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► **To cite this version:**

S. Meli, A. Renda, M. Nicelli, E. Capri. Studies on pesticide spray drift in a Mediterranean citrus area. *Agronomie*, 2003, 23 (7), pp.667-672. 10.1051/agro:2003044 . hal-00886222

**HAL Id: hal-00886222**

**<https://hal.science/hal-00886222>**

Submitted on 11 May 2020

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## Studies on pesticide spray drift in a Mediterranean citrus area

S.M. MELI<sup>a</sup>, A. RENDA<sup>b</sup>, M. NICELLI<sup>c</sup>, E. CAPRI<sup>c\*</sup>

<sup>a</sup> Dipartimento di Scienze Agronomiche, Agrochimiche e delle Produzioni Animali, Sezione di Scienze Agrochimiche, Università degli Studi di Catania, via Santa Sofia 98, 95123 Catania, Italy

<sup>b</sup> ARA s.n.c., via Madonna delle Lacrime 70, 95030 San Giovanni La Punta (Catania), Italy

<sup>c</sup> Istituto di Chimica Agraria ed Ambientale, Università Cattolica del Sacro Cuore, via Emilia Parmense 84, 29100 Piacenza, Italy

(Received 24 October 2002; accepted 16 May 2003)

**Abstract** – The European Directive 91/414/EEC, concerning the authorization procedure for plant protection products, requires the calculation of pesticide spray drift during application through the use of look-up tables based on Ganzelmeier tables. The objectives of this study were to measure the spray drift in citrus crops in a Mediterranean setting, to evaluate the influence of the main agronomic factors influencing the process, and to assess the suitability of the Ganzelmeier data. Eight trials were carried out in 4 different farms, with two application methods in each farm (manual lance application and fan-assisted application). Chlorpyrifos-methyl (RELDAN22<sup>®</sup>) was used as the test compound. Spray drift deposits when the manual lance was used were on average 65% lower than when the fan-assisted sprayer was used. Use of a lance therefore carries a lower pollution risk for surface waters. The amount of spray drift was affected by the relative wind speed (manual application and fan application) and wind direction, temperature, and sprayer characteristics (fan application). The data obtained in this study demonstrate that drift calculated with Ganzelmeier tables under these conditions is greatly over estimated, and a new model is proposed.

**pesticide / spray drift / manual lance application / fan-assisted application / chlorpyrifos-methyl / citrus**

**Résumé** – Études sur la dérive des aérosols de pesticides dans une zone méditerranéenne de production d'agrumes. La Directive Européenne 91/414/EEC concernant la procédure d'autorisation pour les produits phytosanitaires, requiert le calcul de la dérive des aérosols de pesticides durant leur application en utilisant des tableaux d'estimation basés sur les tables de Ganzelmeier. Les objectifs de cette étude étaient de mesurer les dérives de pesticide pour la culture d'agrumes dans une plantation méditerranéenne, d'évaluer l'influence des principaux facteurs agronomiques sur le processus et d'apprécier l'adéquation des données de Ganzelmeier. Huit essais ont été conduits dans quatre exploitations, avec deux méthodes d'application dans chaque exploitation (application à l'aide d'une lance manuelle et avec un pulvérisateur soufflant). Pour le test, du chlorpyrifos-méthyle (RELDAN22<sup>®</sup>) a été utilisé. Quand la lance manuelle était utilisée, les dépôts de dérives d'aérosols de pesticides étaient en moyenne 65 % plus faibles par rapport à l'utilisation du pulvérisateur soufflant. Par conséquent, l'utilisation d'une lance représente un moindre risque de pollution pour les eaux de surface. La quantité de dérive d'aérosols de pesticide était influencée par la vitesse relative du vent (application manuelle et pulvérisateur soufflant), la direction du vent, la température et les caractéristiques du pulvérisateur (système soufflant). Les données obtenues dans cette étude montrent que la dérive calculée à l'aide des tables de Ganzelmeier dans ces conditions est fortement surestimée, et un nouveau modèle est proposé.

