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Improving plant protection product applications in traditional and intensive olive orchards through the development of new prototype air-assisted sprayers

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A B S T R A C T

Because of the pollution caused by inappropriate pesticide applications to olive canopies, the Mecaolivar pre-commercial procurement project was undertaken to develop new airblast sprayers to optimise application efficiency and overcome the limitations of conventional sprayers used in traditional and intensive orchards. Three prototype sprayers were developed, evaluated, and calibrated under laboratory conditions and were tested in the field by spraying trees in traditional and intensive cultivation systems. Water-sensitive paper was used to assess the spray coverage achieved. The prototype sprayers were designed to adapt the deposition nozzle positions to the canopy shape to reduce spray drift and off-target application. The first prototype (P1) consisted of a sprayer with a centrifugal fan and adaptable individual spouts, the second (P2) consisted of a sprayer with six small hydraulically-driven axial fans mounted on two mobile structures, and the third (P3) consisted of two axial fans mounted on a tower-like structure with mobile air outlets. The results of the field test showed that the prototypes could be more efficient than conventional equipment. In applying the same liquid volume, the P2 and P3 prototypes increased the coverage by 61% and 46% on average in intensive and traditional systems, respectively, compared to a commercial airblast sprayer, without a significant decrease in the deposit homogeneity throughout the crown.

1. Introduction

Olives are among the most important crops grown along the Mediterranean basin, especially in Italy, Portugal, Greece and particularly Spain, which is the world's leading olive producer, with a cultivated area of more than 2.5 Mha (FAO, 2012). Much of the olive-growing area in Spain is concentrated in the South, especially in the Guadalquivir River basin (Gómez-Calero, 2009). This increases the risk of pollution associated with the application of pesticides to olive crops in this region. Several studies have detected the presence of herbicides and fungicides in the river and in nearby reservoirs (Espigares et al., 1997; Barba-Brioso et al., 2010; Hermosín et al., 2013; Robles-Molina et al., 2014).

These problems are typically caused by excessive applications of pesticide without concern for the harm done to the environment or to the economy of the application (Miranda-Fuentes et al., 2015b). It is essential, therefore, to develop appropriate application guidelines to ensure the efficiency of such treatments.

The application of pesticides to so-called three-dimensional (3-D) crops, i.e., to the crowns in tree orchards, is much more difficult than the application of pesticides to arable crops. There are two approaches to dealing with the problems of inefficiency and inadequate coverage associated with applying pesticide treatments to olive canopies: improving the dosing system and improving the application machinery.

However, adjusting the spray dose is useless if the application equipment is not adapted to the target canopy. Therefore, efforts have been undertaken to improve airblast sprayers since their

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development in the early 1950s (Fox et al., 2008). Conventional airblast sprayers produce problems associated with off-target losses and airborne drift (Salyani and Cromwell, 1992) and work less efficiently in isolated, large-sized trees with high row spacings (Holownicki et al., 2000). These conditions apply to intensive and most traditional olive cultivation systems, which together account for 98% of the olive-growing area in Spain (AEMO, 2012).

The commercial sprayers used in olive production do not include any type of technology for adjusting the spray to the characteristics of the target canopy, except for, occasionally, ultrasonic ON/OFF sensors used to spray only when the tree crown is detected (Giles et al., 1987, 1989). These sensors have been shown to have a significant impact on application efficiency (Ganzelmeier and Rautmann, 2000; Brown et al., 2008), but their use alone is insufficient to adapt spraying equipment to the specific geometries of irregular trees, as the dose remains constant throughout the length detected by the sensor, without the target leaf surface along this track being taken into account. In recent years, various studies have been conducted to assess the performance of airblast sprayer designs for various canopy types and adjust the applied doses to optimise their performance. Most of these studies have compared traditional pesticide application equipment with a prototype or with commercial equipment that incorporates new technology, and various application variables have been examined as well (Holownicki et al., 2000; Pezzi and Rondelli, 2000; Garcia-Ramos et al., 2009; Landers, 2010; Larzelere and Landers, 2010; Foqué et al., 2012).

