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Plant protection

Development and test of a confining and recycling sprayer for viticulture

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Abstract - In the tropical and subtropical viticulture, it is notorious that the occurrence of a favorable microclimate leads to a high incidence of plant pathologies. This affects the productivity and longevity of the vines. In many cases, the incidence of rainfall and high relative humidity, during most of the vine cycle, leads to a large number of interventions for phytosanitary control. The continuous, and not always correct use of pesticides, causes their residues to be deposited in the environment, leading to changes in the ecosystem, accumulation in non-target organisms and the water, with the potential to cause serious problems for man and his habitat. That matter has highlighted the need for more accurate technologies for the spraying of active ingredients in crops. Therefore, the investigation of more appropriate procedures and equipment is justified, for greater protection of the workers and the microenvironment, as well as for higher efficiency in the application of active ingredients. Based on the above, a prototype of a confining and recycling sprayer was developed and tested at the Centro de Engenharia e Automação (CEA) of the Instituto Agronômico (IAC), in Jundiaí (São Paulo state), between 2017 and 2019 growing seasons. Spray outlets were arranged in vertical ducts and accommodated in two shield panels. The prototype was arranged as a straddle, floating over-the-row. Part of the liquid sprayed, not adhered to the leaves, was collected at the bottom of the shield panels and pumped back into a reservoir for recirculation. Tests were carried out to evaluate the performance as for uniformity of adaxial leaf coverage in the vineyard, using image analysis. The results showed that the mechanical configuration used made it possible to promote significant recovery of the liquid and a satisfactory percentage of leaf coverage.

Index terms: Viticulture, spraying, disease control.

Desenvolvimento e teste de um pulverizador confinador e reciclador de calda para viticultura

Resumo- Na viticultura tropical e subtropical, é notória a ocorrência de microclima favorável à alta incidência de fitopatologias, as quais afetam a produtividade e a vida útil das videiras. Em muitos casos, há incidência de precipitação pluviométrica e alta umidade relativa, durante parte significativa do ciclo da videira, o que leva a um grande número de intervenções para o controle fitossanitário. A utilização contínua, e nem sempre correta de agrotóxicos, faz com que resíduos destes sejam depositados no meio ambiente, levando a alterações no ecossistema e à acumulação em organismos não alvo e na água, com potencial de provocar graves problemas para o homem e seu hábitat. Essa temática tem ressaltado a necessidade de tecnologias mais acuradas para a pulverização de ingredientes ativos em cultivos agrícolas em geral. Portanto, justifica-se a investigação de procedimentos e equipamentos mais adequados para maior proteção do operador e do microambiente, bem como maior eficiência na aplicação de ingredientes ativos. Baseado no exposto, um protótipo de pulverizador confinador e reciclador de calda foi desenvolvido no Centro de Engenharia e Automação (CEA) do Instituto Agronômico (IAC), em Jundiaí (SP), e avaliado entre 2017 e 2019. Ponteiras de pulverização foram arranjadas em dutos verticais, e estes acomodados em dois painéis de contenção. O protótipo foi arranjado em trâmpulo, com flutuação sobre linhas de plantio de videira. Parte do líquido pulverizado, não aderido às folhas, foi coletada no fundo dos painéis de contenção e bombeado de volta a um reservatório para recirculação. Testes foram feitos para avaliar o desempenho quanto à uniformidade de cobertura foliar adaxial no vinhedo, utilizando-se de análise de imagem. Os resultados mostraram que a configuração mecânica utilizada permitiu promover significativa recliclagem de calda e atingir percentagens de cobertura foliar em níveis satisfatórios.

Termos para indexação: Viticultura, pulverização, controle de doenças.

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Introduction

The growing concern with environmental pollution and the levels of residues in food, observed in recent times, justify seeking for improvements in pesticide application methods and technologies, reduced application volume, and better target accuracy, which are the leaves and branches of plants.

In tropical viticulture, due to favorable elements of the climate, there is a high incidence of diseases, which affect the productivity and vine's useful lifetime.

The intensive use of pesticides to control vine diseases causes their residues to be deposited in the environment, leading to changes in the ecosystem, accumulation in non-target organisms and water, causing serious problems for humans (KÖHNE et al., 2009; CIESLIK et al., 2011).

In addition, the excessive use of pesticides, eventually associated with high-volume applications, can not only cause environmental damage but also phytotoxicity and lead to pathogen resistance, by extending the practice (SCAPIN et al., 2015).

According to Chaim et al. (2004), the traditional spraying on some crops, such as the vine cultivated in espalier, can generate losses of active ingredients to the soil, which varied in an experiment, between 34.5 and 48.9%. Also, Contiero et al. (2018), show that spraying losses on growing crops such as beans and tomatoes, ranged from 48% to 59%, considering the drift losses to the soil and air.

Taking into account the intensive use of spraying in viticulture, the search for alternatives to reduce drift losses and improve the uniformity of leaf coverage is justified, to obtain greater efficiency in the control of pests and phytopathologies.

In recent years, several methodologies have been proposed, aiming to study the spray deposition rates in plant canopies (GARCÍA-RAMOS et al., 2018; GREGORIO et al., 2019), as well as the application at variable rates, based on possible variations in plant architecture (GIL et al., 2007; PÉREZ-RUIZ et al., 2011; MAGHSOUDI et al., 2015). Notably, in these cases, it seems to be opportune to add electrostatic spraying as an auxiliary technology to be considered.