**application de pesticide / dérive d'aérosol / lance manuelle / pulvérisateur soufflant / chlorpyrifos-méthyle / agrumes**

### 1. INTRODUCTION

Pesticides have been widely used in agriculture for several decades. However, they may negatively influence the equilibrium of the chemical and biological processes in the environment. One of the most important environmental risks is the contamination of surface water bodies surrounding the field crops such as ditches, streams, and rivers. This may happen as a result of: volatilisation and deposition of the pesticides from the atmosphere in rain, particulates and fog; direct spray drift

during the treatments; lateral infiltration in drainage waters; via runoff transporting pesticide dissolved and sorbed on sediments [1].

Of these sources, spray drift generally has the highest potential to cause a pesticide load to surface waters. The risk from drift is a function of the toxicity of the active substance and also of other variables, such as weather conditions, crop height, foliage density and application technique. Orchard and aerial applications often perceived as causing the greatest drift. There are several studies, particularly from American

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Communicated by Gérard Guyot (Avignon, France)

\* Corresponding author: ettore.capri@unicatt.it

and Canadian authors, concerning drift from aerial applications [4].

The measurement of spray drift depends on several weather, site and operator variables [2]. The lack of comparability in methodology such as field conditions and methodology for collecting the drift deposition, makes it difficult to compare the results of different studies.

The European Directive 91/414/EEC deals with the authorisation of plant protection products (pesticides) and the control of their use. It requires estimation of spray drift during the application of pesticides using Ganzelmeier tables [5]. These tables summarise drift measurements carried out in Germany in field crops: cereals (excluding maize), grapevines, fruit crops (mainly apple orchards) and hops. The results are presented as the amount of the deposit (% of the pesticide applied per hectare) as a function of the distance between the fields and the water bodies. They represent the best available tool for the estimation of the ground deposit by drift at different distances from the target plant. In the latest version prediction can be made to 250 m [10]. Their deficiency is that they do not consider most of the Mediterranean crops (minor and major crops), planting systems and manual application methods. In Italy and in other countries of Southern Europe there are few studies about exposure and drift in field crops [8, 9]. In order to develop better pesticide hazard and risk assessments in Mediterranean areas, it is necessary to supply field data.

The objectives of this study were to measure the spray drift in citrus crops evaluating the influence of the main agronomic factors influencing the process, and to check the suitability of Ganzelmeier drift tables.

## 2. MATERIALS AND METHODS

### 2.1. Field trials

The study was carried out in Catania Province, which is the most important agricultural area of the Sicily region with 108 097 ha of arable land and 102 350 ha of permanent crops.

Citrus groves represent more than 65% of the permanent crops. All the land is based on an alluvial valley called the Catania plain. Some of the citrus groves are located along the sides of main rivers or drainpipes with intermittent water flow used for irrigation purposes.

Most of the citrus orchards are cultivated following 3 planting systems (Tab. I), and pesticide applications are carried out with manual lance or fan-assisted devices. Use of the manual lance achieves greater pesticide localisation on the plants than treatment carried out with the turbo fan driven sprayer. This guarantees a better effectiveness of the phytosanitary treatment. Eight trials were carried out in 4 different farms, with both application methods in each farm. The main characteristics of the orchards are described in Table I.

In each drift trial, a mobile meteorological station was used to monitor air temperature, wind speed and wind direction. Meteorological conditions were recorded at 5 minute intervals at a height of 2 m. The meteorological conditions during the trials are shown in Table II.

### 2.2. Pesticide application

Chlorpyrifos-methyl (RELDAN22<sup>®</sup>) was used as the test compound (referred to as CLP-M in this paper). Its use is widespread in citrus orchards for control of scales, in particular the California red scale (*Aonidiella aurantii* Mask.). This pest is controlled chemically every year.

For both manual lance and fan-assisted application, a turbo fan driven sprayer was used (model EUROTECH, CAFFINI S.p.A) supplied by a 500 L tank and carried by a 4 wheel drive tractor (GOLDONI 240). During manual application, the sprayer was equipped with 2 lances with a VOLPI E BOTTOLI High Pressure Hollow Cone nozzle (1.5 mm  $\phi$ ), always working at 25 bar pressure and with flow rate of 4.5 L·min<sup>-1</sup>. During fan-assisted application, the sprayer was equipped with 6 or 8 working ALBUZ High Pressure Hollow Cone nozzles, working at 20–30 bar pressure and with a flow rate of 2.6–5.9 L·min<sup>-1</sup>, depending on the citrus orchard characteristics (crop, variety, density, crown height, crown projection).

