



Article

Evaluation of Drift-Reducing Nozzles for Pesticide Application in Hazelnut (*Corylus avellana* L.)

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Abstract: Spraying pesticides using air induction nozzles is a well-known method to reduce drift. These drift-reducing nozzles have been tested on many different tree crops (such as apples, citrus, and grapes), but we are still lacking information on their utilization on hazelnut (*Corylus avellana* L.) groves, although hazelnut is a major nut crop in Italy, and in recent years its cultivated area has been constantly growing. This paper reports a comparison between treatments carried out with cone and flat-fan low-drift nozzles versus two conventional nozzles. The distribution quality, the number of droplets per cm² of the target area, and the drift in non-target trees adjacent to those treated were evaluated by analyzing the impact of the droplets on water-sensitive papers placed on the tree canopies. The results show that because no significative differences in terms of application quality were found between the tested nozzles, low-drift nozzles can be a good alternative to the standard nozzles to reduce the drift of pesticide applications in hazelnuts without altering the chosen distribution of the pesticide.

Keywords: pesticides; low-drift nozzles; anti-drift nozzles; spraying; plant protection products

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1. Introduction

The accurate application of plant protection products (PPP) is an essential prerequisite for obtaining the maximum effectiveness of pest and disease control, reducing the impact on the environment, safeguarding the health of operators, and obtaining a quality product, free from pesticide residues. In order to achieve these objectives in operational practice, the efforts of the farmer generally aim to choose the appropriate PPP to apply, calculate the best time to distribute them, and strictly adhere to the indications contained on the product label. However, especially in recent years, the importance of the role played by the equipment used for the application, its efficiency, and its use have been clearly highlighted. This vision is emphasized by the European Directive 128/08, which led to the issuance in the member countries of NAPs (National Action Plans on the sustainable use of plant protection products), which provide for specific actions regarding the use of sprayers and the application phase of the product. In this context, the drift of PPP is a critical element in the management of plant protection.

The drift constitutes the portion of the pesticide that is dispersed as fine droplets or vapor in the air at the time of treatment or immediately after it [1], and it includes endo-drift, which is loss within a treated field but not on the intended target, and exo-drift, the movement of spray droplets beyond the edge of a treated field [2]. The phenomenon is notoriously influenced by multiple factors and, although it can be reduced, it is very likely that it will not be completely eliminated. However, technologies and systems are now

available to mitigate the drift effects [3,4]. The management of the PPP application is the first and most obvious measure to obtain the maximum level of reduction, even if the training and pruning systems, the planting distances, the cultivation environments, and the location of the plants are to be taken into consideration. These practices include the choice, maintenance and functional verification of the sprayer machine and its components (with particular regard to the nozzles), and the adjustment (or calibration) of the machine distribution parameters according to the specific treatment to be carried out [5]. Furthermore, regardless of the systems adopted to reduce drift, the quality of the product application must always be evaluated, which must ensure that the vegetation is adequately protected.

Air induction (or air inclusion) nozzles can increase the droplet size, and are less susceptible to drift due to mixing air with the spray liquid. The peculiar design of these nozzles causes a reduction in the fluid pressure inside the nozzle body so that air is drawn into the nozzle (the Venturi effect) through holes in the nozzle side, which is then mixed with the spray liquid [6,7].

As regards the applications in hazelnut, the technical–scientific literature is rather lacking [8,9]. The pesticide application in this crop can be challenging because traditionally-trained hazelnut orchards have large and dense crowns, and operators prefer to carry out treatments with a high level of spray pulverization, a feature which is not assured by low-drift nozzles. However, drift-reducing nozzles, already widely used for field crops, have also been proven effective in application on many tree crops, such as apples [10–13], citrus [14,15], and vineyards [16,17].

Hazelnut is a major species of interest for nutritional use, and it is the second most economically valuable commercial tree nut crop, after almond. In 2019, hazelnut covered a surface of more than one million of hectares world-wide [18]. Production is mainly concentrated in two countries: Turkey (ca. 70% of the world's production) and Italy (10–15%). In recent years, in Italy, a positive trend in hazelnut cultivation has been occurring [19]. In 2020, the crop covered an area of 88,474 ha [20], and the Province of Viterbo (Central Italy) contributed with around 1/3 of the national production [19].

