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Design and Testing of a Low Cost Micro-Volume Sprayer for Bait Spraying

Daniele Sarri

Università degli Studi di Firenze
Department of Agricultural, Food and Forestry Systems
Piazzale delle Cascine, 15, 50144 Firenze - Italy
http://www.gesaaf.unifi.it

Riccardo Lisci

Università degli Studi di Firenze
Department of Agricultural, Food And Forestry Systems
Piazzale delle Cascine, 15, 50144 Firenze - Italy

Stefano Caruso

Consorzio Fitosanitario di Modena via Santi, 14
41123 Modena - Italy

Valentino Bosco

Dow AgroSciences Italia srl via A. Masini, 36, 40126 Bologna, Italy

Luca Vieri

Dow AgroSciences Italia srl via A. Masini, 36, 40126 Bologna, Italy

Marco Vieri

Università degli Studi di Firenze
Department of Agricultural, Food And Forestry Systems
Piazzale delle Cascine, 15, 50144 Firenze - Italy

Abstract

The European directives 2009/128/EC, devoted to establish a framework for Community action to achieve the sustainable use of pesticides and the 2009/127/EC, related to design, construction and maintenance of machinery for pesticide application, are being changing significantly the pest and weed control. In this context, many studies were carried out in order to develop precision spraying devices and to find alternative at conventional chemical pesticides. On this last regard, one of the rising solutions, is the poisoned sugar-based bait to control the fruit flies. These pests are becoming a great issue for a broad Mediterranean orchard cultivation area, where a lot of damages were documented. Therefore, this study looks the developing and testing of a micro-volume sprayer. An electrical sprayer with an automatic spray controller based on open source Arduino platform, was designed. The prototype was tested in laboratory condition and on cherry growing for two seasons in center Italy to assess the operative reliability. Results showed the efficacy of sprayer and use of bait (Spintor-Fly ®) to the control of the cherry fruit fly.

Keywords: Environmental sustainability, bait, micro-volume sprayer, Arduino platform

1 Introduction

The agriculture of the last decade is experiencing a major change aimed at the actuations of best practices to reduce the environmental impact that the production chains generate [1], [2] even through the information and communication technologies. Due to climate change and global warming, the pest control practices have become essential stages in the farm management because the dangerous effects that might result on the finished product. We are witnessing a double trend: on the one hand, there is a constant evolution inside the pest types that affect orchards, on the other a revolution on the sustainable use of pesticides in accordance to the 2009/128/CE. In fruit growing, the fruit flies are currently the main responsible of crop losses [3]. These, growing inside the fruit flesh, determine a direct damage and besides, create opening for further attack agents such as fungi, bacteria and viruses. The magnitude of fruit flies family, allows them a broad adaptability to many varieties of crops and environments to which is added an high reproductive capacity [4]. In fact, some species such as Bractocera oleae *(Gmelin,1790*), in optimum environmental conditions, may exceed four generations per year [5]. A extremely complex and evolving scenario which involve innovative management approaches based on the implementation of predictive models, the fulfillment of farm-district level monitoring networks, to provide timely and effective pest control. Similarly, is also needed the broad diffusion and use of efficient sprayers [6]. Equally, the pesticide industry is evolving towards the production of reduced environmental impact formulations (particularly those of natural origin like corroborants) accordingly to the emergency of resistance phenomena.

