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Book Title: Safety, Health and Welfare in Agriculture and Agro-food Systems

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Part of the Lecture Notes in Civil Engineering book series (LNCE,volume 252)

Conference paper - First Online: 23 March 2022

Cite this papera as:

Benalia, S., Violi, L., Barreca, P., Zimbalatti, G., Bernardi, B. (2022). Analysis of Spray Behavior Using Different Sprayers in Citrus Groves. In: Biocca, M., Cavallo, E., Cecchini, M., Failla, S., Romano, E. (eds) Safety, Health and Welfare in Agriculture and Agro-food Systems. SHWA 2020. Lecture Notes in Civil Engineering, vol 252. Springer, Cham. https://doi.org/10.1007/978-3-030-98092-4_41

M. Biocca et al. (Eds.): SHWA 2020, LNCE 252, pp. 1–9, 2022.
https://doi.org/10.1007/978-3-030-98092-4_41

Analysis of spray behavior using different sprayers in Citrus groves

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Abstract. This paper reports the results inherent to technical performances of three different sprayers used in citrus orchards in Calabria (Southern Italy). Accordingly, quantitative and qualitative analyses of the spray were performed. Spray quantitative assessment, related to foliar deposit and losses to the ground, was based on the colorimetric method. While spray qualitative evaluation considered water-sensitive paper (WSP) image analysis. This was performed subsequently to field experimental trials, which consisted in spraying citrus orchards with a dye solution and collecting the required samples, i.e., leaves for foliar deposit, petri dishes for ground losses, and WSP for spray qualitative analysis. Statistically analyzed data showed significant differences between the assessed sprayers considering foliar deposition (Kruskal-Wallis: χ^2 = 40.327, df = 2, p = 1.75e^{-9}). In addition, some unfavorable aspects were encountered regarding ground losses and qualitative distribution when applying plant protection products with the tested sprayers.

Keywords: Citrus, foliar deposition, ground losses, plant protection equipment, spray analysis.

1. Introduction

Italy is the third largest producer of citrus in the Mediterranean. In this country, this crop is spread over 149,348 ha producing more than 2.89 million tons, according to the data of the National Institute of Statistics related to 2017 campaign [1]. Thanks to the favorable climatic conditions, citrus thrive well in Calabria (Southern Italy), indeed, this district accounts 37,462 ha, representing 25 % of the domestic citrus area, making this crop one of the characteristic cultivations of the rural landscape.

Diversely from other fruit crops, citrus is characterized by a dense vegetation canopy. Consequently, this makes it a suitable environment for several pests and diseases, engendering the necessity to intervene with crop protection practices, further than adequate pruning, to guarantee yields from both quantitative and qualitative point of view.

Chemical application efficacy technically depends on a series of factors, among which, the maximum vegetation coverage, the maximum evenness, and the optimum penetration of the required amount of the active principle [2]. However, while performing this practice, we often assist to a low deposition of the spray on the target as well as to losses of a great amount of the product in the atmosphere (drift) and to the ground.

This low effectiveness of the application is often attributable to the poor or inadequate calibration and use of the spraying equipment [3]. In fact, depending on the type of treatment, the nature of the formulations and the crop features different operating conditions of the equipment can be set to guarantee effectiveness and sustainability [4]. Following the implementation of the Directive 2009/128/CE [5], which establishes a framework for a sustainable use of pesticides, the present work aims at assessing the performance of crop protection equipment used in Calabrian citrus orchards in terms of spray deposit and ground losses.

2. Material And Methods

2.1 Field and machinery description

To assess spray behavior while performing agrochemical application in Calabrian Citrus orchards, three different sprayers were considered: the Maschio mod. UNIGREEN EXPO mist blower (UGE), mounted on NEW HOLLAND TN95F tractor, the DSM Frutteto 1000 (F1000) and the electrostatic EFFE 3 (EF3) mist blowers, both towed by a MASSEY FERGUSON 3435 F tractor. Experimental trials simulating agrochemical application were carried out in private farms in the Province of Reggio Calabria (Fig. 1a and 1b). Field and main machinery features are reported in the following Table 1. The trials were carried out considering the operative parameters usually employed in each farm.

Fig. 1a. Application of tartrazine solution in a bergamot orchard using Maschio mod. UNIGREEN EXPO mist blower (UGE).

Fig. 1b. Application of tartrazine solution in an orange orchard using DSM Frutteto 1000 mist blower (F1000).