Escolà et al. (2013) and Gil et al. (2013) developed and validated a new concept for spray application for orchards and vineyards, using a system for canopy sensing, volume setting, and liquid flow rate application that is mounted on commercial airblast sprayers. The canopy sensing is performed using a LiDAR scanner in the case of orchards and by ultrasonic sensors in the case of vineyards. The orchard prototype was shown to be able to adapt the sprayed volume to the canopy volume correctly, and the vineyard prototype was demonstrated to save up to 21.9% of the traditionally applied volume in commercial farms.

Testing of such sprayers is very complex because of the large number of factors involved. Computational fluid dynamics (CFD) modelling has been used to characterise sprayer systems and try to predict their performance under various environmental conditions and for various tree geometries and working parameter values (Dekeyser et al., 2013; Duga et al., 2015).

Other attempts to improve pesticide sprayer application efficiency have involved the use of tunnel sprayers, which surround the whole tree and recycle the excess spray to minimise losses (Ade et al., 2005; 2007; Baldoin et al., 2008; Hogmire and Peterson, 1997; Jamar et al., 2010; Pergher et al., 2013). These types of tunnels are useful for small crops, such as dwarf apples and grapes, but are difficult to use in intensive and traditional olive orchards because of the irregular canopy shapes, the heights of the trees (typically greater than 4 m), and the large crown volumes (typically 100 m^3 or more in traditional orchards) (Miranda-Fuentes et al., 2015b).

Because the tunnel system is not suitable for some types of tree crops, other types of system have been developed to attempt to improve pesticide application efficiency. Moltó et al. (2000) designed an electromechanical system for spraying citrus that involved adapting the application elements to the canopy to reduce the spray drift. In this system, a vertical boom with spray nozzles is operated at a fixed distance from the canopy using a signal from an ultrasonic sensor placed in the front part of the prototype. Tests were performed in which the prototype was compared to a handgun sprayer, the most commonly used type of equipment for this treatment, and the results indicated that the new system yielded better coverage for most of the sampling zones and thus better application efficiency. The difference in performance was particularly notable in the inner parts of the canopy, where the handgun sprayer did not achieve proper coverage levels, in contrast to the prototype, which achieved levels similar to those achieved in the outer zones.

In the case of olive trees, it is necessary to find an appropriate solution that fits the special circumstances present in traditional and intensive plantations. The Mecaolivar project arose from various needs identified by the Spanish Government and the olive oil industry in Spain to improve the mechanisation of olive oil production. After a thorough study of the state of the art, the research group AGR 126 of the University of Córdoba decided to develop new airblast sprayer prototypes that would achieve improved application quality and thus do less harm to the environment than conventional sprayers.

This paper describes the prototype development process, the equipment developed, and the results of preliminary tests of the performance of the prototypes.

2. Materials and methods

2.1. Technological requirements for the prototypes

The University research team developed a list of the technological requirements for pesticide sprayer prototype designs. These requirements were made to be concise, direct, and measurable to facilitate manufacturers' understanding of the requirements and to facilitate the manufacturer selection process and prototype evaluation stages.

The technical requirements were established by focusing on the four aspects considered to be the most important: application efficacy and quality, environmental and personal safety, adaptation to specific crop characteristics, and economy and practical aspects (Fig. 1).

Sprayer manufacturers were selected by assessing the adequacy of their solutions with respect to the technological requirements and the backgrounds and expertise of the companies themselves.

2.2. Project organisation

The Mecaolivar project took place from 1 February 2014 to 30 December 2015 and consisted of two phases: a pre-prototyping phase and a prototyping phase. In the pre-prototyping phase, the manufacturers presented their ideas for prototypes that met the technical requirements for the equipment. In the prototyping phase, the manufacturers developed their prototypes, with continuous monitoring by and advice from the University research staff. The prototypes were then tested to assess their performance and evaluate the success of the process as a whole. Fig. 2a illustrates the flow of the project.

Throughout the project, but mainly throughout the prototyping phase, exhaustive technical tracking was implemented for two purposes: technical and scientific support and certification of the work performed by the manufacturers, with payment obligations as milestones were reached.

The tracking process, which was crucial to the development process, was based on a schedule for reaching milestones for each company. All of the companies were given fixed dates to facilitate the certifications and payments for the work performed. At each deadline, a member of the University research staff checked that the planned activities had been successfully completed. If so, a positive report was written and the University paid for the corresponding stage. If not, the company had a period of ten days to repair or complete the work. If the result was still not satisfactory, the payment was postponed until the next payment deadline