 7 km h^{-1} (Raetano, 2011).

Several researchers working with evaporation have used vapor pressure deficits (VPD) to define the air psychrometric conditions since the rate that water droplets evaporate depends almost entirely on the droplet diameter and on VPD between the droplet surface and the surrounding air (Arvidsson et al., 2011).

The VPD is the difference between the saturation vapor pressure and the actual vapor pressure, and these are directly related to the air relative humidity and temperature. The saturation vapor pressure depends on air temperature and as it increases, higher is the saturation vapor pressure. The actual vapor pressure depends on air relative humidity along with the saturation vapor pressure, and it increases increasing the relative humidity (Rodrigues et al., 2011; Vianello & Alves, 2012).

The additives present in pesticides added to the spray solution may reduce or not the time of droplet evaporation and it may influence the losses. Yu et al. (2009a) have not found significant influence of type and concentration of pesticides on water droplets evaporation time. However, Yu et al. (2009b) have found that water droplets had slightly increased the evaporation time comparing to insecticides droplets, what is because of surfactants which may be contained in insecticides. Surfactants increase the droplets spreading on surfaces and provide faster heat exchanges between the liquid film and the air; consequently, lower will be the evaporation time (Gimenes et al., 2013).

Noting the importance of evaporation on pesticides spraying, this work had as objective to evaluate the effect of temperature and relative humidity on pesticides spraying and to estimate sprayed liquid loss by evaporation as function of the air psychrometric conditions.

Material and Methods

The experiment was conducted in the Department of Agricultural Engineering, Universidade Federal de Viçosa, Campus Viçosa, Minas Gerais, Brazil.

For this experiment, a climate chamber was used to obtain the air psychrometric conditions used in this work. This chamber has a volume of 9.7 m^3 and the possibility to control the relative humidity ranging from 30 to 90% and air temperature from 0 to 40 °C.

The VPD was calculated from the Tetens equation (Rodrigues et al., 2011; Vianello & Alves, 2012), which is obtained by the difference between saturation vapor pressure (e_s) and actual vapor pressure (e). To calculate the e_s it was taken into consideration the air temperature value, according to the Eq. 1.

$$e_s = 6.1078(10)^{\frac{7.5t}{237.3+t}} \quad (1)$$

where:

e_s - saturation vapor pressure (hPa); and,
t - air temperature (°C).

Posteriorly, it was determined the value of e from the air relative humidity and the value of e_s.

$$e = \frac{RH\ e_s}{100} \quad (2)$$

where:

e - actual vapor pressure (hPa); and,
RH - air relative humidity (%).

Finally, it was obtained the VPD, as related previously, using the difference between e_s and e.

$$VPD = e_s - e \quad (3)$$

where:

VPD - vapor pressure deficit (hPa).

The air temperature and relative humidity conditions used to obtain the VPD were intentionally established to represent favorable and unfavorable situations to the pesticides spraying. Thus, temperature values of 20, 25, 30, 35 and 40 °C were combined with relative humidity values of 30, 50, 70 and 90% enabling the evaluation of sprayed liquid evaporation in twenty different VPD conditions (2.3, 3.2, 4.2, 5.6, 7.0, 7.4, 9.5, 11.7, 12.7, 15.8, 16.4, 16.9, 21.2, 22.1, 22.2, 28.1, 29.7, 36.9, 39.4 and 51.6 hPa).

For measuring the air psychrometric conditions inside the climatic chamber, it had been used humidity and temperature probes (HMP60 model, Vaisala) which the measuring ranges are between 0 and 100% and - 40 and + 60 °C, respectively. The analog signals of electric voltage of the two sensors were converted to digital signals by a microcontroller (Duemilanove ATmega328 model, Arduino), and then the digital signals were sent to a laptop with a serial system of data transmission.

The effect of air temperature and relative humidity on sprayed liquid evaporation was evaluated from the use of twenty different values of VPD, working pressure of 300 kPa and a spray nozzle (Lurmark LD11002 model, Hypro EU Ltd) which was located in the center of the climatic chamber and at 1 m above the ground. This climatic chamber has a volume of 9.7 m^3. The spray nozzle was installed in a constant pressure valve of 300 kPa (Figure 1). The liquid used for this experiment was tap water.