The aim of this work is to compare the quality of application of hydraulic conventional nozzles (core disks and ATR) with two types of low-drift nozzles (cone and flat-fan air induction nozzles). The endo-drift of the treatments was also assessed by evaluating the distribution quality on non-target trees adjacent to those treated. Moreover, the pesticide application on hazelnut is so far poorly investigated and related studies need to be expanded.

2. Materials and Methods

The experimental tests were carried out in an hazelnut grove (*Corylus avellana* L., var. Tonda Gentile Romana), with a 5 × 5 m layout and a height of about 6.5 m, located in the Viterbo Province, Central Italy (42°15'43.63 N; 12°9'39.2 E) (Figure 1). The trees were trained as a multi-stemmed V-shaped shrub, with 4–5 stems per plant, as is typical of the area. The plants showed uniform vegetative growth. The trials were carried out in July 2020, when the plants reached a full growth stage.

Before planning the experimental design, information on regulation of the sprayers adopted in the area was collected. Moreover, the research group was advised by the local technicians and farmers both on the conventional adopted setup of the sprayer and on the main technical issues of the pesticide application in hazelnut orchards in the region.

The samplers (water sensitive papers–WSP) for the evaluation of the spraying were placed on four plants 10 m apart on each of the four adjacent rows (A, B, C and D) chosen inside the orchard. The sprayer travelled between the central rows (B and C) by spraying the plants with water, according to the four test configurations (Figure 1). The plants on adjacent rows (A and D) were not sprayed, and the distribution analyses of the WSP placed on these plants provided the data for the endo-drift evaluation.



Figure 1. Location and scheme of the experimental test. The red arrow indicates the path of the sprayer (photo from Google Earth).

The assessment of the deposition and losses was carried out by means of 7×10 cm WSP (Syngenta), placed on vertical metal rods according to the following scheme: on each of the four plants of the central rows (B and C) four WSP were placed at a height of 0.5, 1.5, 3.0, and 4.5 m from the ground, while on the lateral rows (A and D) three WSP were placed at 5.0, 1.5, and 3.0 m (Figure 2). In addition, three other WSP, spaced about 0.8 m apart, were suspended from a wire placed between the plants of the central rows, at a height of 6.0 m, for a total of 12 sampling points. A total of 72 sampling points was thus obtained for each treatment.

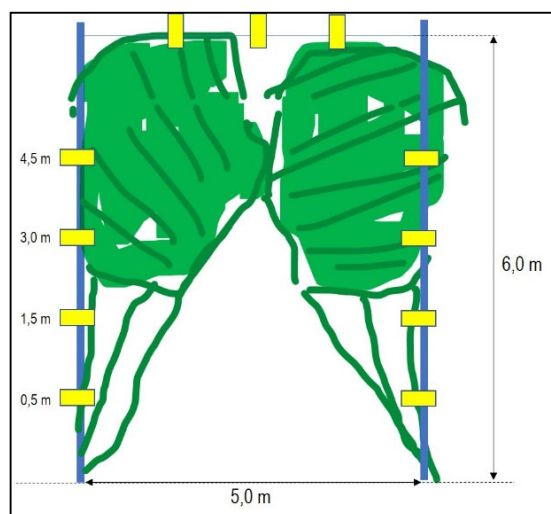


Figure 2. Scheme of the water-sensitive papers' placement on the hazelnut plants.

The analysis of the number of the impacts detected on the WSP allowed us to calculate the number of droplets per cm^2 , and to assess the spray coverage quality [21,22]. The analysis of the WSP was carried out by two methods: (1) by attributing a qualitative score rating of the degree of coverage after a visual reading of the WSP (Figure 3), and (2) by means of a computer-assisted image analysis, carried out after the digitization of the WSP images using a specific MATLAB routine developed at CREA-IT, which uses a

supervised segmentation method based on K-Nearest Neighbors (KNN) multivariate clustering [23,24]. Such a routine allows the automatic counting of the impact stains once the image is segmented. The score attributed through visual analysis is the average of the scores assigned by two researchers who operated independently during the rating of the coverage quality scores. The score rating varied up from -2 (insufficient coverage) to 2 (excessive coverage), by integer values; the score is considered optimal when the values approach 0 (Figure 3). In general, good distribution occurs when the spray spots are well distributed on the WSP but not overlapping, as an index of a uniform distribution.

