(DOI): 10.5935/PAeT.V7.N1.08
This article is presented in English with abstracts in Spanish and Portuguese
Brazilian Journal of Applied Technology for Agricultural Science, Guarapuava-PR, v.7, n.1, p.71-79, 2014

Cientific Paper

Air and liquid volumetric distribution in vertical in a hydro-pneumatic sprayer

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Abstract

The objective of this research was to evaluate the air flow and spray vertical distribution produced by a hydro-pneumatic sprayer. The sprayer was attached to a John Deere tractor, model 5705. The rotation of the fan was set at 226.19 rad s^{-1} (2.160 rpm). The study was performed on both sides of the sprayer, with the intent of identifying possible asymmetries in the air flow distribution. Measurements of air speed were taken at three positions along the fan periphery. The uniformity of liquid vertical distribution was analyzed at pressures of 633, 844 and 1.055 kPa using a vertical collector placed two meters from the center of the fan impeller. The experiment was arranged in a randomized blocks design, with three replications. The air average speed, taken at the ventilation outlet was of 35.5 m s^{-1} and the average vertical speed taken at 0.5 meters from the bar was of 5.9 and 5.1 m s^{-1} to the left and right side, respectively. Variation coefficients for the vertical distribution volume were 136, 136 and 141% for the working pressures of 633, 844 and 1055 kPa, respectively.

Key-words: axial fan; air blast sprayer; vertical distribution of spray solution.

Distribuição volumétrica de ar e de líquido na vertical em pulverizador hidropneumático

Resumo

Objetivou-se com esta pesquisa avaliar o fluxo de ar e a distribuição vertical da calda produzido por pulverizador hidropneumático. O pulverizador foi acoplado a um trator John Deere, modelo 5705. A rotação do rotor do ventilador foi de 226,19 rad s^{-1} (2.160 rpm). O estudo foi realizado objetivando determinar possíveis assimetrias na distribuição do vento. As medições da velocidade do ar foram feitas em três posições na borda do duto do ventilador axial. A uniformidade de distribuição de líquido na vertical foi analisada considerando as pressões de trabalho de 633, 844 e 1.055 kPa, utilizando um coletor vertical. O experimento foi montado no delineamento de blocos casualizados, com três repetições. A velocidade média do ar tomada na saída do ventilador foi de 35,5 m s^{-1} e a velocidade média de ar na vertical tomada a 0,5 metros da barra foi de 5,9 e 5,1 m s^{-1}, para os lados esquerdo e direito, respectivamente. Os coeficientes de variação para a distribuição volumétrica vertical foram de 136, 136 e 141% para as pressões trabalho de 633, 844 e 1055 kPa, respectivamente.

Palavras-chave: ventilador axial; turboatomizador; distribuição vertical da calda.

Distribución volumétrica de aire y líquido en el pulverizador hidroneumático verticales

Resumen

El objetivo de esta investigación fue evaluar el flujo de aire y la distribución vertical del caldo de producido por pulverizador hidroneumático. El pulverizador fue acoplado a un tractor John Deere Modelo 5705. La rotación del impulsor del ventilador fue de 226,19 rad s^{-1} (2.160 rpm). El ensayo se llevó a cabo para determinar las posibles asimetrías en la distribución del

Received at: 10/06/2013 Accepted for publication at: 12/02/2014

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viento. Las mediciones de la velocidad del aire se realizaron en tres posiciones en el borde del ducto del ventilador axial. La uniformidad de distribución del fluido en la vertical fue evaluada teniendo en cuenta las presiones de trabajo de 633, 844 y 1055 kPa, utilizando un colector vertical. El experimento fue dispuesto en un diseño de bloques completos al azar con tres repeticiones. La velocidad promedio del aire tomada en la salida del ventilador fue 35,5 m s^{-1} y la velocidad media del aire tomadas verticalmente a 0,5 metros fue de 5,9 bar y 5,1 m s^{-1} para el lado izquierdo y derecho, respectivamente. Los coeficientes de variación para el volumen de distribución vertical fueron 136, 136 y 141% para las presiones de trabajo de 633, 844 y 1055 kPa, respectivamente.