**Table I.** Principal characteristics of the orchards used in the drift trials.

Trial number	T1 and T2	T3 and T4	T5 and T6	T7 and T8
Name of farm	Truglio G. citrus orchard	Truglio V. citrus orchard	Duca Misterbianco Navelina citrus orchard	Duca Misterbianco Tarocco citrus orchard
Size of field (ha)	10.1	10.5	8.2	10.4
Shape of field	rectangular	rectangular	rectangular	trapezoidal
Slope of field	gentle W-E	gentle W-E	flat	gentle N-S
Location of access road	South side	West side	North-East side	West side
Location of ditch	North side	none	none	East side
Tree orientation	N-S	N-S	NE-SW	W-E
Cultivar	Tarocco nucellare sour orange	Tardivo di Ciaculli mandarin	Navelina nucellare sour orange	Tarocco comune sour orange
Plant density	6 m × 5 m (333 plants·ha <sup>-1</sup> )	4 m × 4 m (625 plants·ha <sup>-1</sup> )	6 m × 4 m (417 plants·ha <sup>-1</sup> )	6 m × 4 m (417 plants·ha <sup>-1</sup> )
Crown projection	5 m × 5.3 m	4 m × 4 m	4.8 m × 4 m	3.8 m × 3.5 m
Crown height	5 m	2.3 m	3.3 m	2.5 m

**Table II.** Meteorological data during trials (average values and range).

Trials	Temperature (°C)	Absolute wind speed (m·s <sup>-1</sup> )	Wind direction (° (degrees))	Relative wind speed* (m·s <sup>-1</sup> )
1°(manual)	34.3 (±1,1)	2.85 (±0.27)	143 (±36) SE - NW	2.28
2° (fan)	35.8 (±0.3)	2.99 (±0.37)	133 (±34) SE - NW	2.05
3° (manual)	34.4 (±1.4)	4.01 (±0.50)	123 (±9) SE - NW	3.35
4° (fan)	37.1 (±0.9)	4.47 (±0.45)	123 (±11) SE - NW	3.75
5° (manual)	36.2 (±0.7)	1.73 (±0.25)	92 (±29) E - W	-1.50
6° (fan.)	32.6 (±3.3)	1.20 (±0.35)	208 (±89) SW - NE	1.02
7° (manual)	33.6 (±2.6)	1.13 (±0.45)	188 (±123) S - N	0.70
8° (fan)	26.2 (±0.7)	0.16 (±0.17)	173 (±108) S - N	0.06

\* Relative wind speed is calculated by trigonometry as the vector of the absolute wind speed perpendicular to the location of the traps.

During manual application, the amount of spray applied varied from 23 hL·ha<sup>-1</sup> to 32 hL·ha<sup>-1</sup> with a concentration of CLP-M of 0.563 g·L<sup>-1</sup> (equal about to 1295–1802 g of CLP-M per hectare), depending on the citrus orchard characteristics. During fan-assisted application the amount of spray applied varied from 25 hL·ha<sup>-1</sup> to 34 hL·ha<sup>-1</sup> with a concentration of CLP-M of 0.563 g·L<sup>-1</sup> (equal to 1408–1914 g of CLP-M per hectare), depending on the citrus orchard characteristics. The equipment was checked before the trials.

The amount of CLP-M applied in each trial is shown in Table III, where it can be seen that “Tarocco nucellare” had the highest rate of application, followed by Navelina (12% less), Mandarin (20% less) and Tarocco comune (27% less). The characteristics of the sprayer are shown in Table IV. The application rate was higher in the trials with denser crowns (Tabs. I and III). Manual applications were generally 3% to 10% lower than fan applications (Tab. III). All pesticide applications were made in accordance the rate of planting, the crown area of the various citrus species and varieties and with recommended turbo fan sprayer and manual lance use conditions (pressure, flow rate, number and diameter of the nozzles).

### 2.3. Drift capture

Drift samples were collected for only a limited distance from the target crop (1.5–7.5 m). The monitored distance from the edges of fields (7.5 m) during this study carried out in the

province of Catania was considerably lower than the studies conducted in Germany [10]. This is because the Catania plane citrus area is intensely cultivated and the distance in between the fields is very low.