In this context, the idea of a sprayer with shield panels seems promising, as it can interfere with the fate of jet streams, or turbulent flow directed away from the target, separating the air from the water flow, reducing the potential for drift losses. Wenneker and Van De Zande (2008) used the combination of spray tips, shield panels, and low liquid pressure (larger droplet diameters), achieving a high reduction of spray drift in apple cultivation.

Pergher et al. (2013) tested a prototype sprayer with shield panels, in a vineyard, but this time, associated with a system for liquid recycling. The authors confirmed the significant potential of the technique in saving spray liquid, without compromising the quality of foliar deposition of the active ingredient.

The aforementioned authors demonstrated a relatively highly complex equipment for subtropical viticulture, given its total mass and low maneuverability potential in more inclined terrain. However, it is clear from the data presented that the temporary enclosing of the target, between shield panels, can help to reduce drift losses and to obtain better liquid deposition on the leaves, through a simultaneous approaching to the two sides of the plant, with a line of directed jets, vertically aligned with the lateral faces of the canopy.

In addition, temporary canopy enclosing (confinement), recovery, and recirculation of spray liquid must accompany adequate levels of uniformity in leaf coverage. Thus, currently, in addition to considering the degree of deposition of active ingredients on the leaves (quantity), as an index of application efficiency, knowledge about the spatial uniformity of their distribution (quality) is sought.

Pergher et al. (1997) showed that the use of different sprayers led to similar rates of leaf deposits on grapevines, but that a greater degree of uniformity of leaf distribution was only achieved with high application volumes. Note, therefore, that the two covering conditions discussed (quantity and quality) are complementary.

This work aimed to develop and test a tunnel sprayer for the confinement of the sprayed target and liquid recycling, for application in viticulture.

Material and methods

a) *Vineyard*

The experiment was carried out at the Centro de Engenharia e Automação/IAC, in Jundiaí (São Paulo State, Brasil), from 2017 to 2019 growing season. A vineyard of the cultivar 'Isabel' (*Vitis spp*), established in 2011, was used. The vines were conducted in the espalier system with spur pruning, and bilateral cordon, with the spacing of 3m x 2m. Pruning was performed with a specific machine, according to Santos et al. (2015); the other cultural treatments of the vines were the traditional ones, recommended for the region (POMMER, 2003).

b) *Prototyping*

The development of prototyping was based on the method of successive approximations, based on related technologies, taking into account the particular situation of Brazilian viticulture, in a tropical and subtropical climate, with a high incidence of plant pathologies during the vine cycle. The conceived ideas were designed in AutoCAD (SolidWorks, Dassault System, France) and subsequent fabrication was performed in a prototype laboratory. Therefore, the adopted product development methodology was based on the following flowchart: concept development > planning > design and manufacturing > pilot production (WHEELWRIGHT and CLARK, 1992).

An indirect induction drop electrification system was added (CHAIM, 2006), composed of a charge amplifier/pulsator, induction electrodes, and specific electrical wiring (SPE Ltda, Porto Alegre, RS). Thus, each spray nozzle installed contained an induction electrode, positioned in the region of the edge of the jet, in the drop formation zone.

For the production of an aerodynamic drag jet, a centrifugal stream fan coupled to two flexible air ducts of 150 mm in diameter was used. The liquid atomization was performed by spray nozzles with hollow cone spray tip (Teejet Spraying Systems Co.). These nozzles were arranged along two vertical and opposite air ducts, so that three spray outlets, each containing two sets of nozzles, were installed in each vertical duct and fixed to the inner wall of the shield panels (Figure 2). Therefore, twelve nozzles were added. The spray outlets were vertically spaced apart by 0.2 m.

Two vertical shield panels (1.2 m x 1.9 m) were built with thin walled iron tubes, and positioned hanging from a support arm, on either side of the vine row, forming a confinement chamber, enclosing the plants during the movement of the equipment (Figure 1).

Part of the liquid sprayed, and not adhered to the leaves, or that passed through the canopy, was collected at the shield's bottoms, in containment basins and pressed back into the sprayer's tank employing two hydraulic pumps (flow rate of 5 L/min, pressure of 1 bar). To ensure pump "priming" and prevent cavitation, a minimum water column was maintained in a "still well" at the bottom of the basins, where a fine mesh filter and a check valve were housed. An electrical circuit based on water level sensors and relays was installed to control the pump discharge cycles (Figure 2).