Palabras clave: ventilador axial; atomizador turbo; distribución vertical de caldo.

Introduction

On spraying pesticides in tree crops, one of the factors that affect the most its efficiency is the distribution uniformity of airflow and spray on the plant canopy. The pulverizations have gained increasingly attention from the producer, society, institutions responsible for environmental protection and food safety, from the labor inspection bodies, and especially by the consumers. The application of pesticides is an agricultural practice that demands knowledge from the agents involved in its performance. A trained applier can significantly contribute in the improvement of application quality, moreover, it is also necessary that the sprayers are in satisfactory state of maintenance and use, in order to improve the pulverizations quality.

The use of airflow in pesticides application, in fruit trees, has meant an important advance in the late 50 s. However, the pneumatic and hydro-pneumatic sprayers have a high degree of inefficiency, mainly due its rapid reduction in air speed, in function of distance. These transportation deficiencies can be noted in the most distant parts of the trees. In orchards, due to the distance from the sprayer to the plant, and the different shapes and sizes of plants, the droplets are more susceptible to meteorological conditions than in cultures of low stature. Therefore, are more subjected to evaporation and drift. The losses increase with the reduction of droplets diameter and the increase of temperature differences between wet and dry bulb. There are difficulties for radial and axial fans produce a uniform aerodynamic profile. Thus, it makes difficult for the operator to select an ideal airflow that will penetrate the canopy, since it depends on several factors, such as type of tree, growth stage, speed of equipment, meteorological conditions, among others (MAGDALENA, 2004).

According to CHAIM et al. (2004), the construction projects of sprayers equipped with fans present some defects that can be easily observed, for example, the localization of the air inlet, generally, at the rear of the machine. For the authors, the air suctioned by the fan, after the droplet cloud, carries great quantity of droplets into the helix, reducing the deposition in the plant. RODRIGUES et al. (2008) states that the factors which are related with the behavior of the air current produced by hydro-pneumatic sprayers must be carefully investigated, because they are responsible by the conduction and distribution of droplets in the target

Now PRAT et al. (2005), affirm that the axial type fans which are commonly used in hydro-pneumatic sprayers, present a good project of construction, favoring the use of sprayers equipped with this fan in a wide range of crops and adverse conditions. For CROSS et al. (2001), the design of axial fans sprayers is also appropriated for a wide variety of crops. These fans are simple, of low cost, robust and reliable, require little maintenance and are easy to operate. Nevertheless, the aerodynamic profile, in heights superior to 5 meters, causes drift and losses to the soil.

MARUCCO et al. (2008) state that, normally, the setting of air for conventional sprayers, with axial fan, is based in the rotation speed of the fan, air speed and in the baffles position, to determine the air direction. The airflow produced by the axial fan must be designed with the same intensity in all tips, uniformly. The air speed that reaches the nearest leaves from the equipment is very high, this increases the risk depending on the air flow direction, and a consistent fraction of liquid is lost. CELEN (2008), on the other hand, states that the axial fans have been most commonly used in air-assisted sprayers, due its simplicity and low cost.

The spraying efficiency can be affect by the shape, size and position of the target, by the density, diameter, terminal speed of the droplet and by the speed and direction of airflow. In some hydro-pneumatic sprayers, the tips are located around the turbine with peripheral air outlet. This configuration improves the machine efficiency, once the air expelled by the turbine transports the droplets to the inside of canopies and moves the inert atmosphere, located in the plant canopy, facilitating the droplets penetration (BALAN et al., 2006). For this reason, the phytosanitary control in fruits is more effective when using sprayers equipped with fan. This occurs due to the necessity of depositing droplets on all leaves spots. PRAT et al. (2008) state that it is the air current that determines if the pesticide will or not reach the tree canopy.