Magan in 2007 has indeed highlighted the acquired resistance by the C. capitata (*Wiedemann*) to the organophosphate insecticide malathion [7]. Recently, the European Commission has requested a risk assessment for dimethoate molecule that is also in the list of candidates for substitution according to the commission implementing regulation (EU) 2015/408 [8]. The use of dimethoate constitutes a risk consequently to its water soluble features, for which, part of the product, is translocated within the plant tissues. As a result of some reported cases of over limit residues detected in fruit and vegetables, the molecule has recently undergone several use restrictions. The alternative to the organophosphate insecticides to control the population at larval and adult stages, are the baits containing a natural insecticide such as the Spinosina. The latter, type A and D, is achieved by the metabolism of Saccharopolyspora spinosa Mertz and Yao (Bacteria: Actinobacteridae) [9], [10], [11]. The molecule has a double mechanism of action, either per contact or by ingestion and a wide spectrum of action which includes species in the Diptera, Lepidoptera, Thysanoptera, Coleoptera, Orthoptera, Hymenoptera orders [12]. Spinosad, being considered a natural product, is approved in organic farming by international corporations, also thanks to its low mammalian toxicity and the reduced environmental impact [13], [14], [15]. Since 2004 [16] was used in Canada on cherry growing with good results and since 2009 [17] in USA. The application of the poisoned protein lure, is completely innovative than the traditional spraying methods, since the maximum effectiveness occurs with patch applications of 30-50 10^{-3} L or bands treatments of 0.3- 0.8 m on the outside of the crown. Unlike the other insecticides, where to the effective distribution a droplets diameter of 200-500 µm (medium to coarse sizes according to Functional classification BCPC [18], is recommended, this type fulfills its function with large drops (very coarse - extremely coarse) [19]. In this respect, the producer specifies that the droplets average diameters must be between 1 and 6 mm (Dow AgroSciences, Bologna, Italy) in such a way that the residence times, thus attractants, are longer. Additional specificities concern to the spatial distribution within the orchard i.e. in ≥ 2,5 10^3 m^2 plots the application can be performed in alternate rows or trees, in particular for citrus fruit and olives groves, while for the cherry and the khaki, is advisable to treat all plants. About the volumes per surface unit (10000 m^2) the water ratio vs. commercial formulation it is 4:1. Therefore, if all the plants are sprayed, only 0,24 g per 10.000 m^2 of spinosad will be distribute. These volumes, when compared to the layout of planting, coincide, for instance to $18\pm1\cdot10^{-3}$ L per plant in a 6 x 6 m olive growing (277 plants per 10000 m^2), to $7.5\pm1\cdot10^{-3}$ L per plant in a 5 x 3.5 m (571 plants per 10000 m^2) per simmon tree or $50\pm1\cdot10^{-3}$ L per plant in a traditional cherry growing 10 x 10 m (100 plants per 10000 m^2) spacing layout. These volumes are significantly lower than conventional treatments where we refers to normal volumes of 1000 L per 10000 m^2. That brings to the needing to use of micro volume sprayers. Among technological innovations for spraying there are many solutions which range in terms of manageable operations, complexity level and consequently, the required investments to implement them [29],[21],[22]. Recent projects such as the European RHEA (http://www.rhea-project.eu/), have highlighted the benefits achievable by variable rate spraying [23], [24]. However, as part of micro volume spraying, the solutions available today are still few [25] and often hardly accepted by growers as a result the high costs and the limited versatility of uses. At the same time, the increasing expansion of open source electronics and cheap informatics technologies, along with the gradual achievement of economies of scale, is starting an innovation process based on the development of low cost technologies. Present study focusses on the development of an electrical sprayer designed for effective management of micro volume spraying, characterized by low-cost open source (Arduino) automatic controller. The idea arises to the need of precisely manage the spraying phase of protein baits made with Spinosad, for adulticide control against the fruit fly Ceratitis capitata *(Wiedemann, 1824*) in cherries Ragholetis cerasi *(Linnaeus,1758*) and olives Bractocera oleae *(Gmelin,1790*). This focus is further motivated by achievable benefits in terms of drift reduction, fewer exposure risks for workers and bystanders, as well as the lower impacts on the environment (water-air-ground).