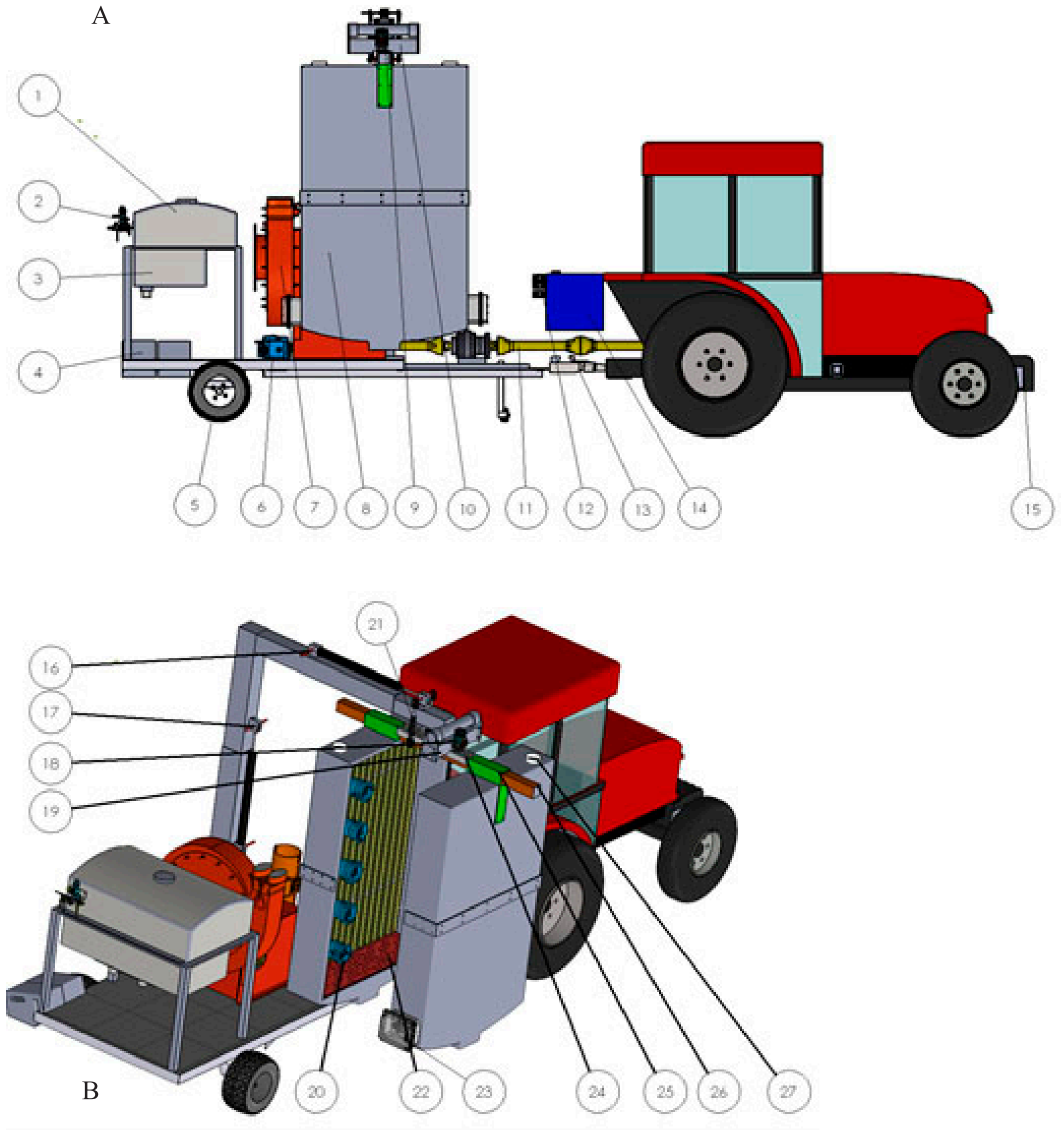

Figure 1. Design and assembly of the main machine components.

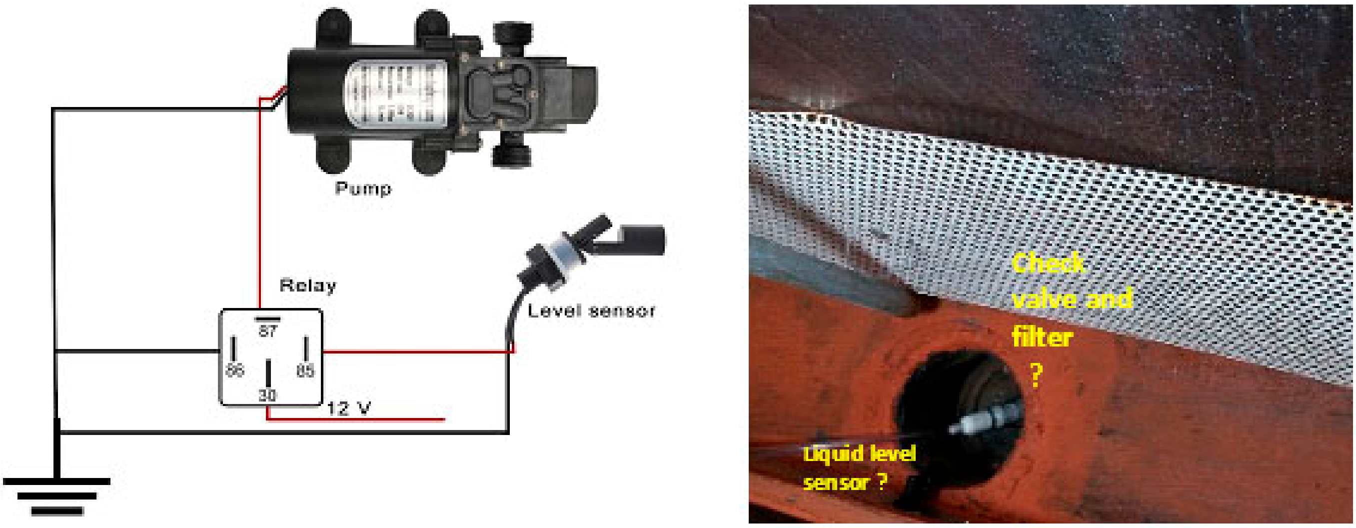

Figure 2. Design and assembly of the main machine components.

The distance between the shield panels was controlled between 0.2 m and 1.0 m, utilizing a drive system based on pinion/rack and a hydraulic motor.

The liquid spraying system had a 400 L tank, pressure regulator, and hydraulic pump. The water pump and the fan were driven through the PTO of a MF 265 tractor (AGCO, Porto Alegre, RS), rated 44 kW (60 hp).

An 'electric-over-hydraulic' circuit was installed to move the shield panels, comprising: oil reservoir, pump, cylinders, directional solenoid valves, and a unidirectional flow control valve. For general control of the actuators, a six-channel "joystick" was used. The hydraulic pump was directly coupled to the crankshaft of the tractor engine.