The spraying in orchards is considered a process with little efficiency, because more than half of the applied dose is lost, implying in economical losses and environment contamination. Nowadays, the most used equipments in citriculture, for control of insects and diseases are the sprayers of transported flow of diverging flux, equipped with hydraulic tips. However, as result of low efficiency, demonstrated in the phytosanitary control when the target is inside the canopy, many producers have chosen to increase the volume of spray solution (TACHIBANA and ANTUNIASSI, 2008).

The aerodynamic behavior of the air curtain on both sides of a hydro-pneumatic spray was studied by RODRIGUES et al. (2008), who found a tendency to greater values of the uniformity coefficient on the right side. Coinciding with the side where the air flow is higher, so it can be concluded that there is a relation between the increase of uniformity coefficient and the higher airflow, and that the spots of lower airflow also present the smallest coefficient. As suggestion, they reported that a possible solution would be to put in the fan baffles with the ability to redirect the air, in order to standardize the flow in the entire extension of the rotor output.

The hydro-pneumatic sprayer must be basically constituted by an efficient air system, with deflectors adapted to the crop type, hydraulic pumps, generally with piston, which can handle pressures higher than 2.000 kPa, and a system of bars with nozzles in semicircle which do not affect the air outlet. The direction and shape of outlet of the deflectors are important to drive the air (CELEN, 2008). The deflectors are designed to control the vertical components of air speed, according to the tree height (ENDALEW et al., 2010).

In Brazil, little is known about the homogeneity of vertical distribution of spray solution in tree crops. There being no standards for commercialization, register or certification of sprayers (BAUER et al., 2006). In an experiment with a bar height of 0.45 m, FOQUÉ and NUYTTENS (2011) analyzed the distribution uniformity in laboratory conditions, finding a variation coefficient of 8.4%. In Europe, the nozzle manufacturer, following the standard EN 12761-2, establishes that for each nozzle, the variation coefficient referent to pressure and height, in laboratorial conditions, must be less than 7%. Currently, according to PAI et al. (2009), depending on the foliage density of trees, there are instrumented sprayers to alter the air flux in real time.

Therefore, the objective of this study was to assess the distribution of airflow produced by the axial fan of a hydro-pneumatic sprayer and, evaluate the uniformity of volumetric distribution of liquid in the vertical.

Material and Methods

The experiment was conducted in the Laboratory of Agricultural Defensives Application in the Universidade Federal de Viçosa, Minas Gerais, located at latitude 20º 45′ S and longitude 42º 52′ W. It was carried out using a hydro-pneumatic sprayer, brand Hatsuta, model SS-420, with piston pump, model S60, and an axial fan with 700 millimeters of diameter and curved blades, attached to a John Deere tractor, model 5705, with nominal potency of 62.5 kW (85 hp). The rotor speed was of 2.160 rpm, measured with a digital tachometer, brand Tako, model TD 303. The minimum period of each reading lasted ten seconds, as proposed in the standard ISO 9898 (ISO, 2000).

The methodology adopted to study the airflow distribution of the fan had as base the theory of turbulent flow, proposed by BRAZEE et al. (1981), ABRAMOVICH (1963) and by the standard ISO 9898 (ISO, 2000). These were also used by PRAT et al. (2005) e RODRIGUES et al. (2008).

The experiment was performed with the tractor on a leveled and protected ground, to avoid effect of the atmospheric air. The weather conditions during the experiment were monitored with a temperature and relative humidity indicator, brand Ummi®. This meter has a temperature sensor with scale from -20 to 100° C, resolution of 1° C and accuracy of ±0.6° C, a relative humidity sensor with scale from 0 to 100%, resolution of 1% and accuracy of ±3% and an Instrutherm anemometer, model AD-250.

In determining the aerodynamic profile, the assessments were performed on both sides of the sprayer, in order to determine possible asymmetries and suggest improvements to the fans manufacturers, for the conditions of application in field. It was used a digital thermo anemometer with hotwire, brand Instrutherm, model TAFR-180.

Following the model proposed by PRAT et al. (2005), the air speed measurements were made in 80 spots, across the contour of the fan outlet. For this, were marked 16 spots around the contour and established five equidistant spots of 12.5 millimeters, covering all width of the diffuser outlet.