2 Materials and methods

2.1. Architecture of the spraying system

The sprayer, developed in collaboration with Andreoli Engineering of Novi di Modena-Italy, was designed according to the ISO standard 16119-4: 2014 and 2009/127/EC specifications. The machine (Fig.1) is tractor mounted and is made up of a main tank for the mixture, with a volume of 85 L and a truncated trapezoidal shape for easy intake even in slope conditions, a washing hands tank and a washing plant tank. The latter is essential with the sugar based bait since being very adhesive, tends to block nozzles and filters with potential damage to the system, so it is advisable to clean the plant after each treatment. In order to wash the machine plant, a two-way selector that get the clean water by washing tank, was implemented. When activated the flow rate performs a rinsing in the main tank and output line. The machine is 12 V powered supplied by the tractor. An electrical 12 V-7A diaphragm pump (Shurflow model 8000-543-238 Costa Mesa, CA) with adjustable bypass and a maximum flow rate of 6.81 l min^{-1} at 0.689 MPa, was used. The sprayer is equipped with pressure gauge, manual pressure regulator, hydraulic agitator and self-cleaning filter, inspectionable even with full tank. A single nozzle, model D2+DC13 TeeJet, mounted on a nozzle holder with check valve, directly connected to the normally closed solenoid valve model BAD2AP 12V 10W (Salvarani, Poviglio, Italy), was used to control the spraying. This was mounted on an aluminum rod extensible from 2 up to 3.5 m relative to the ground and positioned on the rear longitudinal axis of the sprayer. This configuration allows to quickly changing the spraying orientation toward the left or right side to the forward direction. This set up enables spraying plants height up to 8 m.