Previously to the beginning of the experiment, it was done the characterization of droplet spectrum of the spray nozzle using a laser particle analyzer (Spraytec model, Malvern Instruments Ltd) and five spray nozzles at 300 kPa of working pressure and height of 0.50 m, with 5 repetitions for each spray nozzle. The characterization was comprised by the following indicators: volume median diameter (VMD), diameter of droplet that below of this droplet 10% of the sprayed volume is found (Dv10), diameter of droplet that below of this droplet 90% of the sprayed volume is found (Dv90), SPAN (Cunha et. al, 2007), volume percentage made up of droplets finer than 100 μm (%V < 100), with diameter between 100 and 200 μm (100 < %V < 200), with diameter between 200 and 300 μm (200 < %V < 300), with diameter between 300 and 400 μm (300 <% V < 400), with diameter between 400 and 500 μm (400 < %V < 500), with diameter between 500 and 600 μm (500 < %V < 600) and, finally, coarser than 600 μm (%V < 600).

Figure 1. Experimental system built to estimate sprayed liquid loss by evaporation as function of the air psychrometric conditions. (A) spray nozzle; (B) constant pressure valve; (C) trays.

To determine the sprayed liquid loss due to evaporation, first of all it was obtained the mean evaporative efficiency for the experimental system. So, it was used three combinations of air temperature and relative humidity which provided the three highest VPD values (36.9, 39.4 and 51.6 hPa). The need to determine the mean evaporative efficiency using the highest VPD values is because at the lowest values the evaporation would be very low and it would be impossible to determine the evaporation for each VPD condition when using the methodology described at the next paragraph. Thus, to ensure more accurate values of evaporation, it was used the three highest VPD values to determine the mean evaporative efficiency for the experimental system, and then it was possible to estimate the liquid evaporation at each specific VPD, as described at Equation 8.

Thereby, after the stabilization of each air psychrometric condition, the spraying system was operated during 10 s. Subsequently to the stabilization after spraying, the liquid, that has not evaporated and has deposited in the trays placed below the spray nozzle, was weighted by a precision scale with a maximum capacity of 1500 g and resolution of 0.01 g (ARA520 model, OHAUS®). Previously to the performing of these steps, it was collected the sprayed liquid volume during the 10 s to know the total mass applied in the treatments. For all processes three repetitions were performed.

Thus, with the amount of sprayed liquid and collected liquid by the trays, it was possible to quantify the evaporated liquid for each repetition in these three VPD conditions:

$$m_{ev} = m_t - m_b \tag{4}$$

where:

m_{ev} - mass of evaporated water in the climate chamber (g);

m_t - mass of the total sprayed (g); and

m_b - mass deposited in the trays placed below the spray nozzle (g).

With value of mass of evaporated water, the evaporation efficiency in the experimental system was calculated by the equation:

$$\xi = \frac{\dfrac{m_{ev}}{V_c}}{\rho_{vs} - \rho_v} \tag{5}$$

where:

ξ - evaporation efficiency in the experimental system (%);

V_c - climate chamber volume (m^3);

ρ_{vs} - absolute density of water vapor saturation at wet bulb temperature (g m^{-3}); and

ρ_v - absolute density of water vapor for a specific condition of air temperature and relative humidity (g m^{-3}).

To calculate the variables ρ_{vs} and ρ_v, the following equations were used:

$$\rho_{vs} = \frac{216.68 e_s}{T_w} \quad (6)$$

where:
T_w - wet bulb temperature (K).

$$\rho_v = \frac{216.68 e}{T} \quad (7)$$

where:
T - air temperature (K).

After determining the mean evaporation efficiency (ξ_m) in the climate chamber from the three highest values of VPD, it was estimated the mass of evaporated liquid for all of the specified VPD using the equation:

$$m_{ev}' = \frac{v_c \xi_m \left(\rho_{vs} - \rho_v\right)}{100} \quad (8)$$

where:
$m_{ev'}$ - estimated mass of the evaporated liquid (g).

The climate chamber evaporative potential, that is the maximum amount of water vapor which the air may absorb for each treatment, was also calculated to be compared with the estimated mass of the evaporated liquid:

$$p_{ev} = v_c \left(\rho_{vs} - \rho_v\right) \quad (9)$$

where:
p_{ev} - chamber evaporative potential (g).

Finally, it was estimated the sprayed liquid loss due to evaporation by calculating the fraction of evaporated liquid:

$$F_{ev} = \frac{m_{ev}'}{v_t} \times 100 \quad (10)$$

where:
F_{ev} - fraction of evaporated liquid from the total sprayed for each treatment (%); and
v_t - amount of sprayed liquid (g).