Subsequently, from the air outlet section area of each spot and from air speed, the airflow ratio produced by the fan was determined. The uniformity variation of air distribution can occur due to factors such as, diffuser design, presence of the deflector and proximity of the fan wall. For this, it was used the methodology proposed by BRAZEE et al. (1981), and was established a factor for quantification of this parameter (Equation 1 and 2).

$$Q = \sum_{i=1}^{i=n} a_i \omega_{0i} \qquad \text{(Eq. 1)}$$

In which:

Q = air flow ($m^3 s^{-1}$);

a_i = areas of the section where are done the measurements (m^2); and

ω_{0i} = speed in each point ($m s^{-1}$).

$$\eta_1 = \int_0^{B_{0m}} \frac{\omega_0}{\omega_{0m}} \frac{\partial Bom}{B_{0m}} \qquad \text{(Eq. 2)}$$

In which:

η_1 = coefficient of uniformity of air velocity;

ω_0 = air velocity in each point of opening of the fan outlet ($m s^{-1}$);

ω_{0m} = maximum velocity of air in the section ($m s^{-1}$); and

B_{0m} = outlet width (m).

In order to study the behavior of air distribution, as occur in plants, wind speed readings at heights from 0.1 to 2.5 meters were performed, being done five readings for each height, totalizing 375 spots on each side. The results were analyzed to determine the symmetry of the aerodynamic profile, on both sides of the bar.

The uniformity of liquid distribution in the vertical was analyzed using a vertical collector, built with polyvinyl chloride elbows (PVC), of 200 millimeters of diameter, half inch hoses, beakers, funnels and two bars of Metalon (20 x 30 millimeters) of 4.5 meters of height (Figure 1). The collector was positioned was placed two meters from the center

Figure 1. Vertical collector used for the determination of uniformity in the volumetric distribution.

of the fan impeller and the liquid collected, in one liter beakers, following the description given by the standard ISO 9898 (ISO, 2000). The center to center distance, between each PVC elbow, was of 0.3 meters. To prevent water ooze through the external part of the hoses, thus getting inside the beakers, it was used inverted funnels, following the model of a bellflower.

It were studied both sides of the sprayer, at working pressures of de 633, 844 and 1.055 kPa, indicated for the nozzle of empty hollow cone JA-2, commercialized by the Jacto Company. The average time for liquid collection was five minutes. The methodology with vertical collector was used by LANDERS (2012).

The experiment was assembled using a randomized blocks design, with three repetitions in all assessments. The data was analyzed using descriptive statistic tools, presenting data of variation coefficient and the observed averages.

Results and Discussion

The experiment was performed with temperature varying between 19 to 22° C, the air relative humidity varied from 82% to 85%, and there was wind absence, for the study of fan airflow. During tests for the uniformity analysis of volumetric distribution of spray solution in vertical, the temperature varied between 22 to 24° C, the relative humidity varied from 80% to 82% and the wind speed was lower than 2 m s^{-1}.

The air speed, measured in 16 positions, in the fan outlet, showed that there was similarity between sides. The average speeds obtained in the fan outlet were 34.3 and 36.7 m s^{-1}, respectively, for left and right side, with a general average of 35.5 m s^{-1}. The air speed uniformity coefficient was 0.81 and 0.85, for left and right side, respectively. This value indicates a homogeneous distribution of air between the bar sides. The air distribution in the right side was superior to the left side, probably, because of the heterogeneity in air speed, which occurs due to the project of axial fans. The highest speed in the right side inferior part occurred due to the fact that the fan inferior part was closed and the air was unable to exit. Another reason was the rotation direction of the fan. This impasse has been reduced in sprayers with tower type systems. The feasible solution to the air use is the development of a mechanism, together with the fan, for the air reuse or the use of tower type systems which direct the airflow more uniformly in the plant canopy.