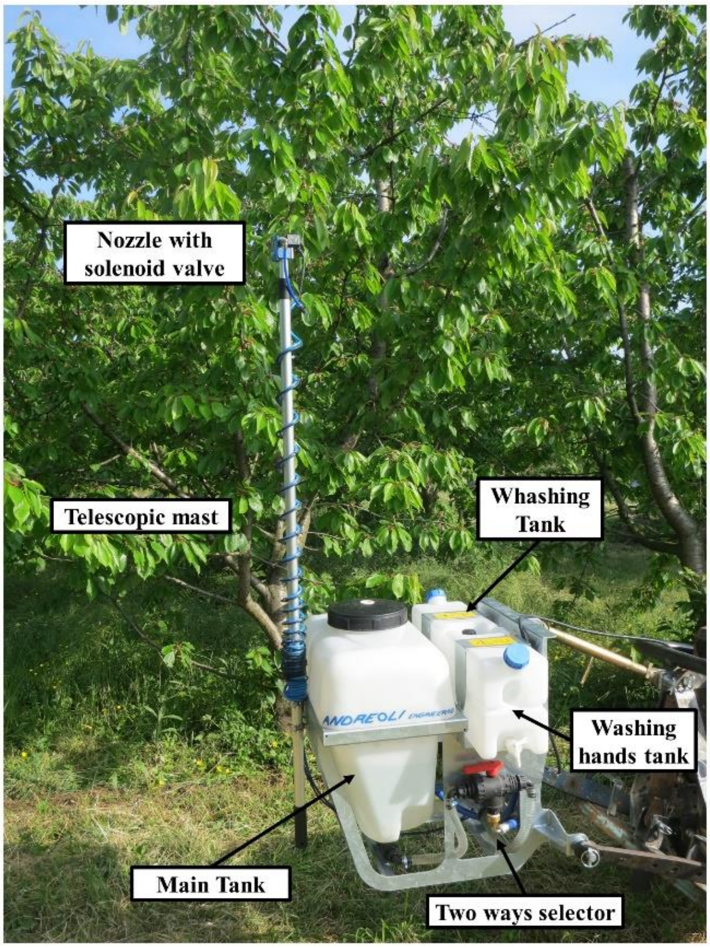


Figure 1. Main elements of the micro-volume sprayer for bait spraying

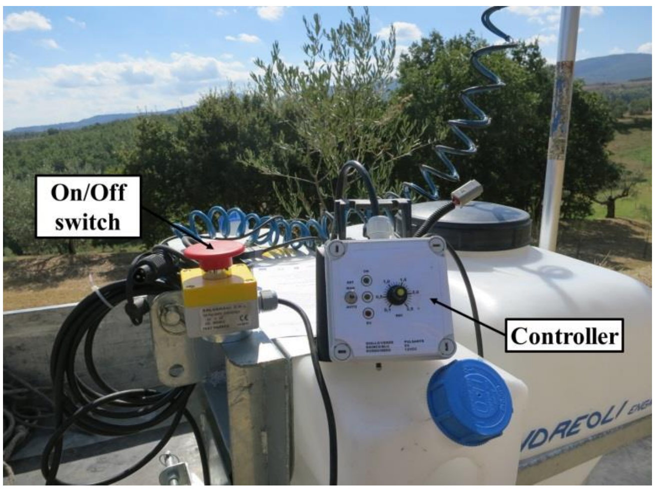


Figure 2. User interface and switch of the controller

Pursuing the way of low costs, the electronic control was implemented on ARDUINO® platform (Fig.2). The latter, has been housed on an electronic board designed to manage the overall voltage supply and the electric driving of the solenoid valve. A mosfet model IRFL014N (Infineon Technologies Italy, Padua, Italy), controlled by a digital output signal (DO4) from the microcontroller to enable the solenoid valve drive, was used. Aiming at the reduction of the Vcc instability issues arising by tractor power supply a DC/DC 12V/5V converter has been installed in the mainboard (Fig. 3). This architecture has allowed to limit the total cost to 1.000 € of which 85,25 € for the controller. Given that the sprayer was in a development stage, shall be expected that such cost, in the case of mass production, could be further reduced.

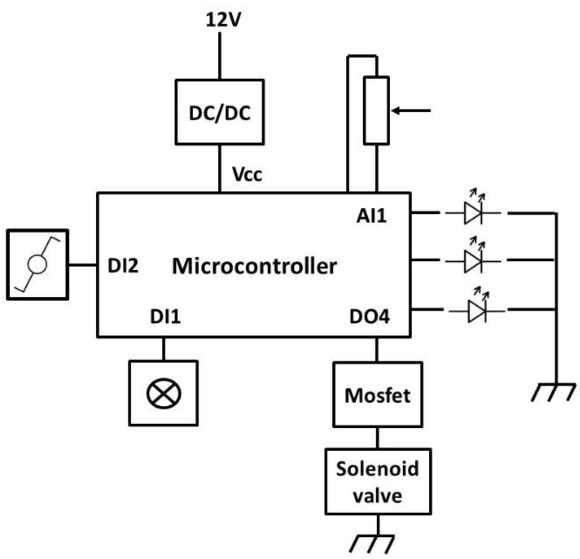


Figure 3. Controller circuit diagram with relative input and output signals: DI1 On/off Swiitch, DI2 Manual and automatic mode selector, AI1 Timer selector, DO4 solenoid valve driver

The spray control is designed to operate on a wide-ranging spectrum either in orchards either in the traditional olive groves with large spacing layout, thus with interruptions between plants on the row, but also for the modern intensive plants raised on continuous wall. A view to providing a configurable tool according to the workers and operating environment requirements, a setting mode based on the opening and closing times, was choice. This is done by acting on a potentiometer which, in turn, generates an analog input signal on the microcontroller AI1. In light of dosage declared by pesticide producer and the pump operative range, the timer was designed to work between 0,1 to 2.5 s with intervals of 0.1 sec. These timings were chosen in relation to the pump features and within the possible cultivation fields. A selector DI2 shall ensure the choosing between two operating modes: manual (MAN) or automatic (AUTO) (Fig.3).