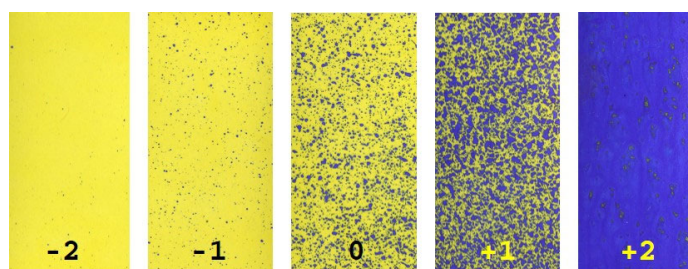








Figure 3. Example of the scores (from -2 to $+2$) assigned to the water sensitive papers by visual rating, according to the quality of the coverage. A score equal to zero is an ideal quality coverage.

An air-blast sprayer with an axial fan (F.lli Muzzi, model RC15S) with a 1,000 L tank, pulled by a Massey Ferguson 3660F (Xtra) tractor, was used for the tests.

The sprayer configurations adopted in the experimental field tests are summarized in Table 1. The following nozzles were used: cone disk core (ceramic) 1.2–1.2; ATR cone 80° , ISO (green); cone low-drift TVI 80° 02 (yellow) and 04 (red); flat-fan low-drift CVI 80° 02 (yellow) and 04 (red); all of the nozzles were made by the company Albuz.

Table 1. Main characteristics of the sprayer configurations under test.

Test	Nozzles		Vertical Distribution Adjustment	Number of Nozzles N.	Pressure bar	Fan Regulation	Forward Speed km/h	Volume Rate L/ha
P	Disk core 1.2–1.2		As usual	8	8	2	6.8	356
V	ATR cone 80° , green		Vertical test bench	8	8	1	5.9	409
R	Cone low-drift TVI 80° 02		Vertical test bench	4	8	2	5.9	318
	Cone low-drift TVI 80° 04			4				
X	Flat-fan low-drift CVI 80° 02		Vertical test bench	4	8	2	5.9	318
	Flat-fan low-drift CVI 80° 04			4				

Before trialing the flow rates of the nozzles, the actual operating pressure and the vertical distribution diagrams were determined for each sprayer configuration. For this last purpose, a vertical tray test bench (AAMS-Salvarani mod. 904520) with 14 mounted plates was used. An adjustment of the vertical distribution was made before the 'V', 'R' and 'X' trials, while the configuration 'P' was considered the usual sprayer's setup, and no vertical distribution adjustment was made. Only in one test ('V', the one with ATR cone traditional nozzles) the sprayer's fan speed was set on position 1, obtaining a reduction of the air speed and volume provided by the fan.

The micrometeorological conditions during the tests were continuously monitored by a Kestrel 4500 portable weather station.

The data regarding the coverage quality and the number of droplets per cm² obtained from the WSP placed on the plants of the two central rows (B and C) of the experimental plot were analyzed in order to assess the quality of the spray distribution. The data coming from the two adjacent rows (A and D) gave information relating to the potential drift. Then, the data of the 12 WSP placed at 6 m from the ground, between rows B and C, were analyzed in order to obtain an evaluation of the spray deposition in the upper part of the crown.

The statistical elaboration of the data was performed with the software R [25].

3. Results

During the trials, the air average temperature was 27.8 °C, the wind remained stable (with an average wind speed of 0.7 m s⁻¹), and the relative humidity was 51.8%.

The four different configurations tested provided similar values of volume rate, which ranged from 318 to 409 L/ha (Table 1).

After a preliminary statistical test on the variables' distribution, the values of the number of droplets per cm² and of the visual scores of the WSP were found not to be normally distributed after the Shapiro–Wilk test, which examines whether a variable is normally distributed in a population [26]. Therefore, in order to analyze the data set and compare the differences in the average values of each test, a statistical non-parametric test—namely the Kruskal–Wallis test—was applied. This test is the non-parametric equivalent and rank-based test of the one-way analysis of variance (ANOVA) [27].

The visual scores and the number of droplets per cm² of the WSP are showed in Figure 4; Figure 5, respectively.

In terms of quality coverage, rated assigning a visual score ranging from −2 to 2, the best result was obtained with the treatment 'R', which employed the cone low-drift nozzles (Figure 4a), which gave a score closer to 0 (ideal coverage quality). However, after the Kruskal–Wallis test, these differences were proven not to be significantly different (Table 2). The homogeneity of the treatments was even more clear after evaluating the endo-drift of the treatments, assessed by the rating of the WSP placed in the rows adjacent to those treated (Figure 4b). In this case, all of the WSP presented similar average scores.

