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# Short communication. Performance of pneumatic spraying with an over-the-row sprayer in high density apple tree orchards

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## Abstract

In order to optimise an over-the-row pneumatic sprayer working in high-density apple tree orchards, tests have been conducted to study the deposition and distribution of its droplets. Field tests were conducted in an «artificial orchard» made with wooden posts and in an orchard of high density apple trees. To evaluate the quality of distribution, colored water droplets were collected on white plastic cards, which were then photographed. The effect of the angle between nozzle orientation and travel path on droplet deposition around wooden posts was studied. It was also studied the influence of air speed on the deposition on the apple trees and the drift and slide down of droplets. Tests show that the best nozzle position to get a uniform coverage around wooden posts which simulate tree trunks is face to face. This position also creates a tunnel of turbulence made by the wind without any physical wall. An air speed of 55 m $s^{-1}$ at the exit of the nozzles is the best to get uniform deposition of droplets in all areas of the trees. An smaller air speed of 41 m $s^{-1}$ gives a worse deposition on the back of the leaves, while a larger air speed of 63 m $s^{-1}$ gives a poor deposition on the outside leaves and can detach fruits when they are present on the trees.

**Additional key words:** air assisted spraying, droplets distribution, *Malus sylvestris*.

## Resumen

**Nota corta. Eficiencia de la pulverización neumática con un pulverizador en arco en plantaciones de manzanos de alta densidad**

Con el objetivo de optimizar un pulverizador neumático en arco trabajando en plantaciones de manzanos de alta densidad, se han hecho ensayos para estudiar la eficiencia de la pulverización y la distribución de las gotas. Los ensayos de campo se hicieron en una «plantación artificial» hecha con postes de madera ocupando el lugar de los árboles, y en una plantación de manzanos de alta densidad. Para evaluar la calidad de la distribución se recogieron gotas de agua coloreada en pequeñas láminas de plástico que fueron fotografiadas inmediatamente después de la aplicación. Se estudió el efecto de la orientación de las toberas respecto a la dirección de avance sobre la deposición de gotas alrededor de los postes de madera. También se estudió la influencia de la velocidad del aire sobre la deposición de gotas en varias posiciones de los manzanos y sobre la deriva y el escurrimiento de las gotas. Los ensayos mostraron que la mejor posición de las toberas para obtener una deposición uniforme alrededor de los postes o los troncos es enfrentadas entre sí. Esta colocación crea un túnel de turbulencia que hace que el viento quede concentrado en el espacio entre toberas. La velocidad del aire de 55 m $s^{-1}$ a la salida de las toberas fue la que obtuvo una distribución de gotas más uniforme en todos los puntos de los árboles. La velocidad más lenta de 41 m $s^{-1}$ produjo peor deposición en el envés de las hojas, mientras que la más rápida de 63 m $s^{-1}$ originó menos deposición en las hojas del exterior del follaje y puede provocar el desprendimiento de frutos cuando estén presentes en los árboles.

**Palabras clave adicionales:** distribución de gotas, *Malus sylvestris,* pulverización asistida por aire.

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High-density fruit tree orchards are a useful way to optimise exploitation of soil, fertilisers and water (Ortiz-Cañavate *et al.,* 1994), but they require machines specially adapted to the size and shape of the trees (Chen *et al.,* 1988; Chipriana *et al.,* 2000). At present, many research projects are aimed at reducing and controlling the use of pesticides in agriculture, trying to increase their efficacy at decreased doses.

Air assisted sprayers are the best adapted to tree orchards because of the ability of the air stream to carry the droplets inside the canopies. Most of the studies spray the canopy from one side, because the usual size of the trees is too big to work simultaneously from right and left. Planas *et al.* (1988) observed that deposition increased by reducing the air flow from 8.2 to 4.5 $m^3$ $s^{-1}$, but found reduced uniformity within the canopy. Farooq and Salyani (2002) studied the deposition of droplets along the depth of citrus canopy (spray deposition was improved as volume rate increased). The mechanical effect of air stream on apple trees was studied in laboratory by Svensson *et al.* (2002). When several air streams are directed from different points in such a way that they converge on the tree, a turbulence is created which improves the deposition of the droplets and reduces drift (Furness and Pinczewski, 1985).

In this research, the performance of a pneumatic sprayer mounted on a U inverted arm passing over the row of high-density apple trees have been studied, spraying from both right and left sides. Although hydropneumatic sprayers are the most usual machines employed in fruit orchards, the high-density apple tree orchard is more similar to a vineyard of trellised vines (in the shape of plants and space between plants) than to a traditional fruit orchard. For this reason, the orchard of high density apple trees have been sprayed with a pneumatic sprayer. Porras Soriano *et al*. (2005) have proved that penumatic sprayers are more efficient on trellised vines than hydraulic and hydropneumatic. The aim of this work was to determine which parameters improve the distribution of droplets and reduce losses due to drift and leakage.