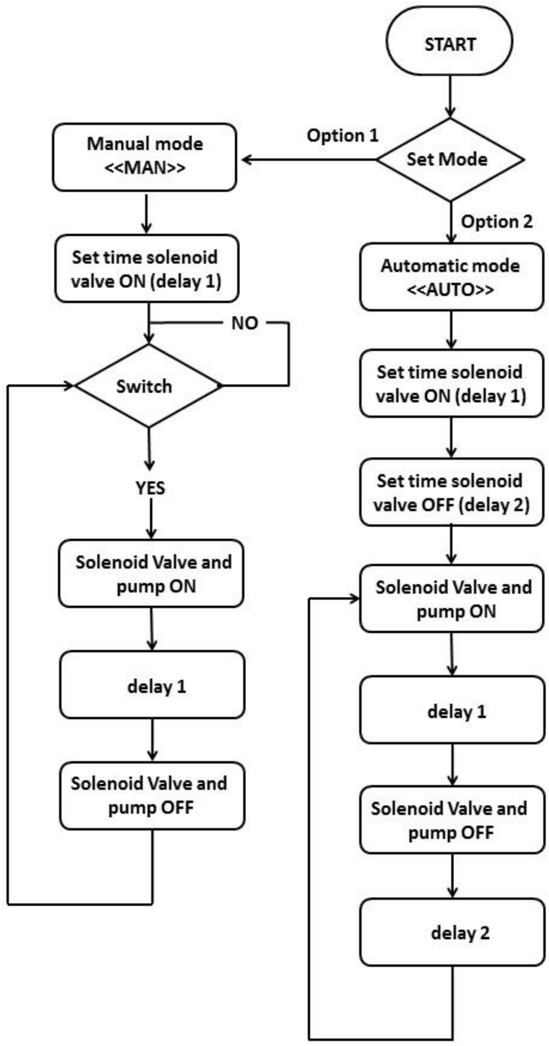


Figure 3. Block diagram of the micro volume sprayer controller

The former provides for manual actuation (switch-on) of the machine when the tree must be sprayed through a button. In that case, the switching on generates a digital input DI1 which drive the solenoid valve, through the DO4, for the set delay. This requires the spraying time configuration which shall be necessarily performed simultaneously to the sprayer set up in order to check the actual volumes distributed. With automatic mode, the logic foresees only the off delay setting which coincides with the solenoid valve inactivation time, since the on time holds the same duration. Then, when the switch is activated, an on/off cyclic times repetition starts. The last operating mode, is indicated in trellis orchard where canopies overlapped one another in structure similar continuous wall. This simplifies considerably the work leaving to the worker just the proper forward direction and the speed management. Once set the operating pressure, shall be checked the volume actually dispensed and then acting on the potentiometer to increase or decrease the solenoid valve opening time, to achieve the desired volume. Three LEDs indicate the system status:

• "Green" active and working (fixed: In spraying - flashing: pause - Off: turned off)
• "Yellow" configuration (on - spraying time - flashing: off time)
• "Red" opened solenoid valve (turned on solenoid valve switched ON - turned off solenoid valve switched off)

2.2. Experimental arrangements and data collection

Laboratory test

Aiming to assess the sprayer efficiency, tests (a) to characterize the sprayed doses varying the time at (t1) 0.5 sec, (t2) of 1.5 sec, (t3) 2 sec, (t4) 2.5 sec, (b) and to analyze the flow rate regularity, were carried out. Moreover, the repeatability of volumes provided in the MAN and AUTO mode (c) were analyzed with additional test.
The first set of tests have been carried out to verify that the sprayer, calibrated to get extremely coarse droplets, was capable of delivering a sufficient dose to comply with the dose per hectare therefore the minimum dose per plant. Hence, a sprayer calibration by setting the operating pressure to 0,5 MPa and adjusting the opening-closing time of the solenoid valve, to spray the desired dose i.e.$10 \pm 1 \cdot 10^{-3}$ L per plant was performed. Such volume is the required dose per hectare to control the Ragholetis cerasi (*Linnaeus, 1758*) in the cherry growing object of the field tests (see paragraph Field Test). It was therefore examined the measurement of the volumes of 50 samples sprayed in manual and automatic mode by weighing with scale with 250 g capacity, 0,001g division and ±0.003 g of linearity (kern model PCB 250-3).
For the repeatability analysis it has been proceeded to a preliminary compliance check of the times t1, t2, t3, t4 than the effective time. This was done by measuring the activation and shutdowns times of the solenoid valve via oscilloscope. The pump flow Qp constancy assessment was indirectly determined by comparing the volumes measured at each dispensing times t1, t2, t3, t4. All of the laboratory tests were carried out at temperature of 23 ° C and relative humidity of 68% by supplying the system with stabilized power voltage.