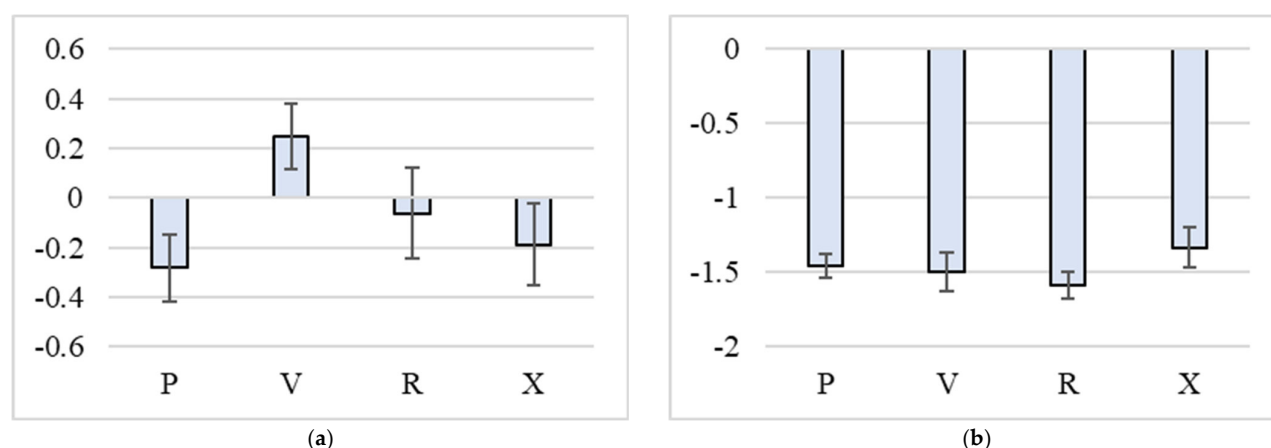


Figure 4. Average values \pm standard error of the visual scores of the WSP obtained in (a) the central rows and (b) the adjacent rows, by the four sprayer configurations.

The average number of the impacts per unitary area shows that the four types of tested nozzles gave similar results in the target rows (central rows, Figure 5a). Regarding the evaluation of endo-drift carried out on the adjacent rows (Figure 5b), the treatments

with low-drift nozzles clearly showed the lowest number of impacts on the WSP, even though also these figures are not statistically different.