Research was carried out in the experimental field of the College of Agricultural Engineering (Polytechnical University of Madrid). Tests were performed in two orchards:

— An «artificial orchard» made of wooden posts, with three lines of posts spaced 2 × 1 m, 20 m length. Posts were 2 m high.

— A high-density apple tree (*Malus sylvestris* L.) orchard. This orchard is 43 m long, with three rows of trees, 3 m between rows and 0.5 m between trees along each row. In winter time and at the start of summer they were pruned with an horizontal cut bar positioned 2.4 m above the ground.

The machine used in the tests was a pneumatic sprayer mounted on an over the row tractor with a free clearance of 2.45 m (Gil *et al.,* 1994). The sprayer has a wide diameter pipe in an inverted «U» shape to pass over the row of trees, with nozzles in both vertical arms of the «U» pipe (Fig. 1). The sprayer fan is driven by a hydraulic motor. The maximum air flow is 2300 L $s^{-1}$. To measure the air speed, a Pitot's tube with a Kiel bore was used.

To send the liquid from the tank to the nozzles, the sprayer has a centrifugal pump driven by a hydraulic motor. The speed of the centrifugal pump is regulated by a flow control valve in the oil circuit arriving to its driving motor. The pressure of the water with pesticide is 1.5 bar (150 kPa) before it is divided in several lines to go to each nozzle.

Tests were performed with coloured water with a black dye. Plastic cards covered with a layer of silicone spray to keep the droplets almost spherical were placed

**Figure 1.** Rear view of the sprayer mounted on the over-the-row tractor.

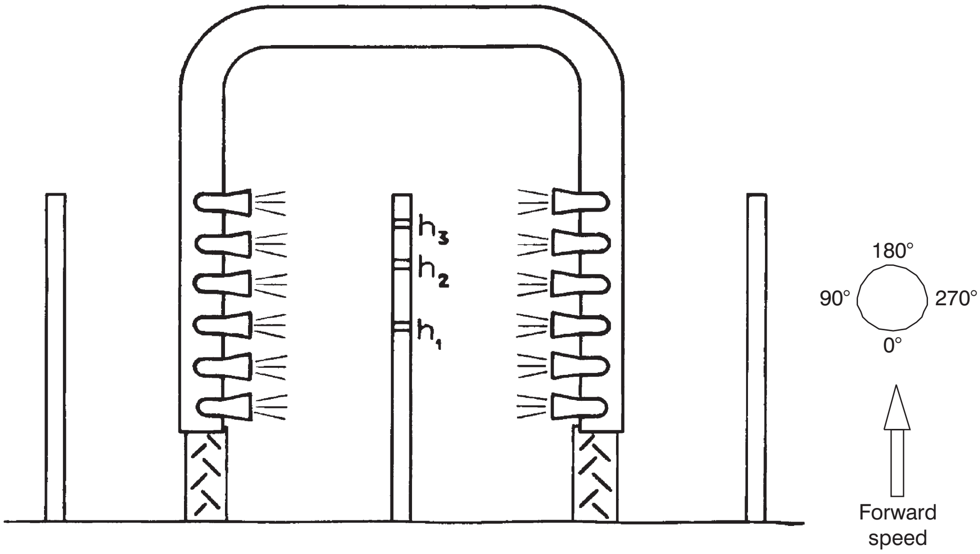


**Figure 2.** Location of plastic paper strips at different heights and around the posts.

in several positions on the posts and on the trees to collect the water. The plastic cards were photographed with a black and white 100 ASA film, then measured with an image analyser, that provided: number of droplets within each size of the range selected by the user, volume of liquid in the droplets of each size (assumed each black point is the main circle of an sphere), the arithmetic average diameter of all droplets and the volume/surface average diameter. Later, the average volumetric diameter was calculated as the cubic root of the quotient of the overall liquid volume divided by the overall number of droplets.

To study the influence of the angle of nozzles on the deposition of droplets around the trunk, tests were made on the «artificial orchard» at three different nozzle angles measured from the normal to the travel path: A) nozzles 45º backwards, B) nozzles 30º backwards, C) nozzles perpendicular to the travel path.

Strips of plastic paper were placed around the posts on three different heights as shown in Fig. 2.

Tests in the apple orchard were performed with three nozzles on each side, spraying on the rows of trees from the right and from the left simultaneously. White plastic cards were placed in several positions on the front and back of the outer leaves (Fig. 3, position x), on the front and back of the inner leaves (position y), on the left, back, rear and front of the trunk (position z), on the soil (position s) and in the lines of trees next to the one to be sprayed (position v). Three air speeds at the nozzle exits were considered: (1) 63 m $s^{-1}$, (2) 55 m $s^{-1}$ and (3) 41 m $s^{-1}$. The experiments followed a complete factorial design.