The vertical velocity, obtained at 0.5 meters from the fan outlet, in each position, presented maximum values of 10.2 and 9.4 m s^{-1} for the left and right side, respectively. However, the average air speed in the right side was 5.1 m s^{-1}, and in the left side 5.4 m s^{-1}. These results were higher than the 3 m s^{-1}, recommended by DI PRINZIO et al. (2010) for the central and superior area of the plant. The airflow produced by the fan was 5.4 and 5.7 m^3 s^{-1}, respectively, for the left and right side, with an average of 5.6 m^3 s^{-1}. Similar results were obtained by PRAT et al. (2005), who analyzed the air aerodynamic behavior in an axial fan.

Several characteristics influenced the airflow produced by the fan, mainly the environmental conditions in the local where was being performed the experiment. PAI et al. (2009) studied, in controlled setting and without losses of air to the environment, with a sprayer equipped with axial fan, being the outlet airflow of 16.3 m^3 s^{-1}. Now MINGUELA and CUNHA (2010), states that the necessary airflow for cultivation depends of factors such as the tractor velocity, distance between lines, tree height and a coefficient which varies with the foliar density. In this study, it was observed that on the right side, the velocity was higher at the inferior part, in relation to the left side (Figure 2). However, in average, the variation between sides was of only 7.8%, due to the speed on the left side being higher above 0.5 meters, compensating the higher speed on the right side, when close to 0.1 meter from ground level.

The airflow distribution, by the fans, has as function to dislocate the air mass inside the tree canopy and introduce a new air mass loaded with droplets. In this study about the air speed was possible to notice that the nozzles on the bar, forming the semicircle, do not have the same distance in relation to the target, because the nozzles in the inferior and superior part of the bar are farther from the plant canopy. This is one of the reasons, together with lower air speed, why the deposition of spray solution is lesser in the superior part of plants.

In Brazil, still there are not many studies which show with exactness an ideal range for airflow for pulverization in trees. The orchards generally are not conduced with cuttings and, this is an indicative that the ideal air volume, necessary to conduct the droplets to the inside of plants canopies, is higher than that recommended in Europe.

The following factors can affect the air

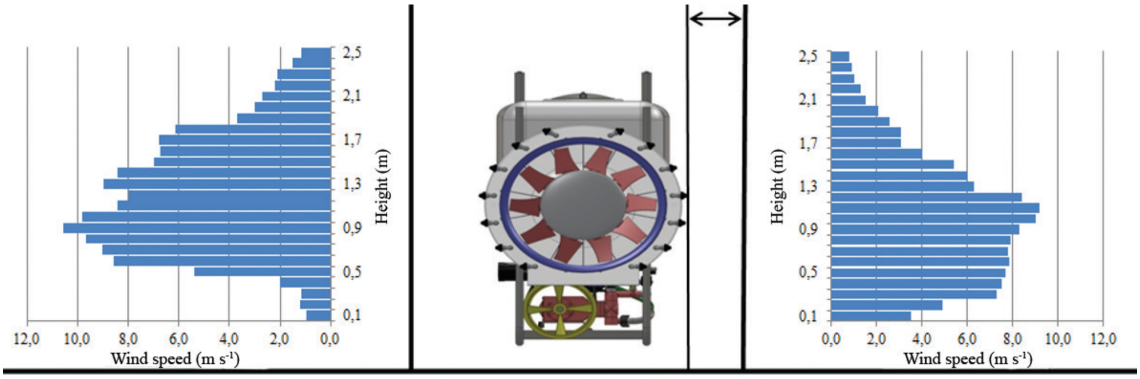

Figure 2. Speed of vertical distribution of air at 0.5 m from the outlet of the fan.

distribution uniformity, such as: width of the diffuser outlet, type of deflector, number of fan blades and its shape (straight or curved), besides of blade thickness, because when it is thinner, they produce smaller air velocities. The hollow blades, with internal gas flux, presented by SARRAF et al. (2011), are more economic, due the amount of material necessary for manufacturing the same.