The drift was captured by means of filter paper lines (chromatographic paper) 5 cm wide, fixed to the wooden boards by staples. The wooden boards (transects) were placed along one side of the field in the lee of the wind before the pesticide application. The total number of transects was 8–10 in each trial. Half of the transects were placed in between the crop rows and the others in the line of the crop rows (except trials T3 and T4, Tab. I). Immediately after the pesticide application, each paper trap was cut into 1–1.5 m sections and each section was sealed in a glass jar. Samples were cooled and stored at -20 °C (within 12 h of collection) until analysis.

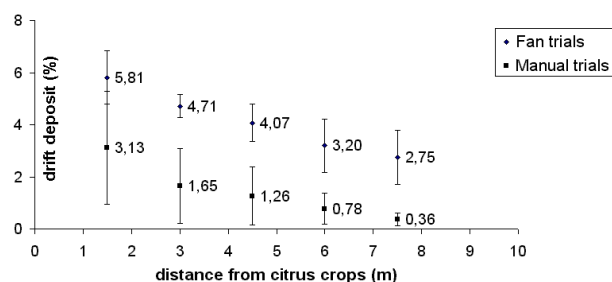
**Table III.** Amount of chlorpyrifos-methyl distributed per hectare in the citrus orchards (g·ha<sup>-1</sup>).

Trial number	Citrus spp. and cv.	Manual trials	Fan trials
T1 and T2	<i>C. aurantium</i> Tarocco nucellare	1795.5	1885.5
T3 and T4	<i>C. deliciosa</i>	1467.9	1505.3
T5 and T6	<i>C. aurantium</i> Navelina	1588.5	1631.3
T7 and T8	<i>C. aurantium</i> Tarocco comune	1273.5	1415.3

**Table IV.** Technical characteristics of manual, fan driven sprayer and nozzles for each trial.

Trial	Fan size (Ø cm)	Work pressure (bar)	Orifice size (Ø mm)	Spinner size (Ø mm)	Rate of flow (L·min <sup>-1</sup> )	Sprayed volume (L·ha <sup>-1</sup> )
1°	-	25	1.5	-	4.5	3194
2°	82	30	*1.5-°1.2	*1.2-°1.0	*5.9-°3.9	3353
3°	-	25	1.5	-	4.5	2609
4°	82	20	°1.2	°1.0	°2.6	2676
5°	-	25	1.5	-	4.5	2825
6°	82	28	1.2	1.0	3.1	2900
7°	-	25	1.5	-	4.5	2262
8°	82	24	1.2	1.0	3.0	2516

\* = two nozzles; ° = six nozzles.



**Figure 1.** Pesticide spray drift: fan-assisted trials vs. manual lance trials (average of median values of each trial; error bars state trial to trial variability).

## 2.4. Analytical method

CLP-M was extracted from samples of papers by partition into dichloromethane using sonication in an ultrasonic bath. CLP-M was quantified by capillary column gas chromatography with Nitrogen-Phosphorous Detector. Positive samples were confirmed by GLC-MS. The limit of quantification (LOQ) was  $0.0005 \mu\text{g}\cdot\text{cm}^{-2}$ . Recovery measured on blank chromatographic paper and calculated on three replicates at 4 levels was always higher than 95%.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Effect of method of application

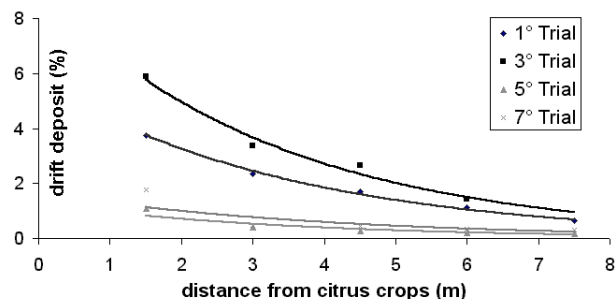
The amount of CLP-M intercepted by the paper traps was greatly affected by the method of application (Fig. 1). Tests conducted by manual lance have recorded an overall deposit of CLP-M 65% lower than tests carried out with the fan application. The difference between manual and fan applications is more pronounced the greater the distance from the sprayed crop. In the closest sample to the crop, the drift from manual application is 46% lower than the drift from the fan application, whereas in the furthest sample, the difference is 87%.

The uncertainty associated with the fan application (coefficient of variation 10–30%) is generally lower than the uncertainty associated with the manual application (coefficient of variation 70–90%). This indicates that the fan application gives a more uniform deposition pattern than the manual application. The variation between the trials with the manual application can be attributed mainly to the meteorological conditions (see next section).