To smooth the pendulum movements of the shield panels, two automotive dampers were installed on their support arms.

Figure 1 and 2 shows the main components of the system: 1 - sprayer tank; 2 - pressure regulating valve; 3 - sub-tank; 4 - counterweights; 5 - reinforced wheel set; 6 – spraying pump; 7 - centrifugal fan; 8 - shield panels; 9 - support shaft; 10 - rocker arm; 11 - set of cardan shafts; 12 - directional solenoid valves; 13 - mechanical coupling; 14 - hydraulic oil reservoir; 15 - hydraulic pump; 16.17 - double-action hydraulic cylinders; 18 - hydraulic motor; 20 - spray outlets; 21 - dampers; 22 - perforated plate; 23 - liquid pump; 24 - rack and pinion; 25 - support sleeve; 26 - transverse shaft; 27 - air inlet.

c) *Evaluation of liquid recovery*

c.1) In the laboratory

The sprayer performance was evaluated based on spraying recovery tests, under static conditions, in the absence of vegetation. The average net liquid flow between the six spray outlets was 2 L/min (at a pressure of 345 kPa).

The static tests were carried out, with six replications, totaling 24 experimental units, with a factorial design (2 x 2), with the following configurations: a) 0.5 m opening of the panels; b) 1.0 m opening of the panels; c) at zero motion speed and 2600 RPM fan speed.

Data were subjected to normality tests and, after verifying the normal distribution, the variables were subjected to analysis of variance (F test; $p \leq 0.05$), using the SISVAR program (FERREIRA, 2011). Tukey's test with 5% probability was used to compare means.

c.2) *In the vineyard*

In the 2018 harvest, field tests were carried out, using two plant lines, in sequence, in a 240 m spraying path, which was covered only once on chosen dates, throughout the crop cycle. Therefore, six vines were randomly chosen, in each row, to evaluate the crop average leaf area index (LAI) (m^2 of leaves/m^2 of soil).

A computational algorithm (Vitiscanopy) was used to calculate the LAI, according to De Bei et al. (2016). Canopy image analysis, obtained "in situ", was used to calculate the parameters of plant architecture, based on its porosity ("gap frequency"). Therefore, the transmission of direct incident solar radiation through the canopy was evaluated, to estimate the LAI by Beer's Law (DE BEI et al., 2016).

d*) Experimental setup to study leaf cover*

The prototype's ability to promote the coverage of leaves with active ingredients was verified, in two spraying conditions, namely: a) electrostatic spraying; b) traditional spraying (switching off the droplet electrization system).

d.1) Analysis of the leaf cover percentage (2018 harvest)

The application of liquid, in all cases, was performed under a pressure of 345 kPa, with a tractor power take-off speed of 540 RPM and a linear speed of 3.5 km/h. The application rate was 300 L/ha. Fluorescent tracer Saturn yellow, at the rate of 1g/L was added to the liquid. Traditional and electrostatic sprayings were used equally in the experiment.

In the vineyard, two rows of 128 meters in length, divided in 16 spans (eight meters between posts), were used to analyze the leaf cover. The leaves, totaling 120, were randomly sampled. Two spans at the head of the lines were eliminated. Four leaves per span, in the outer layer of vines were collected.

Therefore, 120 treatments (120 leaves) were adopted in a completely randomized design, and the frequency distribution of data was observed for some ranges of percentage values of leaf cover.

During application, the air temperature varied between 24.5 and 26 °C, the relative humidity between 50 and 60%, and the average wind speed between 1.5 and 2.0 $m.s^{-1}$.

After being collected and stored in paper bags, the leaves were analyzed in the laboratory. For this purpose, they were fixed on a white plate to improve the contrast and then photographed in an environment under ultraviolet light, to highlight the drops containing the "tracer".

A Canon® brand digital camera (model EOS Rebel T5), fitted with special lenses (Canon EF 50 mm), was positioned at a distance of 40 cm for taking the images.

The processing and analysis of the images took place through the ImageJ® software (National Institute of Mental Health, California, USA), using an operational routine to facilitate the processing and finally, determine the total coverage of droplets on the leaves, following Lino et al. (2008).

The images were used to verify the effect of spraying and to calculate the total percentages of adaxial leaf cover.

d.2) Numerical verification of the uniformity of the leaf cover (2019 harvest)

The same experimental procedure, used to verify the percentage of leaf cover (previous item) was repeated in the 2019 growing season. However, in this case, 122 leaves were collected from the outer layer of the canopy, immediately after spraying. In a distance of 240 m, two types of spraying were performed, say, traditional (TS) and electrostatic (ES).

Therefore, in this case, 122 treatments (leaves) were established in a completely randomized design and the data means were compared using the Tukey test at 5% probability.

Occasionally, when comparing two leaf blades with different coverage percentages, the one with the lowest value may present a greater degree of uniformity of the ingredient's distribution (Figure 6), which may make this concept a relative one, moreover, depending on the visual judgment. Therefore, in the 2019 harvest, a method was developed to observe, in more detail, the degree of uniformity in the spatial distribution in the adaxial part of leaves, sprayed with the prototype.

Thus, a coefficient of variation of the spatial spray distribution on the leaves was derived, to numerically detect the degree of uniformity, based on the segmentation of the area of the target leaves. Thus, the leaf area was divided into four zones (clusters), following the method of cluster analysis (KASSAMBARA, 2017) and according to Table 1.

Table 1. Idealization of leaf area segmentation into four zones (clusters) based on percentage of leaf coverage data.