The differences in airflow, between both sides of the sprayer, indicate that on the right side the air current is downward, while on the left it is upward. The reason for this behavior lies in the direction of fan rotation, where there is the possibility that the distribution is inverted, if the rotation direction was also altered, agreeing with MION et al. (2011) results. An alternative is using sprayers with more than one fan, thus distributing more homogeneously the wind in the plant canopy, including the possibility of reverse flow between the fans to reduce the effect caused by air concentration in the plant inferior part by the axial fans, corroborating with GARCIA-RAMOS et al. (2009), that suggests the use of two fans of reverse rotation in the orchards pulverization.

The coefficient of vertical variation of liquid was 135%and 137%, for the pressure of 633 kPa. In the pressure of 844 kPa, the coefficient was 138% and 135% and, for the pressure of 1.055 kPa, the variation coefficient was of 142% and 141%, respectively, for both sides on the bar. The average coefficient of variation for the respective pressures was 136%, 136% and 141%, respectively for the pressures of 633, 844 and 1.055 kPa. The results indicate that as higher as the pressures were and, consequently, the effects of evaporation and drift, higher will be the variation of liquid collected in the beakers (Figure 3).

The pulverization in trees depends on the canopy geometry and requires that, sometimes, the spray solution volume be higher in the superior canopy of the plant. The producer, through selection of the nozzles, can alter the volume applied in each canopy level. Nevertheless, the fan influence can provoke an irregularity in spray solution distribution. This occurs because the biggest droplets are directed downwards by the gravity (Figure 4).

The behavior of the air current produced by the fan was similar to the obtained for volume collected in the beakers. It was observed that in the inferior part, the deposition was superior to the obtained at the height of three meters, such as found by MION et al. (2011).

In calibrating the hydro-pneumatic sprayers, it must be considered the direction and uniformity of the airflow, in such way that it provides a uniform deposition of spray solution in the entire canopy, independent of plant geometry. The deficiency in distribution of airflow and the uniformity of vertical volumetric distribution of the spray solution, in trees, can be equated with the use of sprayers developed with other manufacturing projects. Some studies, such as the one from EBERT et al. (2009), indicate that the configuration adopted in the fans and sprayer's project, for trees, can better homogenize the distribution of air and spray solution in the trees canopies.

During the last years, the methodologies and equipments used in application of pesticides have considerably evolved. However, many improvements still can be made in relation to existing flaws in the projects of sprayers designing. Hydro-pneumatic sprayers are one of the main equipments

Figure 3. Device used to measure the uniformity of the vertical volumetric distribution.

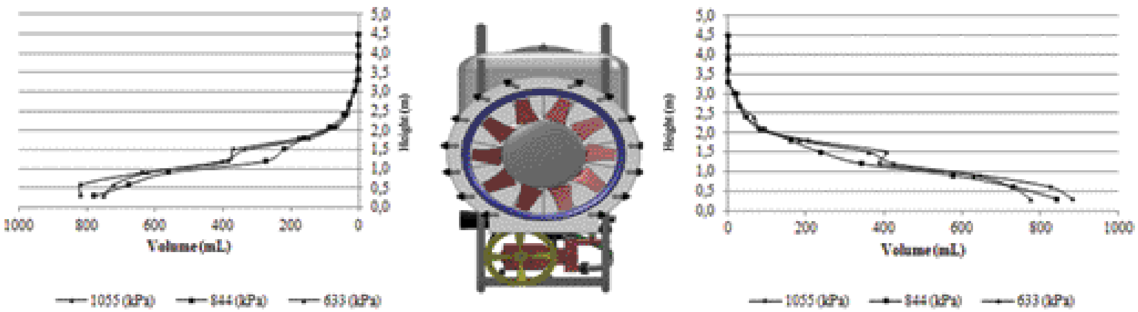

Figure 4. Uniformity of the vertical volumetric distribution.

used for pulverization in trees crops. Therefore, there is the need of performing tests in these equipments, which enable greater efficiency of air distribution and, consequently, better functioning of the sprayer, be it technical, economical and environmentally reliable.