Inside the climate chamber it was placed a small fan (VM20-01 model, Ventisol) with power of 14 W and paddle dimensions of 5.5 x 9.0 x 2.0 cm working at rotation of 2,400 rpm to promote the homogenization of air.

The pressure used in the experiment was obtained from a stationary sprayer (S-12 model, Yamaho) with rotation of 800 rpm, nominal flow rate of 12 L min^{-1}, power between 0.75 and 1.12 kW and maximum pressure of 3,516 kPa. This sprayer was driven by an electric motor (F56H model, Weg) with rotation of 3,570 rpm and power of 1.5 kW.

Statistical analysis for fraction of evaporated liquid was done in a completely randomized design with twenty treatments (twenty VPD) and three repetitions. Data were subjected to the regression analysis using the “t” test at 1% of probability.

Results and Discussion

The characterization of droplet spectrum which was produced by the spray nozzle Lurmark LD11002 is presented in Table 1.

Comparing the values obtained of Dv10, VMD and Dv90 with the reference graph of ANSI/ASAE S572.1 (2009) standard for nozzle tip classification, it is observed that all of these three parameters are within the range of fine droplets, so this nozzle tip has droplets classified as fine.

With the exception to the saturated environment, at all the others psychrometric conditions the environment has capacity to retain water vapor, i.e. the environment has the potential to evaporate water. The evaporation potential of the climate chamber used during the experiment is presented in Figure 2.

As shown in Figure 2, as the temperature increases and the relative humidity decreases the greater is the liquid evaporation potential by the environment.

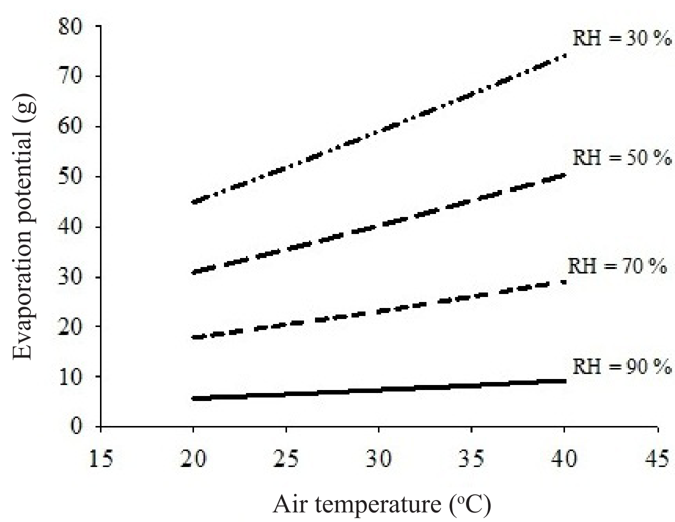

Figure 2. Water evaporation potential of the climate chamber as a function of temperature and distinct values of relative humidity (RH).

Table 1. Droplet spectrum of the spray nozzle Lurmark LD11002 in the working pressure of 300 kPa.

Dv10	DMV (µm)	Dv90	Span	%V < 100	100 < %V < 200
84	172	368	1,65	17,0	42,9
200 < %V < 300	**300 < %V < 400**	**400 < %V < 500**	**500 < %V < 600**	**%V > 600**	
22,2	10,2	4,6	1,9	1,2	

The evaporative potential of the environment at 90% of relative humidity ranged from 5.72 to 9.30 g of water vapor with an increase of temperature from 20 to 40 °C. For the environment at 70%, 50% and 30% of relative humidity, the evaporative potential raged, respectively, from 17.88 to 29.07 g, 30.91 to 50.34 and 44.92 to 74.20 g increasing the temperature from 20 to 40 °C. This modification of evaporative potential for different psychrometric conditions occurs because the relative humidity is the relation between the amount of water vapor existent in the air and the amount which would prevail in saturated conditions, at the same temperature (Zolnier, 1994). Thus, if the relative humidity is low, it means that there is little water vapor in the air; and when the temperature increases, higher is the capacity of this same air to contain water vapor (Santos et al., 2013).

Even with the climate chamber having a relatively high evaporative potential (74.20 g), i.e. high capacity to retain water vapor, the estimated amount of evaporated liquid was low, with the greatest evaporation of 23.7 g at the temperature of 40 °C and relative humidity of 30%, as it is presented in Figure 3. At the condition with temperature of 20 °C and relative humidity of 90%, which is considered a great condition for pesticides application due to its low evaporative potential, there was evaporation of 1.9 g, what is relatively very low. It shows that the exception to the condition with the air saturated by water vapor, the evaporation will occur in any other psychrometric condition, which may be significant or not (Figure 3).