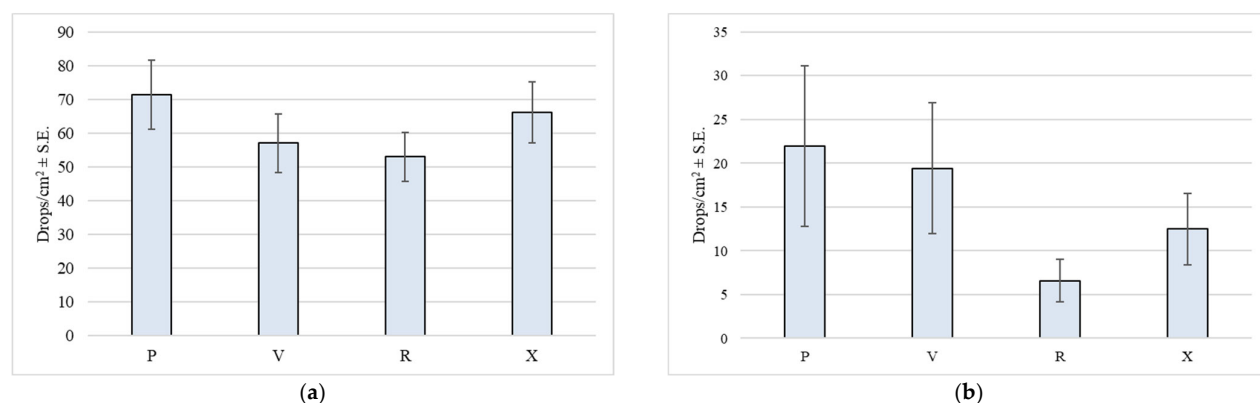
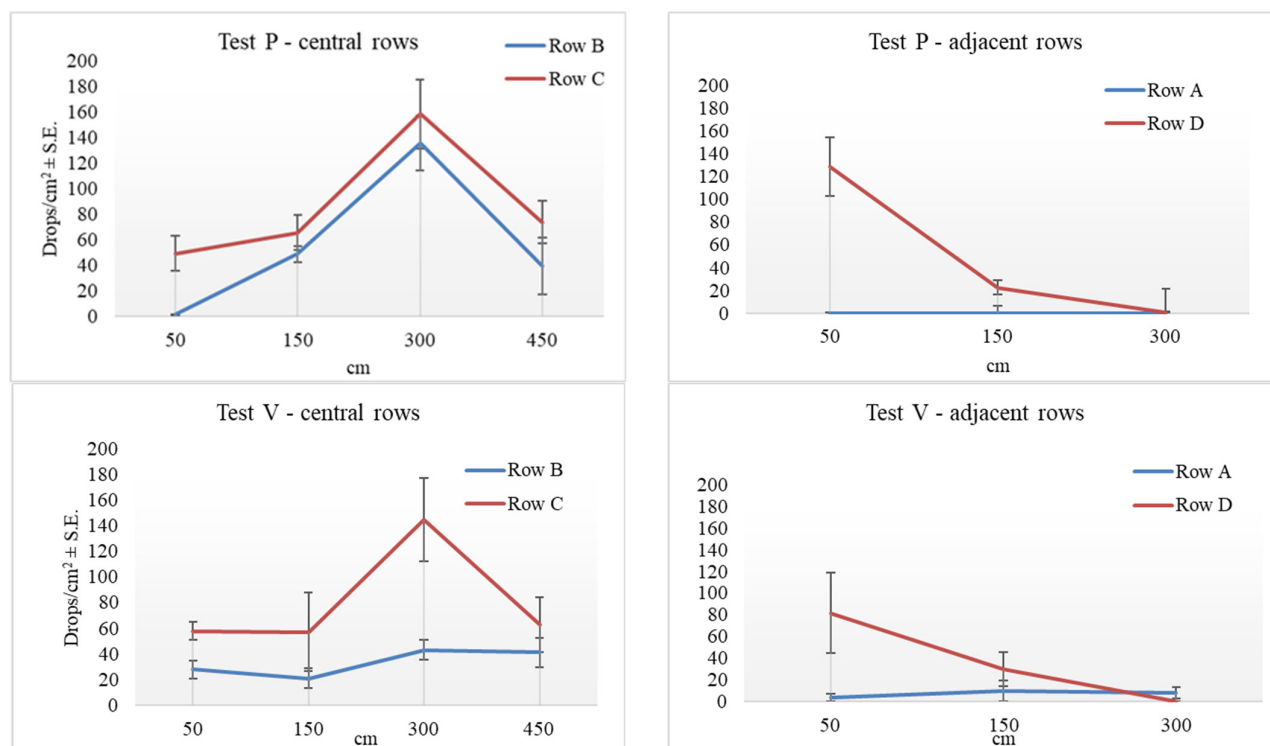


Figure 5. Average values \pm standard error of the number of droplets per cm² collected on the WSP obtained in (a) the central rows and (b) the adjacent rows by the four sprayer configurations.

The results in terms of the number of droplets per cm² is shown in detail in Figure 6, in which the values are reported for each row of plants. In this case too, no statistically significant differences among the treatments was observed (Table 2). However, the treatment 'X' which utilized the flat-fan low-drift nozzles, showed a better result in the samples placed at 150 cm of height, a position where the coverage of the vegetation is particularly needed. The treatment 'R', the one with cone low-drift nozzles, showed the best results in terms of drift reduction, with the lowest number of droplets per cm².

All of the treatments show a peak of impacts per cm² in the row 'D' (those on the right of the treated zone, watching the plot from behind), especially at 50 cm of height.