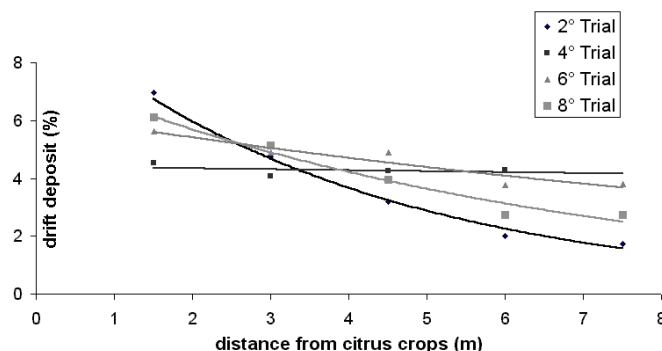
### 3.2. Effect of meteorological conditions

Figure 2 shows that when the manual application is used, the amount of drift is greater when the relative wind speed is higher (Tab. II). Although the absolute wind speed in trial T5 was higher than in trial T7, the measured drift deposition was lower because the wind blew away from the drift tapes (Tab. II).

Trial T5 (the lowest drift deposit) was 80–90% lower than trial T3 (the highest drift deposit) at all measured distances



**Figure 2.** Manual lance drift trials (median values of each trial).



**Figure 3.** Fan-assisted trials (median values of each trial).

from the crop, which indicates that the effect of wind speed is the same, whatever the distance from the crop. This is not in agreement with the results of Holterman et al. [6] for a drift study with a boom sprayer.

Figure 3 shows that when the fan application was used under conditions of high relative wind speed ( $3.75 \text{ m}\cdot\text{s}^{-1}$ , trial T4), there was no reduction of drift deposition over the distance measured in this experiment. In the other three trials, the drift deposition reduced with distance from the crop. However, there was no clear relationship between deposition (Fig. 3) and relative wind speed (Tab. II).

There are several explanations for this phenomenon. One explanation is that the treatments using the turbo fan sprayer caused more turbulence than the treatments with the manual lance, thus the turbo fan causes greater variability of the pesticide drift deposit [2]. Another explanation is that the variability of the drift data was influenced by the turbo fan sprayer use conditions, in particular the number and specification of the operating nozzles, which were not the same for all tests (Tab. IV). The protocol varied from trial to trial because of the various dimensions of the citrus groves (extension, rate of planting and covered area by crown).

A further reason for the variability in the drift data in the fan-assisted experiment is the air temperature (Tab. II). In trial T8, the air temperature was around  $10^\circ\text{C}$  colder than in the other trials. It is well known that the volatilisation of CLP-M is highly temperature dependent. In trial T8, the high values of drift deposition may have been because CLP-M did not volatilise as fast as in the other trials.

The low wind speed and low temperature in trial T8 may have been evidence of thermal inversion. Studies on spray drift carried out by MacCollom et al. [7] about turbo fan sprayer use, in the presence of thermal inversion phenomena, show that spray drift may deposit at a greater distance than in the absence of thermal inversion. MacCollom et al. suggest [7] that atmospheric thermal inversion is usually linked to wind speed  $\leq 1.1 \text{ m}\cdot\text{s}^{-1}$ , as occurred during the 8th drift test (Tab. II).

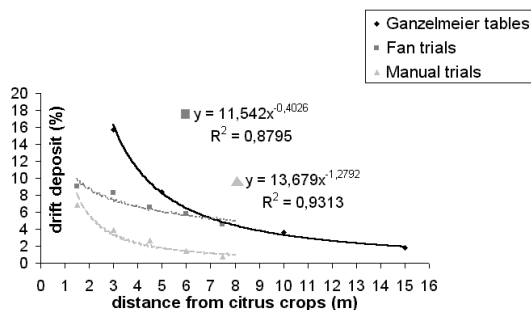
### 3.3. Comparison with reference values

An attempt was made to compare these results with the “reference drift values”, published in Germany by the Federal Research Centre for Agriculture and Forestry [5, 10] and approved as the correct procedure in the authorisation of plant protection products. The aim was to obtain “reference drift values” for citrus groves, which are not given in the German tables.