Table 1. Field and machinery characteristics used in trials

	Unit	UGE	F1000	EF3
Observed area	m^2	1000	896	1512
Crop layout	m	5 x 5	7 x 8	7 x 9
Tank capacity	l	400	1000	1000
Distributed volume	$l·ha^{-1}$	800	1529	165
Advancement speed	$Km·h^{-1}$	1.8	0.3	0.3
Exercise pressure	bar	20	15	15
Nozzle type		Albuz 1.0 Pink HCI60 green	Albuz 1.5 in brass	Anti-drift MGA 8001
Nozzle number		12	16	14

2.2 Quantitative and qualitative assessment of spray distribution

The quantitative analysis of the spray is based on the estimation of foliar deposit and ground losses expressed in $\mu L·cm^{-2}$. This is performed through the calculation of the intercepted volume by the target (leaves and captors) of a food dye solution applied in the field using the sprayer as to simulate a plant protection product (PPP) application [6-7]. Therefore, a solution of tartrazine yellow (E102, 85%) was used, as reported by Sánchez-Hermosilla et al. [8] and Sánchez-Hermosilla et al. [9]. Subsequently to spraying operations, samples were collected individually and put in hermetic bags for laboratory analysis as carried out by Bernardi et al. [10]. These included, washing the samples with a known amount of distilled water in order to extract the captured dye by each target. After that, each solution was analyzed using the UV/Visible scanning spectrophotometer Shimadzu UV-1800 at 426 nm, this being the absorbance peak of the tartrazine yellow solution, to determine the solution concentration and subsequently the solution volume that reached each target. Afterward, the leaf area of each sample was measured using a leaf area meter (LI-COR 3100, LICOR, USA), to reference the intercepted volume of tartrazine solution to the relative area and express it in µL cm^{-2}.

To assess foliar deposit evenness on the tree canopy, different foliage heights were considered for leaf sampling. Particularly, in the first trial, when implementing the sprayer UGE, leaves were sampled at about 1 to 1.2 m for lower foliage, at 2 m for intermediate foliage and above 2.5 m for upper foliage. However, int the second and third trials, using respectively the sprayers F1000 and EF3, sampling was performed taking into account just the lower and upper foliage, as tree dimensional characteristics were different from those of the first trial. Hence a total of 96 natural samples (leaves) were collected. For ground losses, Petri dishes used as artificial captors, were randomly positioned between the rows interested by tartrazine yellow application. A minimum of 10 captors were used in each trial, for a total of 36. In addition, water-sensitive papers (WSP) were randomly set amongst the vegetation (Fig. 2a and 2b), to assess spray distribution from the qualitative point of view as carried out by Bernardi et al. [10].

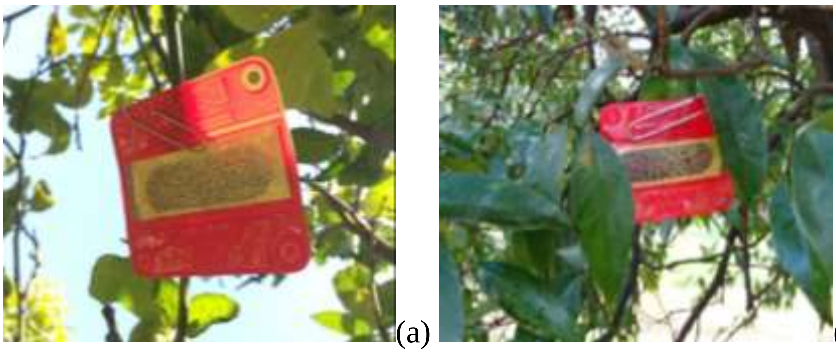

(a) (b)

Fig. 2. Water-sensitive paper used for qualitative assessment of foliar deposit.

As the distributed volume was not equal in all the trials, the foliar deposit and ground losses data were first normalized referring them to a volume of 1000 $l \cdot ha^{-1}$.

The obtained data were statistically analyzed using R software (version 3.3.1). First, data normal distribution was checked by performing the Shapiro-Wilk normality test. After that one-way analysis of variance (ANOVA) was applied when data normality was verified, otherwise, the non-parametric Kruskal-Wallis was chosen to highlight any difference between the treatments.

Water-sensitive papers were analyzed with ImageJ 1.45s software using Java (1.6.0-20). This included the conversion of their scanned images into grayscale and then to a binary process that permitted particle (or spot) counting.