Cluster Center values	Standard deviation for cluster center values	Average values for cluster center data	Coefficient of uniformity for a vine leaf, (%)
Cluster 1	X1	Y1	[X1/Y1]x100
Cluster 2			
Cluster 3			
Cluster 4			

A cluster center is an indicator of the spatial variability of the cluster's data. Therefore, comparing the values of cluster centers with each other, if they present the same color intensity the degree of distribution is maximum and the spatial uniformity is maximized. The same procedure was used by Santos et al. (2012), to study management zones in precision viticulture. There are no reports, however, of this type of analysis in experiments involving the issue of spraying.

d.2.1) Methodology for operationalizing leaf surface segmentation

The images generated from the sprayed leaf samples were analyzed following the procedure developed by Lino et al. (2008), that is, the images were "broken" into the RGB (red, green, and blue) channels and a processing routine was repeated for the 122 samples collected, as follows: channel B (blue) was used to calculate the area of the leaves, by transforming it into a binary image (black and white), consisting only of the leaf area (black) and the background (white).

Channel G (green) (Figure 3B), which presented the best contrast between drops and leaf, was used to measure the deposition area of the drops. The final coverage of the leaf, Cf, was obtained by the equation:

$$Cf = Ag/Af \qquad 1$$

where Ag is the sum of the droplet areas and Af is the leaf area.

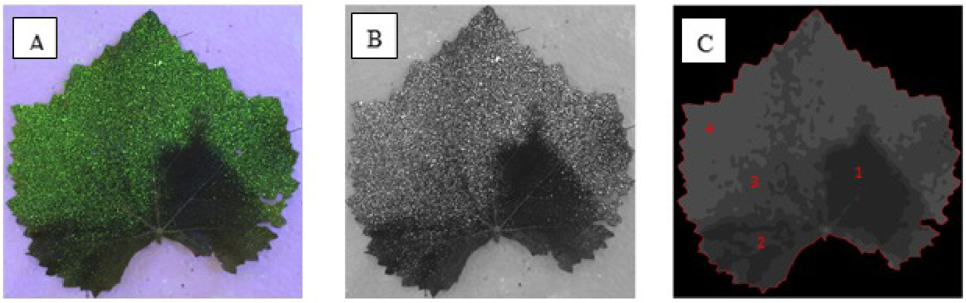

Figure 3. Vine leaves depicting: A- original; B - channel G (Green); C - segmented leaf in four clusters.

The same channel G was filtered to eliminate outliers and homogenize the leaf regions.

Next, the segmentation of spatialized data was performed, using the K-means technique (KASSAMBARA, 2017).

Therefore, for each leaf, an image divided into 4 regions was obtained, with a cluster center value for each one (Figure 3A to 3C), and then calculating the percentage of coverage in each of these regions.

Finally, the coefficient of variation of the color intensity values between the centers of the clusters was calculated for a leaf, to verify the degree of spatial uniformity of the coverage obtained with the spraying generated by the prototype (ES and TS).

Results and discussion

Aspects of the prototype's mechanical performance

The field tests showed that the adopted towing configuration (Figure 4) allowed good drivability, and once the machine is positioned between the planting line and the shield panels were adjusted, it became easy to maintain the evolution of the spraying work in the field path, without problems in headland maneuvers. However, a greater spray outlets recoil can be achieved by separating the vent line from the spray line. Placing the ventilation in a vertical curtain, next to the spray outlets, would allow the nozzles to be retracted, which could facilitate the contour of the posts.

Figure 4. Vineyard operation of the recycling sprayer prototype.

The vertical permanence of the shield panels was guaranteed by the pendular system adopted, in which the confinement chamber fits by itself. However, when passing through the posts, a small number of ultrasonic sensors, if added, could help identify them, or to differentiate plant mass, making the shield panels self-compensate in terms of distance from each other, for good traffic. In fact, in works with traditional broadcast sprayers, canopy architecture variation, that has been adopted to guide the dose application (GIL et al., 2013), can be adapted to the type of technology under discussion. A greater degree of automation in this sense would allow greater independence of the operator from the spray target, allowing him (her) to develop higher operating speed, which is interesting in ultra-low volume applications. On the other hand, adopting the reception of the georeferenced position can allow the operator to be completely independent of guidance along the planting line.

The total suspended mass of the chamber, with all components for spraying and recovery of the solution, around 250 kg, made possible the stabilization of the sprayer with few counterweights, installed on the opposite side of the said chamber (Figure 4). It is noteworthy that future research can verify whether using other materials, the total mass could be reduced and whether the frontal installation, mediated by a lateral frame (SANTOS et al., 2015), could allow better drivability and lower cost. In fact, according to Jamar et al. (2010), the adoption of the technology under discussion depends on achieving low manufacturing cost and ease of drivability, in the most varied terrain conditions, which are the main limiting factors in the advancement of the tunnel sprayer technique.

Foqué et al. (2012) studied, in laboratory, the use of vertical jet curtains, as in this work, in the laurel cultivation. Satisfactory results were produced with this type of spray nozzle distribution, obtaining variations in the degree of efficiency, as the type of nozzle, jet angle, and working pressure varied.

On the other hand, it has been proven that spray nozzles with hollow cone spray tips, as used in this work, are promising drift reducers in various types of sprayers (GREGÓRIO et al., 2019), which shows that the configuration used in the present prototype presents synergy between its constructive elements.

Likewise, field experiments by other authors have shown that the combined adoption of shield panels and mixed jets, with larger droplets diameter, are important factors in reducing spray losses (WENNEKER; ZANDE, 2008), which aligns with the mechanical construction used in this work.