The CLP-M concentrations due to spray drift and intercepted by chromatographic paper traps have been calculated as a percentage of the mean doses applied,  $1531 \text{ g}\cdot\text{ha}^{-1}$  for treatments carried out by manual lance and  $1609 \text{ g}\cdot\text{ha}^{-1}$  for treatments carried out by turbo fan driven sprayer (Tab. III). These data have been expressed in accordance with the indications of the FOCUS-Surface Water Group [3] that recommends the use of the 90th percentile of the data in order to express the situation of worst case.

Since the tables published by the German Research Centre do not contemplate studies on citrus, the data from this study were compared to the relative base values of fruit crops in an advanced growth state. Although these crops (apples and pears) are characterised by rates of planting, crown surface areas, projections and heights that are different from citrus, they lend themselves more to the comparison than other crops. The German data were obtained from studies carried out in Germany with weather conditions characterised by wind speed  $\leq 5 \text{ m}\cdot\text{s}^{-1}$ , by wind direction perpendicular to the deposit body and by average temperatures lower than  $25 \text{ }^\circ\text{C}$ . Such environmental conditions were very different from those during the tests conducted in Sicily (Tab. II).

Figure 4 shows a comparison of the Ganzelmeier data with the data from this study. For both kind of spray treatments, the



**Figure 4.** Citrus drift trials (90th percentile of the measured values) vs. basic drift values for late fruit crops (Ganzelmeier tables).

Ganzelmeier data over-estimate the amount of pesticide spray drift in citrus orchards. This indicates that the Ganzelmeier data are poorly suited to simulating drift in citrus crops.

The pesticide residues on the ground after treatments conducted by manual lance show that the risk of surface water pollution is lower than when treatments are carried out by turbo fan driven sprayer. There is a good correspondence of the CLP-M drift deposit with an exponential trend (correlation coefficient = 0.93). The data from the turbo fan sprayer tests showed an exponential trend but with a lower correlation coefficient (0.88). The fitted lines have been extrapolated in Figure 5 to show “basic drift values” up to 15 m.

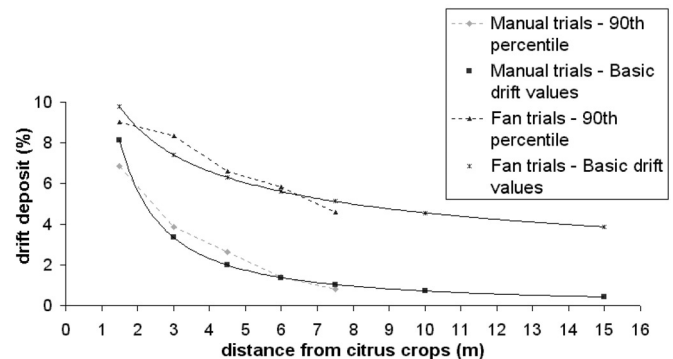
## 4. CONCLUSIONS

The most important consequence of use of the manual lance in this study was the reduction of deposited pesticide by spray drift by an average of 65% compared to the use of the turbo fan driven sprayer. This indicates a lower pollution risk of surface waters when the manual lance is used.

Several factors affected the deposition patterns, including climatic factors and the technical specification of the sprayer. For pesticide distribution by manual lance, the relative wind speed considerably affected the amount of CLP-M deposition. For the tests carried out by the turbo fan driven sprayer, it seems that the wind direction, thermal inversion and the sprayer specification affected the pesticide deposition on the ground. Thermal inversion may increase the environmental pollution risk with the use of a turbo fan driven sprayer.

“Drift reference values”, published in Germany for apples and pears, have been obtained by studies carried out in very different climatic and topographical conditions from the Mediterranean area. The comparison of the data obtained in this study with the Ganzelmeier data has shown that the reference values over-estimate the drift, making them unsuitable for the simulation of drift in Mediterranean citrus.

The data obtained by this study have allowed the elaboration of a provisional model, similar to the Ganzelmeier model, using an exponential trend for both manual lance and fan-assisted applications.



**Figure 5.** 90th percentile of the measured values of Citrus drift trials vs. their basic drift values.

**Acknowledgements:** The analytical work was carried out by Nicelli, Renda and Meli were responsible of the field work, Capri was the manager and coordinator of the project: the paper was discussed and written by Capri and Meli. All the authors thank very much all the farmers and the other people collaborating in this work.

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