3. Results and Discussion

Normal distribution of foliar deposit data was checked by performing the Shapiro-Wilk normality test. The results showed that the null-hypothesis is rejected (W = 0.78758, p-value = $1.867e^{-10}$). Hence, the Kruskal–Wallis test was used to compare the foliar deposit generated by each tested equipment. Such a test showed a significant difference between the performances of the tested sprayers in terms of foliar deposit (Kruskal-Wallis $\chi2$ = 40.327, df = 2, p = $1.75e^{-9}$). The mean and median values corresponding to the normalized foliar deposit generated by these sprayers are reported in the following Table 2.

Table 2. Mean and Median values of the normalized foliar deposit ($\mu l \cdot cm^{-2}$) for each sprayer type.

	UGE	F1000	EF3
Mean values ($\mu l \cdot cm^{-2}$)	4.366	3.662	10.180
Median values ($\mu l \cdot cm^{-2}$)	3.9330	3.6985	9.0240

The One-Way Anova performed on the foliar deposit obtained by UGE in the first trial did not show any significant difference according to foliage height (F= 0.434; df (2; 21), Pr (>F) = 0.654) meaning that vertical distribution evenness is quite guaranteed when using this sprayer with the previously mentioned parameters (Fig3).

Fig.3. Normalized foliar deposit mean values obtained by UGE in the first trial according to foliage height ($\mu l \cdot cm^{-2}$).

The same situation was verified for the sprayer F1000 (F= 0.246; df (1; 32), Pr (>F) = 0.623) as shown in the following Fig.4, for the sprayer EF3 normal foliar deposit was significantly affected by sampling height (Kruskal-Wallis $\chi2$ = 8.2696, df = 1, p = 0.004032). Mean values are reported in Fig. 5.

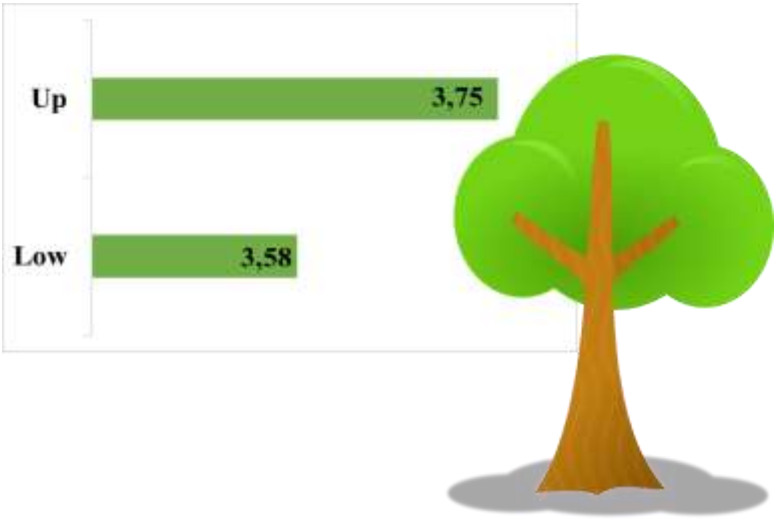


Fig.4. Normalized foliar deposit mean values obtained by F1000 in the second trial according to foliage height (µl·cm^{-2}).

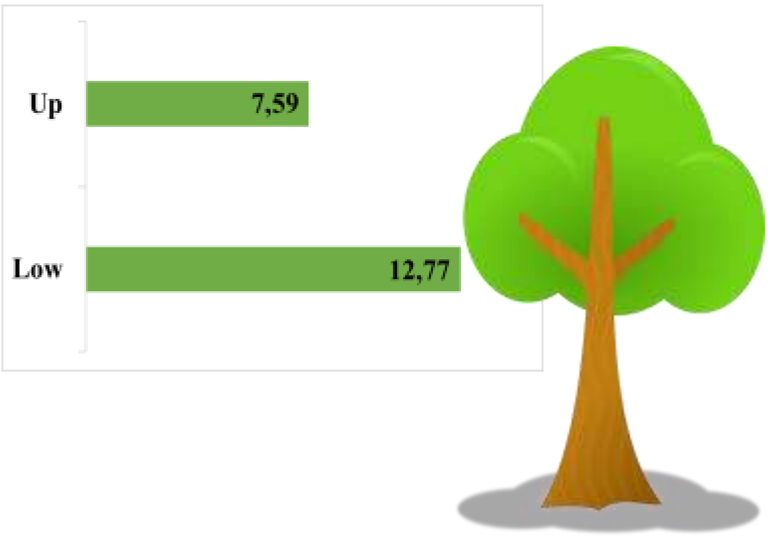
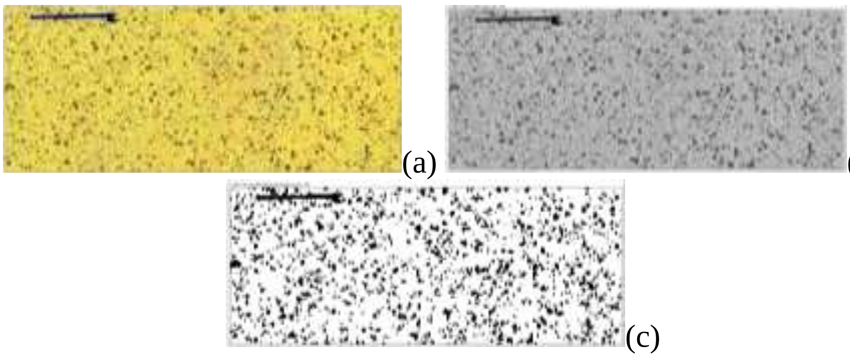