Figure 5 shows the profile of the relation between liquid pressure and flow, obtained in the laboratory, whose values were used in the pre-calibration for the field work.

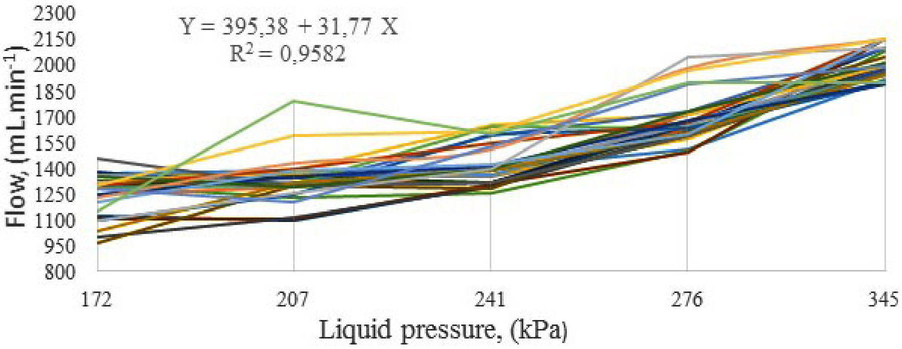

Figure 5. Relationship between liquid flow rate and pump pressure determined for spray nozzles.

Analyzing the curves together, it can be seen that, within the pressure range adopted, the flow varied, on average, from 1200 mL.min^{-1} to 1900 mL.min^{-1}. By the regression equation (Figure 5), it is noted that for each unit of pressure increase there is an increase of 31.77 mL.min^{-1} of liquid flow, which is the degree of resolution achieved, with a high value for the coefficient of determination.

This range is suitable for low to high volume application rates, according to what is observed in commercial machines (CONTIERO et al., 2018). The equation obtained (Figure 5) was used to adjust dosages in field experiments.

In the static tests for liquid recovery (Table 3), values from 60.5% to 97.3% were obtained, under different conditions of shield panels opening and ventilation.

The mean values of liquid recovery data differ statistically regarding the variable distance of opening of the panels and also regarding ventilation (Table 2 and 3). There was no significant interaction between distance and ventilation. Therefore, the variation in the opening of the panels and the aerodynamic drag conditions affect the liquid recovery rate. However, the effect of the opening of the shield panels is independent of the effect of ventilation.

Table 2. Analysis of variance for liquid recovery data.

Souces of variation	Degrees of freedom	Sums of squares	Mean squares	F	p
Distance	1	1208,420	1208,420	802,005	<0,001
Ventilation	1	2564,734	2564,734	1702,163	<0,001
Dist x vent	1	0,400	0,400	0,266	0,612
Residual	20	30,135	1,507		
Total	23	3803,690	165,38		

Level of significance: 0,05.

Table 3. Mean values for recovery rate at liquid pressure of 345 kPa, with and without ventilation.

Shield panel aperture (m)	Recovery rate, %		
	No ventilation	Ventilation (2600 RPM)	Average air velocity in the spray outlets, (m/s)
0.50	75.1±1.0 a	95.0±0.1 c	9.2
0.50	76.3 ±0.61 a	97.3 ±0.5 c	9.2
1.0	60.5 ±1.4 b	81.4 ±1.0 d	9.2
1.0	62.0 ±0.9 b	83.0 ±1.0 d	9.2

For the same row and column, data followed by the same letter do not differ by Tukey’s test (P<0.05).

Notably, under greater opening, the capacity for liquid recovery was decreased. Under ventilation, a drop in liquid loss was observed, in comparison with the condition of zero ventilation. When the air reaches the sprayed droplets, there is an improvement in their transport, due to the aerodynamic drag towards the target. On the other hand, it is noted that there is never total recovery of the applied liquid, even in laboratory conditions, where there is minimal wind interference and no culture is present. A small fraction of the applied liquid remains on the walls of the panels, internally, and some fraction externally, in addition to a part that evaporates and the one that drifts to the microenvironment, due to the turbulence generated in the spraying.

Under dynamic conditions (Table 4), however, the maximum recovery rate decreased due to the presence of the canopy and the additional effect of wind flow entering the spray chamber through the front opening, even at low operating speeds. Notably, under field conditions, when the LAI is zero, after pruning, the liquid recovery is close to 70%, and the lowest recovery occurs when the LAI is at its maximum, in November the 3rd.

Table 4. Values for liquid recovery rate, on different dates, for two planting lines (240 m path), under liquid pressure at 345 kPa and ventilation at 2600 RPM.

Data (2018)	LAI	Shield panel aperture (m)	Recovery rate %	Applied volume (L/ha)
3- Ago	0	0.70	69	200
3- Set	0.29	0.65	50	200
11- Set	0.53	0.60	57	250
30- Set	0.70	0.70	50	350
9- Out	0.98	0.70	39	400
3- Nov	1.60	0.70	30	420

With the observed recovery rates (Table 3 and 4), it can be projected that in large areas the potential for recovery and recirculation of spray liquid is high, that is, the rates of drift to the soil and to the microenvironment suffer a decrease.

Spray recovery values, in the intervals described in Table 4, were observed by Pergher and Zucchiatti (2018), who reported values between 31% and 67.2%, for vines with LAI in development, when they evaluated a sprayer prototype with a similar liquid recycling circuit. Cerruto et al. (2012) when testing a similar prototype, designed for vines conducted in the system known as “goblet”, showed values of 45.5% of liquid recycling, in the berry development stage. Even though the prototypes compared only show similarities with the present one, the data reveals that at least 50% of the liquid can be recovered, in this type of configuration for pesticide spraying.