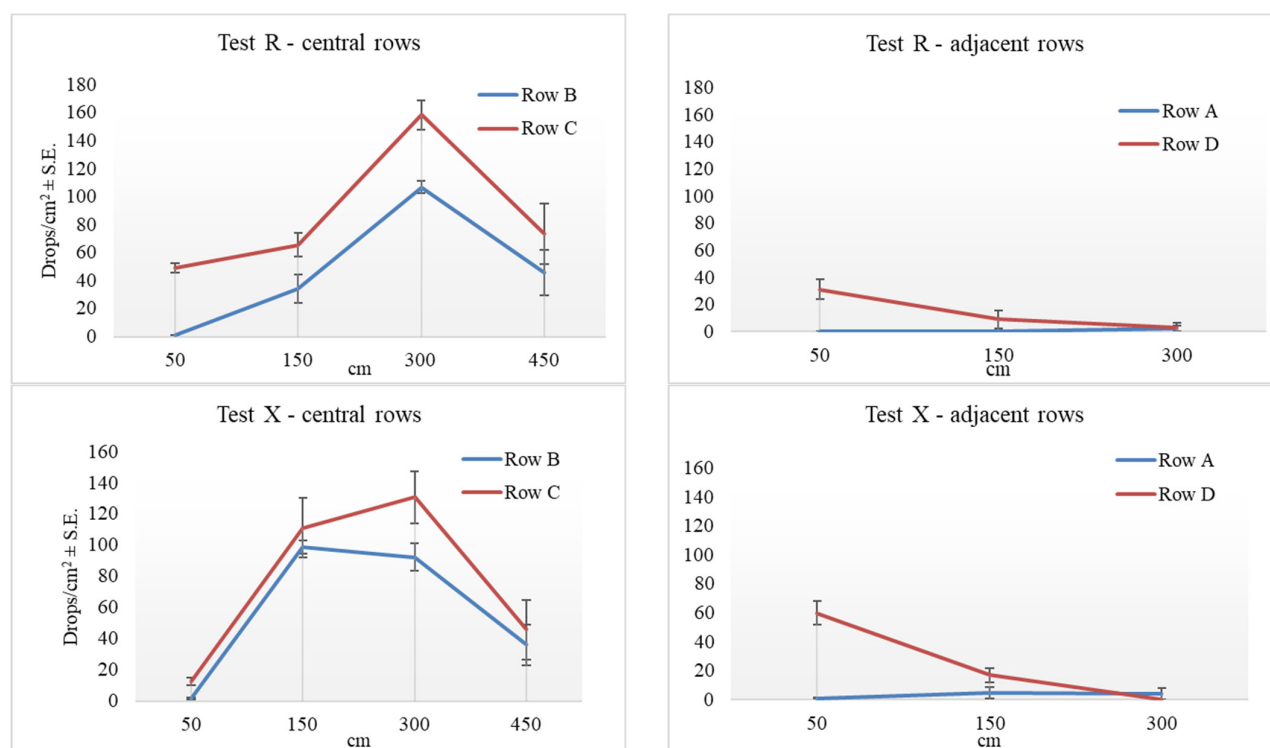


Figure 6. Average values \pm standard error of the number of droplets per cm^2 collected on WSP by the four sprayer configurations. The figures show the values for the central rows (B and C) on the left and the values for adjacent rows (A and D) on the right.

Regarding the results of spraying in the upper part of the trees, evaluated by means of the WSP placed at 600 cm of height, the results in terms of droplets per cm^2 , and of the visual quality scores, are summarized in Figure 7. In this case, the differences are statistically significant, with the worst result provided by the treatment 'V' (ATR nozzles), which appears to be unable to correctly cover the tops of the plants (Table 2).

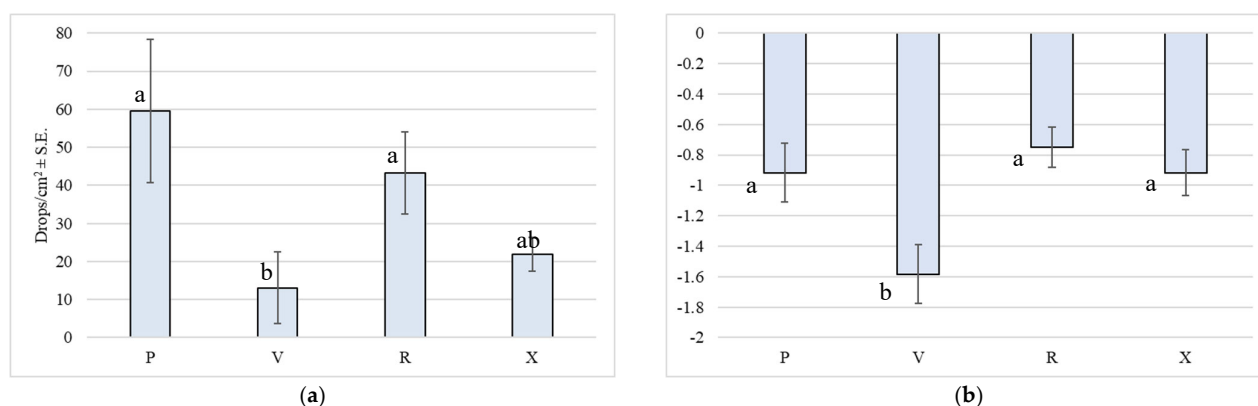


Figure 7. Average values \pm standard error of the number of droplets per cm^2 (on the left), and of the visual scores for the WSP placed at a height of 6 m (the difference between the means is not statistically significant for the means with the same letter).