Fig.5. Normalized foliar deposit mean values obtained by EF3 in the third trial according to foliage height (µl·cm^{-2}).

The foliar deposit generated by a determined spraying machine represents the resultant of the adjustment of its operative parameters and constitutes an important factor for the evaluation of spray quantitative and qualitative assessment. In fact, the study conducted by Garcerá et al. [11], allowed the modelling of the impact area coverage as well as of the efficiency of two oily formulations according to spray deposit in laboratory conditions. The results they obtained were subsequently validated in the field considering the cochineal of the citrus fruits *Aonidiella aurantii Maskell* (CRS) as a reference pest. Deposits of 1.01 $\mu L \cdot cm^{-2}$ for the organophosphorus formulations and 3.41 to 4.72 $\mu L \cdot cm^{-2}$ for the mineral oils, were necessary to obtain the efficiency of 90% of a generation with prevalence of juvenile stages. The authors believe that deposits of 3.41 $\mu L \cdot cm^{-2}$ for the first category and 4.72 $\mu L \cdot cm^{-2}$ for the second category are adequate for the control of subsequent pest generations. The sprayers UGE and F1000 generated spray deposit like those recommended in this study. Even though spray deposition generated by the sprayer EF3 is relatively high, if compared to the two other sprayers, it remains lower than that obtained by De Araújo et al. [12] (12.42 $\mu L \cdot cm^{-2}$) who assessed spray deposit according to spray volume, fruit growth and rainfall in citrus black spot control.

Qualitative analysis carried out by analyzing water-sensitive paper images (Fig.6a, 6b,and 6c) showed that drop foliar coverage reached 46.364 % with drop dimensions varying from 0.001 cm^2 to 0.04 cm^2 when using the sprayer UGE. The average foliar coverage obtained by the sprayer F1000 was 38.23 %, while for the sprayer EF3, it was of 37.84 % with droplet dimensions varying from 0.002 cm^2 to 0.013 cm^2 for both.



(a) (b) (c)

Fig. 6. Conversion and analysis of water sensitive paper for spray qualitative analysis: (a) original image, (b) gray-scale image, (c) application of a binary process.

Also for ground losses, a significant difference was found between the analyzed equipments (Kruskal-Wallis $\chi 2 = 20.481$, df = 2, p = $3.57e^{-05}$). The mean and median values of the normalized ground losses produced by these sprayers are reported in Table 3. These data show the high amount of losses generated by both sprayers F1000 and EF3, indicating that these two systems need adjustment of operative parameters.

Table 3. Mean and Median values of the normalized ground losses ($\mu l \cdot cm^{-2}$) for each sprayer type.

	UGE	F1000	EF 3
Mean values ($\mu l \cdot cm^{-2}$)	1.504	5.836	8.341
Median values ($\mu l \cdot cm^{-2}$)	1.04300	6.01514	5.40900

4. CONCLUSIONS

The present work constitutes a preliminary evaluation of the equipment employed in citrus crop protection in Calabria. The obtained outputs clearly reveal that this practice presents critical issues. Although somehow the foliar deposit was homogeneous considering foliage height, the qualitative analysis of spray as well as the ground losses confirmed that two of the three tested sprayers need serious adjustments of the operative parameters before implementing them in plant protection practices. Further experimental trials are needed in view to enhance this practice by increasing agrochemical application efficiency and significantly reducing the losses.

Acknowledgment

The present research was realized in the framework of the National Operative Project PON Ricerca e Competitività 2007-2013, PON03PE_00090_3 MODELLI SOSTENIBILI E NUOVE TECNOLOGIE PER LA VALORIZZAZIONE DELLE FILIERE VEGETALI MEDITERRANEE” funded by the Italian Ministry of Education, University and Research.

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