In practical terms, recovery, and recirculation of 50% of the spray liquid volume, as seen in Table 4, for a developing LAI, means that half of the spray volume applied, which would be lost, would recirculate and thus never reaching the microenvironment, in the terms of the spraying under study. This fact becomes important, given that the number of sprays used in Brazilian tropical and subtropical viticulture, in the vine cycle, is high, and maybe greater than 15 recurrences (SHIMANO; SENTELHAS, 2013).

Aspects of the leaf coverage obtained from the prototype

Figure 6 shows some representative results of coverage percentages, using or not electrostatic spraying. These results show values that are among those with the highest frequency within the total of 120 leaves analyzed.

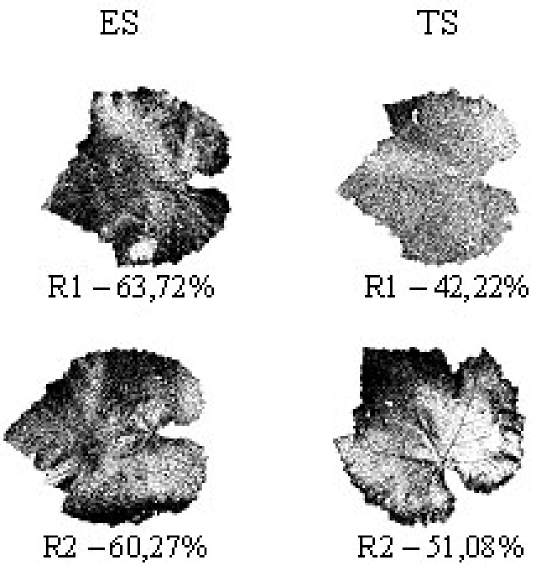

Figure 6. Coverage percentages in sample replications (R) of vine leaves; 2018 harvest. More intense color indicates greater deposition of tracer ingredient; ES-electrostatic spraying; TS-traditional spraying.

On the other hand, in Figure 6, it is highlighted that, in the visual comparison between a coverage value of 63.72% and another of 42.22%, in the latter, there is a better distribution of ingredients. Therefore, for this type of analysis, a greater degree of deposition does not always mean a greater degree of uniformity.

Figure 7 shows the frequency diagram of coverage percentages for all of the 2018 crop data, obtained along a 240 m path, adding those obtained with traditional (TS) and electrostatic spraying (ES). It is observed that the occurrence of leaves with low coverage is small, close to 5% and that the highest frequency of coverage data is in the range of 42.02% to 58.02%, which represents almost half of the data. A range of higher values, between 90.02% and 100%, had a significant frequency, close to 26% of the data. In general, concerning the accumulated frequency, it is noted that 75% of the coverage data are in the range of 42.02% and 74.02%. The results show that the mechanical configuration achieved in the prototype was able to promote a satisfactory percentage of coverage, with a high frequency of occurrence of values well above 30%, which can be considered an adequate minimum level for the control of plant pathologies (BRINK et al., 2016).

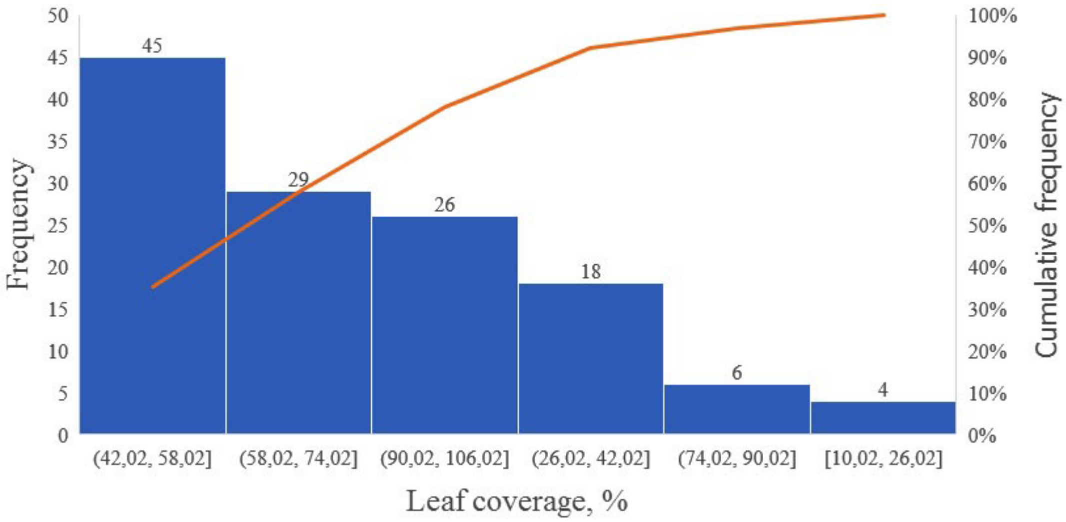

Figure 7. Frequency distribution for leaf coverage percentage ranges, obtained in a vineyard spraying; 2018 harvest.

Brink et al. (2016), in a laboratory experiment, showed that, for various parts of 'Chenin blanc' vine inoculated with *B. Cinerea*, a value of 30% coverage (percentage of area covered by fluorescent pigmentation and fenhexamide) was sufficient to control the diseases. Although, Van-Zyl et al. (2010) and Brink et al. (2016) highlighted that the minimum percentage of coverage concerning the control of plant pathologies may vary with the fungicide used, the cultivar in question, and the incident pathogen, among other factors.