Table 2. Kruskal–Wallis chi-squared statistics and P-values for the position of the samples, year, and method of quality application evaluation of the WSP.

WSP Position	Evaluation	Kruskal-Wallis Chi-Squared	d.f.	p-Value
Central rows	Visual score	5.6092	3	0.1322
	Droplets per cm ²	1.8353	3	0.6073
Adjacent rows	Visual score	1.4996	3	0.6824
	Droplets per cm ²	6.6379	3	0.08438
At 6 m from the ground	Visual score	11.937	3	0.007603
	Droplets per cm ²	13.233	3	0.004159

4. Discussion and Conclusions

The present work tested four different sprayer configurations in order to compare low-drift and traditional nozzles for the treatment of hazelnut. The pesticide applications in this crop are mainly challenged by the crown shape and size of traditionally-trained orchards. Farmers usually tend to obtain a fine pulverization of the spray when they try to reach the upper part and the inner portions of the vegetation. However, this method can lead to an increase of drift, with pesticide losses outside of the treated field. Air induction nozzles can overcome this inconvenience because they produce coarser and heavier droplets, which are less affected by the aerial lift. Numerous scientific and technical studies have shown that low-drift nozzles can also guarantee an adequate protection in tree crops. However, information on the utilization of this category of nozzles in pesticide application in hazelnut is rare. Moreover, given the particular geometric conformation of the crowns of the hazelnut, which is traditionally trained as a multi-stemmed V-shaped shrub, it is not easy to transfer the acquisitions deriving from experimental tests made on other tree crops. Experimental tests are consequently needed.

Generally, the obtained results showed that the coverage quality and the number of droplets per surface unit were statistically comparable for both low-drift and conventional nozzles. The four tested configurations entailed a similar volume rate per hectare and the same working pressure. Only the configuration ‘V’ (with traditional cone ATR hydraulic nozzles) showed a scarce capability to reach the upper part of the vegetation, even if this treatment utilized at the highest volume rate (409 L/ha). This result is easily explained by the fact that the configuration ‘V’ was the only one with the setting of the sprayer’s fan to position ‘1’, which produces a reduced air speed and volume.

Regarding the evaluation of the endo-drift conducted on the adjacent rows (Figure 5b), the treatments with low-drift nozzles clearly showed the lowest number of impact stains on the WSP, with a greater reduction achieved by the test ‘R’ with cone low-drift nozzles. However, these figures are not statistically different, likely because the obtained data were highly variable according to the height of sampling. In particular, all of the treatments show a peak of impacts per cm² in the row ‘D’ (those on the right of the treated zone, watching the plot from behind), especially at a height of 50 cm. This phenomenon is due to the strong asymmetry of the spraying towards the right (being the direction of rotation of the fan clockwise) caused by the typical effect of the axial fan, which blasts the air asymmetrically on the right and left side of the vegetation. The adjustment of the vertical pattern distribution can be achieved using a vertical test bench. However, such a defect was only partially mitigated by the adjustment made with the test bench for the configurations ‘V’, ‘R’ and ‘X’, because the asymmetry of the distribution remained clearly visible on the WSP.

The adopted experimental scheme allowed us to investigate the penetration of the drops at a height that is not frequently examined in experimental spraying tests, which is instead considered of particular interest for the phytiatric efficacy of the treatment. As for the results obtained by examining the WSP placed at a height of 6 m, in the upper central area of the vegetation, the use of the anti-drift nozzles did not give any problem, and the coverage quality appeared to be even better than that produced by traditional

nozzles. In detail, at a height of 6 m, the coverage provided by the ‘V’ treatment (with a reduced fan speed) turned out to be the worst.

In conclusion, the present work showed some low-cost technical solutions which are easily transferable to farmers, i.e., the low-drift nozzles appeared to assure—in the studied conditions—a regular spray coverage of the vegetation and a reduction of the drift during treatments to hazelnut. In order to obtain a more complete picture, the next stage of this research entails the study of biological data on insect and disease control.

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