In field studies, Balan et al. (2008) have found that the deposition resulting from spray nozzles which produce very fine and fine droplets decreases significantly as the temperature increases and the relative humidity decreases, what may have happened because of the evaporation losses. However, besides low air relative humidity provides a higher pesticides loss by evaporation, this condition can also speed up the evaporation. Yu et al. (2009a) have reported that the time for complete evaporation of droplets with diameter of 246 μm reduced 35 s by changing the relative humidity from 90% to 30%.

The percentage of sprayed volume lost due to evaporation as a function of VPD is presented in Figure 4. As it can be noted, as the VPD is increased higher is the percentage of sprayed volume lost due to evaporation reaching about 27% with the spray nozzle LD11002 at the working pressure of 300 kPa. However, the evaporation may reach values even higher with the use of pesticides with high vapor pressure, which may favor higher evaporations (Carlsen et al. 2006).

From the regression analysis it was adjusted a linear equation for the percentage of sprayed liquid loss as a function

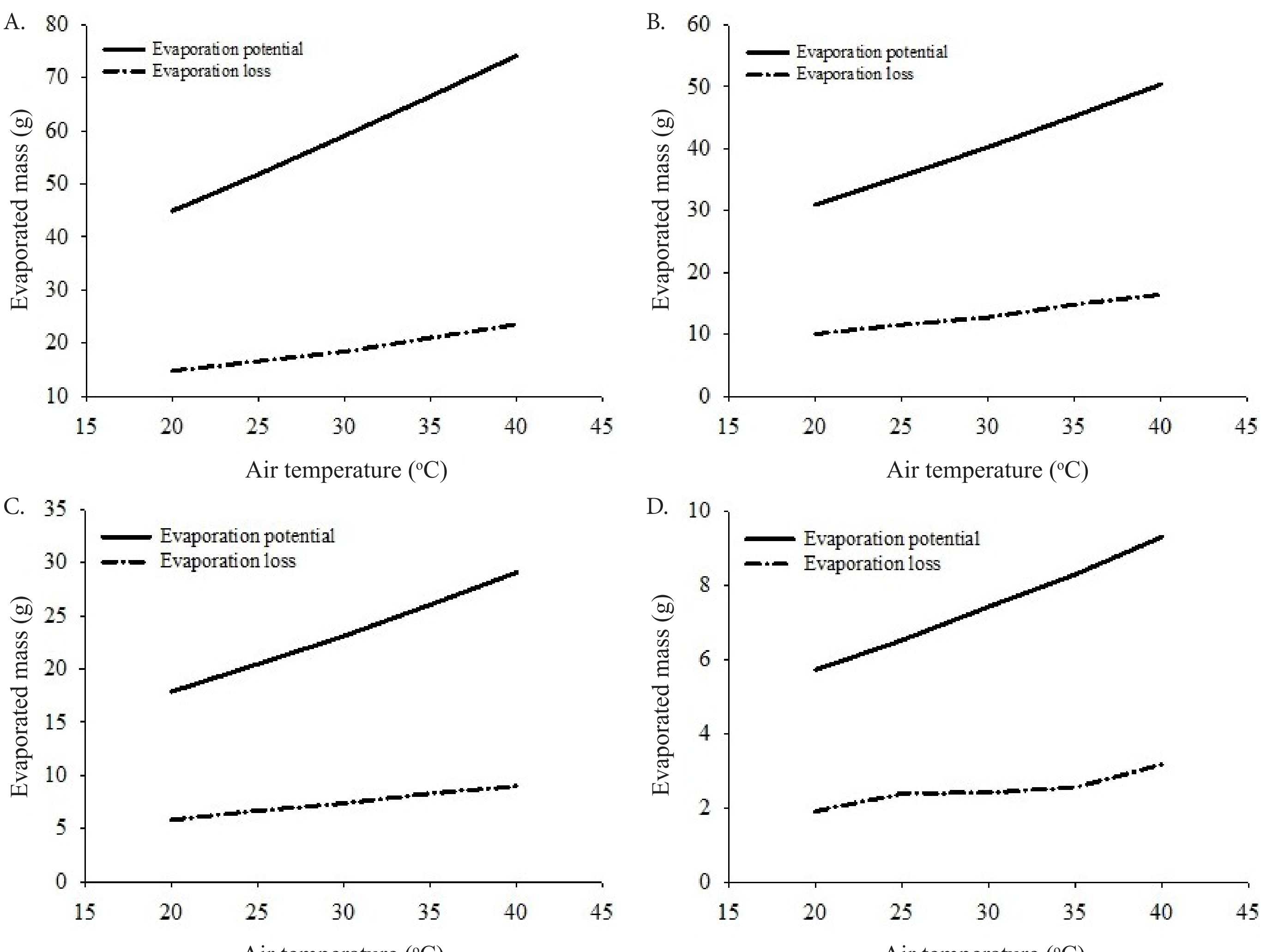

Figure 3. Evaporation potential of water inside the climate chamber and water loss by evaporation, which was determined based on the air enthalpy, as a function of temperature and distinct values of relative humidity. A. 30%; B. 50%; C. 70%; and D. 90%.

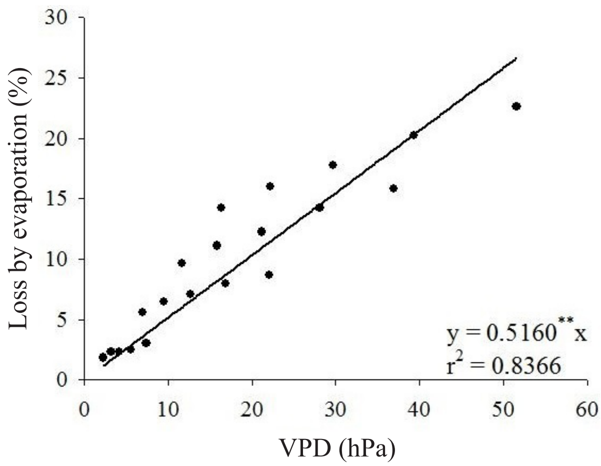

Figure 4. Relation between liquid percentage loss due to evaporation and vapor pressure deficit (VPD) by spraying using the spray nozzle LD11002 at the working pressure of 300 kPa.

of vapor pressure deficit. However, this model is limited to the methodology used in this work: VPD between 0.0 and 51.6 hPa, spray nozzle LD11002 which has VMD equals to 172 μm at the working pressure of 300 kPa and flow rate of 0.620 L min^{-1}. Although 2.3 hPa is the lower value used, the experiment was limited from 0.0 to 51.6 hPa because 0.0 hPa is too close to 2.3 hPa and it is physically impossible to have evaporation at this condition.