The analysis of variance indicated that the factors: nozzle angle, position around the posts and interactions between them were highly significant. Nozzles face to face (treatment C) gave the best uniformity in all the circumference around the posts. Nozzles 30º backwards (treatment A) gave the best coverage in positions 135 to 225º, and coverage was only significantly different from the other two treatments in position 180º. Collectors at position 180º had the greatest coverage in all treatments; this position is in the front of the post in relation to the forward speed, meaning that it can receive droplets for a longer time when the sprayer has passed each post. All treatments had smaller coverage in positions 0º to 45º. Both A and B treatments had smaller coverage in positions 0º to 45º. For these reasons, the most favourable position for the nozzles to achieve uniform coverage around the trunks was face to face (position C).

In the front and back side of the left outer leaves, which were closest to the nozzles, the treatment at highest air speed (1) gave significantly less coverage than the one at 55 m $s^{-1}$ air speed (2), and significantly less than the one at the lowest speed (3) on the back of the leaves. In the centre of the canopy, the front of the

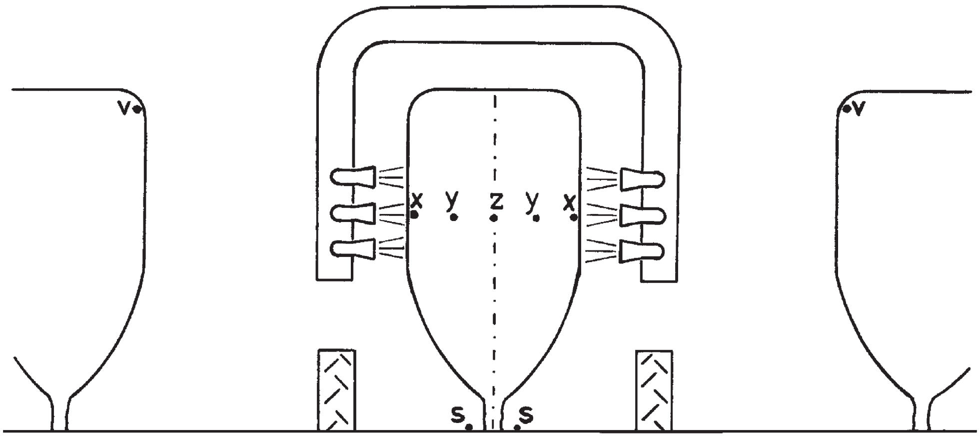


**Figure 3.** Position of the plastic cards on the trees and on the soil to collect the droplets.

leaves also got less coverage with the highest air speed treatment. The smaller coverage on the front of the leaves at higher air speed can be caused by the leaves turning by the wind and adopting a position parallel to the air stream, with a minimum cross-section to intercept the droplets (Ade, 1993). In the lowest air speed treatment there was a significant difference in coverage between the front and back of the leaves (greater on the front and smaller on the back); the coverage on the back of the leaves was not different from the coverage collected on the soil to the left and right under the trees. This small coverage on the leaf back could be caused by a reduced turbulence in the middle of the canopy at low air speed, resulting in that only the front part of the leaf intercepted the droplets. Around the trunk of the trees, the highest coverage was found, mainly on the left and right sides. Only the treatment 3 gave a poor coverage at the rear of the trunk. It seems that the uniformity of coverage does not only depend on the nozzle angle as was seen in the test carried out on posts, but also the wind speed influences the deposition around the tree trunk. A higher air speed generates a larger turbulence of the wind from both sides of the tree and increases the deposition in the front side of the trunk. This can explain the criticism of tunnel type sprayers that they spill most of the product to the rear (Ade, 1993). An excessive air speed spreads the droplets towards the rear of the tunnel. In general, the best coverage at most tree positions was achieved at 55 m $s^{-1}$ air speed.

Only on the front part of the leaves the droplets were larger with lower air speed and, as expected, their size decreased as the air speed increased. It was noticed that on the back of the leaves, droplets were smaller at lower air speed, possibly because of less turbulence and movement of the leaves, which prevents heavy droplets being in suspension and only smaller droplets can reach the back of the leaves. Larger droplets collected on the trunk in treatments 1 and 2 could be the result of the accumulation of impacts.

Only a small number of droplets were collected in the soil under the trees and their size was not significantly different from that of droplets collected in the trees.

In previous tests carried out in summertime (Gil *et al.,* 1996), the plastic papers placed in the neighbouring row of trees did not collect any droplets. The conclusion is that there is no drift of droplets when the treatment is performed with nozzles placed face to face, because the wind is concentrated in the area between the nozzles. The turbulence generated inside this tunnel increased the deposition on the inner part of the trees, but some droplets fall on the soil.

Treatment 2 also gave the best uniformity of distribution in all collectors. This speed can be recommended with the nozzles placed face to face. Treatment 3 gave a poor deposition on the back of the leaves and on the rear of the trunk. Treatmen 1 did not give a good coverage on the leaves that were closest to the nozzles.

In these tests, nozzles passed very close to the outer leaves of the trees because the right and left arm of the sprayer could not separate more. It may be interesting to test other air speeds with nozzles more separated from the tree canopy.

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