Hydro-pneumatic sprayers are equipments equipped with pulverization nozzles for the fractioning of spray solution in droplets, and with a fan for the transportation of the same to the interior of the plant canopy. The air current produced by the fan conducts the droplets into the canopy interior. However, there is energy expenditure for the fan functioning and great part of it is lost due to bad distribution of air at the sprayer outlet. Trees canopies vary with age and plant species. Therefore, it is necessary that the directing of air current in the distribution column of sprayer is adjusted by the operator, in such way that is obtains greater volume and airflow in areas where the canopy is denser.

The airflow intensity is determined by the air velocity generated by the fan, directly influencing the vertical distribution of the applied liquid. Different projects and characteristics of deflectors have been developed for sprayers with airflow. Thereby, the fan height can influence the application efficiency in relation to the plant. The higher or lower fan height can prevent that the spray solution reach leaves in different areas of the canopy. Thus, as greater the distance between the nozzles of pulverization and the target, lower will the air capacity in transporting droplets and higher will be probability of evaporation and drift.

Conclusions

The air uniformity coefficient was considered homogeneous, being of 0.81 and 0.85 in the left and right side of the fan, respectively.

The variation coefficient for the volumetric distribution of liquid in the vertical was of 136%, 136% and 141% for the pressures 633, 844 e 1055 kPa, respectively.

Acknowledgments

To the National Council of Research and Scientific and Technological Development for the concession of a scholarship and to the Foundation of Support for Research of the Minas Gerais State, for funding this research.

References

Abramovich, G. The theory of turbulent jets. Fitzmatgiz, 1960. English translation, edited by L. H. Schindel. MIT Press, Cambridge, USA, 1963. 671p.

Balan, M.G.; Abi Saab, O.J.G.; Sasaki, E.H. Distribuição da calda na cultura da videira por turboatomizador com diferentes configurações de pontas. Ciência Rural, Santa Maria, v. 36, n. 3, p. 731-738, 2006.

Bauer, F.C.; Raetano, C.G.; Pereira, F.A.R. Padrões de distribuição volumétrica de pontas de pulverização de jato plano 11002, com e sem indução de ar, sob diferentes espaçamentos e alturas. Engenharia Agrícola, Jaboticabal, v. 26, n. 2, p. 546-551, 2006.

Brazee, R.D.; Fox, R.D.; Reichard, D.L.; Hall, F.R. Turbulent Jet Theory Applied to air sprayers. Transactions of the ASAE, St. Joseph, v. 24, n. 2, p. 266-272, 1981.

Celen, I.H. Effect of angle of sprayer deflector on spray distribution in dwarf Apple tres. Journal of Agronomy, New York, v. 7, n. 2, p. 206-208, 2008.

Chaim, A.; Pessoa, M.C.P.Y.; Ferracini, V.L. Eficiência de deposição de pulverização em videiras, comparando bicos e pulverizadores. Pesticidas: Revista de Ecotoxologia e Meio Ambiente, Curitiba, v. 14. n. 0, p. 39-46, 2004.

Cross, J.V.; Walklate, P.J.; Murray, R.A.; Richardson, G.M. Spray deposits and losses in different sized apple trees from an axial fan orchard sprayer: 1. Effects of spray liquid flow rate. Crop Protection, Oxford, v. 20, n. 1, p. 13–30, 2001.

Di Prinzio, A.; Behmer, S.; Magdalena, J.C. Equipos pulverizadores terrestres. In:_____. Tecnología de aplicación de agroquímicos. 1ª Edição. Alto Valle, Argentina: Red CYTED "Técnicas sostenibles de distribuición de agroquímicos" Área de comunicacones del INTA Alto Valle, Argentina, 2010. 196 p.

Ebert, R.C.; Burns, J.K.; Morgan, K.T. Spray Volume, Distribution, and Efficacy of 5-Chloro-3-methyl-4-nitro-1H-pyrazole for Loosening Sweet Orange. HortScience, Alexandria, v. 44, n. 7, p. 1895-1899, 2009.