Considering 5% an acceptable loss due to evaporation, the pesticides spraying should not be done when the VPD is higher than 9.7 hPa, i.e. air temperature and relative humidity about 25 °C and 70%, respectively. Once this same VPD can be obtained by the combinations of others values of air temperature and relative humidity, and VPD is also what defines the air evaporative potential, the recommendations of ideal climate conditions for spraying should be done by using the values of VPD instead of values of air temperature and relative humidity. Thus, in order to avoid evaporation loss over than 5%, sprayings should be avoided when VPD is higher than 9.7 hPa. A way to avoid high evaporation losses, when the climate conditions is not the best, is using air induction spray nozzles (Arvidsson et al., 2011; Gil et al., 2014) or using spray nozzles with higher nominal flow rate (Nuyttens et al., 2009), which produce coarser droplets than the spray nozzle LD11002 and then the evaporation may be lower (Xu et al. 2010; Yu et al., 2009a; Yu et al., 2009b).

However, for the same VPD used in this experiment, in field conditions it is possible to have higher losses since the environmental conditions in this situation are more favorable to evaporate because there are constant air renovations surrounding the spraying boom, renovations that may be done by wind or air displacement caused by the advance of the sprayer. Chaim et al. (1999) have found losses up to 45% due to evaporation and drift in tomato pesticides application and these losses could be even higher using spray nozzles that produce finer droplets, once fine droplets are evaporated faster than coarser droplets.

Conclusions

Even obeying the recommendations of climate conditions for a safe pesticides application, there are sprayed liquid losses due to evaporation in these conditions.

For the spray nozzle LD11002 and working pressure of 300 kPa, the pesticides loss due to evaporation can reach about 27% under meteorological conditions characterized by low wind velocity, high temperature and low relative humidity, that characterize a VPD of 51.6 hPa.

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