Field test

Data were collected in the 2012 and 2013 seasons in order to assess the operational capabilities of the prototype in cherry plots cultivar durone. The survey involved two farms, located in the municipality of Vignola, Modena - Italy a traditional production area of IGP cherry (protected geographical indication) for a total area of 7 hectares. Companies were chosen among those that in previous years had suffered huge fly damages. Given that in the study area was taking place a validation testing on a bait poisoned adulticide "Spintor-Fly®" (Dow Agrosciences, Bologna, Italy) by Plant Protection Modena Consortium and CRPV Emila Romagna Region, for the spraying was used the developed prototype. The cherry growings were trained to free vase with a mean height of 4.5-5.0 m an average diameter of 2,7 m and a planting distances of 5 x 4m with a density of 500 trees per hectare. The study orchards were in organic farming with high fly cherry pressure (damage recorded in previous years > 30 % infestation) in particular in middle and late cultivars. The dose per hectare was 5 liters, equal to $10\pm 1 \cdot 10^{-3}$ per plant. To verify the effectiveness of the system has been identified a 1000 m^2 control plot 200 m far from the treated area. In 2012 the treatments with Spintor-Fly® were six (May 8, May 15, May 24, Jun 1, Jun 6, Jun 13) as in 2013 (May 19; May 26; May 31, Jun 5, Jun 12, Jun 21).

In both years, the spraying stages have been started when the cherry fly flight's was detected. This was monitored by yellow sticky traps Rebell type placed both in the treated area either in the control plots also considering the rainfall. The traps check was performed at 24-48 hour intervals until the first fly-catching, then the controls were made a weekly basis. In both seasons, at the harvest of various cultivars (in the sprayed and control), samples of 100 fruits per cultivar to check the infestation level, were carried out [26]. As regards the diameter evaluation of the sprayed droplets, given the needing to spray medium-large droplets, a visual analysis of the distribution quality were taken with water-sensitive paper placed on the vegetation.

2.3. Statistical analysis

Normality of the variables investigated was evaluated with ShapiroWilk normality tests [27]. The analysis of the sprayed doses according the time t1, t2, t3, t4 (a), was analyzed with non-parametric method through the evaluation of the operating ranges of the minimum and maximum and standard deviation. Due to the violation of normality (Shapiro-Wilk test *p-value* < 0.05) for the response of liquid flow rate (b), a non-parametric randomized block analysis of variance through a Friedman test was undertaken. These test were also used to check the repeatability of volumes provided in the MAN and AUTO mode (c) because of a heavy tail distribution (Shapiro-Wilk test *p-value* < 0.05) encountered. The examined variables were the dose automatically and manually sprayed compared to the desired value. Statistical significance was in set at 0.05. All statistical analyses were performed in RStudio [28] (ver.3.3.1, R Foundation for Statistical Computing).