Ferreira et al. (2013), tested a towed turbo sprayer (KO-A 2000 Speed Jet) on coffee crop, obtaining percentage values of leaf coverage ranging from 17.47% to 47%, determined in different parts of the canopy, under different liquid application volumes. Moniz (2020), studying different spray tips and spray volumes applied in the soybean crop, observed, through the visual analysis of a trained panel, that in the crop profile, a range from 14.04 to 55.85 in the percentage of coverage has been achieved.

Therefore, although there is no standardization in the expression of published results, regarding the issue of leaf coverage, for spraying prototypes, it is noted that, for different crops and different techniques adopted, the results achieved in this study fit or are above the range of values obtained elsewhere. Thus, satisfactory values in leaf coverage uniformity were reached, using the spraying technique under discussion.

Aspects of leaf coverage uniformity

Figure 8 shows the coverage uniformity values obtained with the leaf image segmentation technique (Figure 3) and their distribution along the machine path, in the order of sequential sample collection. In this case, a separation was made between electrostatic (ES) and traditional spraying (TS), for an "ad hoc" observation of the presence in the prototype of an electrostatic spraying system, since this detail increases the manufacturing cost. On the other hand, it is appropriate to bring up the determination of the spatial uniformity of the distribution of ingredients, through a numerical evaluation, less dependent on visual analysis (Figure 6), which may be more suitable for studying prototypes aiming at spraying efficiency.

A closer look at the coverage data can show if, once an active ingredient has been deposited, it is spatially well distributed over the leaf surface, which can be determined by an index of spatial variation of uniformity.

Figure 8 shows the variation curves of the coverage uniformity coefficients, obtained from the weighting between the values of the center of the clusters, determined for all leaves sampled in the outer layer of the canopy. Note that, regardless of whether the droplet electrization system is energized or not, variations in the coefficients between 5% and 45% are observed, with an average trend line of the data around 25%.

When the data were separated, considering the independent use of electrostatics (ES), a smoother curve was obtained, and the values of the coefficients of variation, from leaf to leaf, remained lower, that is, the distribution of ingredients was kept more uniform, up to approximately the thirtieth sample. In general, in this respect, the electrostatic spray curves are smoother and the values remained lower in a larger number of samples.

Table 5 shows that the mean values of the uniformity coefficients, for the two curves, do not differ statistically, and the fluctuations of the curves are described by the standard deviation values.

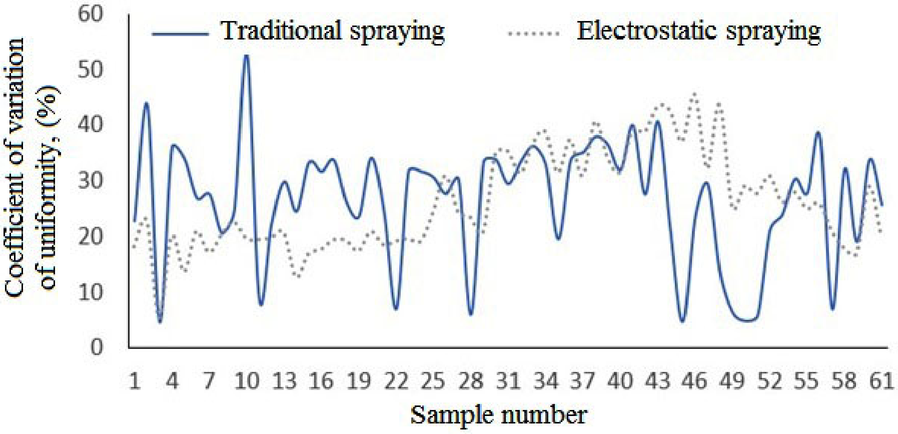

Figure 8. Coefficients of variation of the spatial uniformity of leaf cover, obtained with vine leaf sampling; 2019

Table 5. Statistical description for the coefficient of uniformity values.

Data	n.	Average	Standard deviation
Traditional spray (TS)	61	26,15 a	8,86
Electrostatic spray (ES)	61	26,55 a	10,73

Data followed by the same letter do not differ by Tukey's test (P<0.05).

Therefore, according to the discussion presented, the electrization of droplets is justified, due to the potential for improvements in spraying efficiency. Moreover, the use of the technology can contribute positively in applications at lower volumes, ensuring greater uniformity in the coverage of leaves, under a more critical condition, for the maintenance of a correct jet stream, under a probable reduction in droplet diameters.

Under low volumes, with a mixed amount of droplets of various dimensions being generated, between 30 and 200 μm, electrostatic spraying can help to achieve an optimal working point, that is, a minimum amount of spray solution with a maximum and evenly distributed coverage in the leaves, as discussed by Contiero et al. (2018). From now on, other studies, specifically related to pesticide application technology, will be able to detail this issue, regarding the practical application of the prototype developed in this work.

Conclusions

With a prototype of a towed recycler sprayer, with a confinement chamber, based on floating shield panels, it was possible to recycle the liquid at around 50% of the applied dose, for a vineyard with a developed LAI.

The distance between shield panels and the ventilation conditions influenced the spray liquid recycling capacity.

The prototype was able to promote a percentage of leaf coverage, most frequent in a range of 40% to 70%.

Numerical indicators of the variation of spatial uniformity in the distribution of spray liquid on the leaf showed that values between 5% and 45% were reached, with a less fluctuating degree of spatial uniformity between leaves, in an electrostatic spraying condition, which justifies its introduction into the equipment of the type.

The prototype studied, equipped with operational tools easily available on the domestic market, is a valid solution for the mechanization requirements of phytosanitary treatments, in vines grown in espaliers and similar crops.

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