Endalew, A.M.; Debaer, C.; Rutten, N.; Vercammen. J.; Delete, M.A. A new integrated CFD modelling approach towards air-assisted orchard spraying - Part II: Validation for different sprayer types. Computers and Electronics in Agriculture, Amsterdam, v. 71, n. 2, p. 137-147, 2010.

Foqué, D.; Nuyttens, D. Effect of air support and spray angle on coarse droplet sprays in ivy pot plants. Transactions of the ASABE, St. Joseph, v. 54, n. 2, p. 409-416, 2011.

Garcia-Ramos, F.J.; Vidal, M.; Bone, A. Field evaluation of an air-assisted sprayer equipped with two reversed rotation fans. Applied Engineering in Agriculture, St. Joseph, v. 25, n. 4, p. 481-494, 2009.

ISO. Internation Organization For Standardization. Norma ISO 9898 - equipment for crop protection: Test methods for air assisted sprayers for bush and tree crops, 2000.

Landers, A. **Cornell patternator**. Disponível em: <http://web.entomology.cornell.edu/landers/PATTERNATOR.htm>. Acesso em 24 de janeiro de 2012.

Magdalena, J.C. Monterola, L.V. Efecto de la utilización de pulverizadores de flujo transversal e hidroneumático tradicional sobre la calidad de los tratamientos fitosanitarios en manzanos (Malus domestica, Borkh). 144f. 2004. (Tese de doutorado) Universidad Politécnica de Valência, Valência, Espanha.

Marucco, P.; Tamagnone, M.; Balsari, P. Study of Air Velocity Adjustment to Maximise Spray Deposition in Peach Orchards. In: Agricultural Engineering International. the CIGR Ejournal. Manuscript CIGR Journal, v. X, 2008.

Minguela, J.V.; Cunha, J.P.A.R. Manual de aplicação de produtos fitossanitários. Aprenda fácil, Viçosa, Brasil. 2010. 588p.

Mion, R.L.; Sombra, W.A.; Duarte, J.M.L.; Nascimento, E.M.S.; Viliotti, C.A.; Lucas, F.C.B.; Monte, C.A. Uso de mesa vertical como parâmetro para regulagens de turboatomizadores. Engenharia Agrícola, Jaboticabal, v. 31, n. 2, p. 352-358, 2011.

Pai, N; Salyani, M.; Sweeb, R.D. Regulating airflow of orchard airblast sprayer based on tree foliage density. Transactions of the ASABE, St. Joseph, v. 52, n. 5, p. 1423-1428, 2009.

Prat, M.I.H.; Teixeira, M.M.; Rodrigues, G.J.; Milán, H.C. Aerodinámica del ventilador axil del pulverizador Hatsuta-420 empleado en frutales. Ciências Técnicas Agropecuárias, Havana, v. 14, n. 3, p. 22-30, 2005.

Prat, M.I.H.; Teixeira, M.M.; Milán, H.C.; Costales, A.G.F. Modelos matemáticos para la determinácion de las características aerodinámicas del flujo de aire de un pulverizador para frutales. Ciências Técnicas Agropecuárias, Havana, v. 17, n. 2, p. 6-12, 2008.

Rodrigues, G.J.; Teixeira, M.M.; Filho, E.I.F.; Picanço, M.C. Características do fluxo de ar de um pulverizador hidropneumático para aplicação de agroquímicos em plantas arbustivas. Engenharia na Agricultura, Viçosa, v. 16, n. 2, p. 199-207, 2008.

Sarraf, C.; Nouri, H.; Ravelet, F.; Bakir, F. Experimental study of blade thickness effects on the overall and local performances of a Controlled Vortex Designed axial-flow fan. Experimental termal and fluid science, Paris, v. 35, n. 4, p. 684-693, 2011.

Tachibana, A.; Antuniassi, U.R. Avaliação de sistemas de aplicação de defensivos para a citricultura. Energia na Agricultura, Botucatu, v. 23, n. 1, p. 01-17, 2008.