3 Results

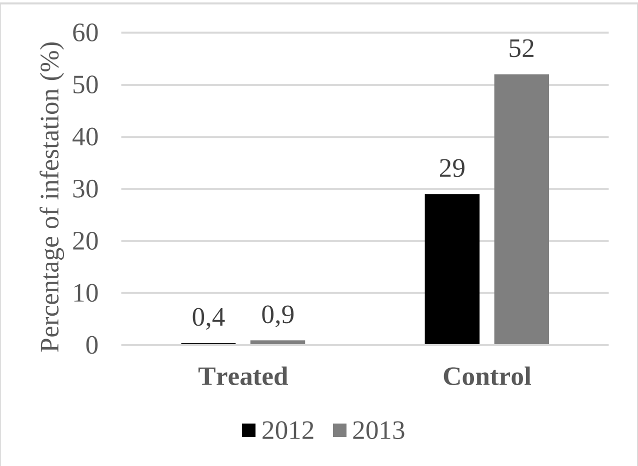
The tests concerning the characterization of the deliverable volumes have highlighted values suitable for the micro volume spraying. As showed in table 1 the volumes were included in the range $9{,}89\pm 0{,}72\ 10^{-3}$ L to $50{,}14\pm 0{,}51\ 10^{-3}$ L. Beneath of 0.4 seconds of driving time was documented an increase of the standard deviation with obvious reduction of the measure repeatability. This was referable to the pump rpm variation when the machine was powered up. In fact, although the pump motor turns continuosly, at the opening time the solenoid valve creates a pressure drop of 0.03 ± 0.01 MPa with a consequent increase in the number of revolutions. Based on the above considerations and, in light of the required volumes to control the Ragholetis cerasi (*Linnaeus, 1758*) on cherry growings under study, a 0.6 s t_{spot} drive time was set.

Table 1. Descriptive statistics for the laboratory test

	Mean Volumes (10^{-3} L)	Std dev (10^{-3} L)	Std dev (10^{-3} L)	Flow Rate (L min^{-1})
t1 (0.5 s)	9.89	0.71	0.71	1.22±0.078
t2 (1.5 s)	30.48	0.67	0.67	1.21±0.027
t3 (2 s)	40.52	0.60	0.60	1.21±0.017
t4 (2.5 s)	50.14	0.51	0.51	1.20±0.012
t_{spot} (0.6 s)	10.21	0.71	0.71	1.22±0.074

The tests conducted on the flow rate analysis, showed constant values to the times t1-t2-t3-t4 change, therefore no statistical significant differences were found. This trend confirms the constancy of the delivery system to the selectable times. The average value stored was 1.21 ± 0.008 L min^{-1}. The repeatability of the dispensed volumes with manual and automatical operating mode have not been significant difference (p-value 0.94), therefore, the developed controller, was able to optimally manage the dispensing timing. No dumping effect due to the pressing the button were detected. Results showed a high repeatability of volumes distributed with a standard deviation of 0.73 MAN and 0.71 in the test AUTO respectively. The poisoned baits (Spintor Fly®) based treatments resulted in a strong reduction of the damage on the fruit in the sprayed areas compared to the not sprayed control plots. In sprayed parcels, the damage by Ragholetis cerasi (Linnaeus, 1758) ranged from 0.4 and 0.9 % of infested fruit against an attack level recorded on untreated of 29.2 % with peaks up to 52 %. Historgam 1 (Fig.5) shows the results in the two years of activity. Data are expressed as mean percentage of infested fruit in different cultivars within the experimental area. This confirms both the reliability of prototype for micro doses distribution either the efficacy of poisoned protein lure such as the Spintor Fly® for the control of Ragholetis cerasi (*Linnaeus*, *1758*).

Figure 5 Histogram of the field validation testing for the commercial pesticide "Spintor-Fly®" during the 2012-2013 seasons.



4 Conclusion

A spot sprayer based on low cost electronics was developed for pest control of Mediterranean fly in orchards. Field tests showed that the sprayer was robust and effective to the specific spraying of micro-volumes. The adoption of new procedures and technologies that optimize pest control of Mediterranean fly is mandatory to European directive 2009/128/CE. The poisoned bait spraying is an attractive solution for organic farms and is competitive with the main chemicals used in conventional and integrated companies. The use of these spraying techniques significantly reduces the drift and the exposure risks from operators and bystanders. In operational terms are reduced the primary input requirements like water and fuel as well as the operating times. A further advantage is the possibility of spraying orchards with scalar maturation or promiscuous. However currently is still limited the diffusion of such sprayers due to the high costs and the limited versatility of uses. The spread of such equipment and new pesticides such those investigated, could be used in smooth areas and consortium between fruit producers with timely and consistent action. This could rationalizing the defense system by Diptera Tefritidi to fruit district level.

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