3
"Pollution in field, greenhouses and housing of animals"

ORAL PRESENTATION

A novel, air-assisted tunnel sprayer for vineyards

Pergher G., Petris R.
Department of Agriculture and Environmental Sciences, University of Udine, Viale delle Scienze, 208, 33100 Udine, Tel. 0432-558656, fax. 0432-558603, E-mail: pergher@uniud.it

Abstract

Tunnel (recycling) sprayers have long been recognised as an important tool to reduce drift losses. Depending on the crop and the growth stage, tunnel sprayers may recycle up to 60% of the spray volume, thus enabling the farmers to control pests even at reduced PPP dose rates. However, the introduction of tunnel sprayers in Italian vine-growing farms has been hindered by high machine cost, low working speed, and often unsatisfactory uniformity of deposition, generally related to the difficulty of correctly managing the air currents inside the tunnel.
Recently, a new prototype, air-assisted shielded sprayer has been has been developed by the University of Udine and Agricolmeccanica s.r.l. The two-row, tractor mounted sprayer uses a lamellae separator wall, placed in front of each nozzle boom, to recover the excess spray which has not deposited on the canopy.
Initial tests have been conducted to analyse the effects of the main sprayer settings (air flow rate, distance between the shields, and orientation of the air outlets) on spray recovery. Maximum recovery rate was 95.1% under static conditions. The sprayer was then used for spray application in the vineyard during the whole 2007 season, showing high reliability and work capacity. The recovery rate was 34% to 77% under field conditions, depending on the leaf area of the crop and other factors.

Keywords: recovery rate, air flow rate, static tests.

Introduction

Tunnel sprayers have long been recognised as an important tool to reduce both airborne drift (Schmidt, 1989) and soil contamination (Siegfried and Holliger, 1996). Because of their ability to recover and recycle most of the spray fraction that has not been retained by the canopy, these sprayers may make efficient pest control possible even at reduced PPP dose rates (by 15% to 50%, Siegfried and Holliger, 1996).

On the other hand, and despite of substantial benefits, the introduction of tunnel sprayers in Italian vine-growing farms has been hindered so far by several factors, mainly the higher machine cost, lower working speed, and poor manoeuvrability. However, the main problem seems related to the difficulty of developing a suitable air-assistance system, and of correctly managing the air currents inside the tunnel so as to ensure good distribution quality over the foliage, along with a satisfactory spray recovery rate. As a fact, most of the tunnel sprayers for vineyards available on the marked are sold without any air-assistance. This typically leads to insufficient spray penetration into the canopy and low deposition on leaf under sides (Siegfried and Raisigl, 1991; Siegfried and Holliger, 1996; Viret *et al.*, 2003).

A two-row, air-assisted prototype tunnel sprayer has been recently developed in a joint project conducted by the University of Udine and Agricolmeccanica s.r.l. (Torviscosa, Udine). The main objective of the project was to improve the quality of distribution as compared to existing tunnel sprayer models, and particularly spray coverage in the inside of the canopy and on leaf under sides, which may be critical for controlling some important diseases such as of downy mildew (as shown by Viret et al., 2003). Additional objectives were: to obtain a high spray recovery and recycling rate; to increase working speed and manoeuvrability even in narrow-spaced vineyards; and to keep the machine's structure as simple as possible, so as to reduce manufacturing costs and selling price.

Initial tests were conducted to gather baseline information on machine performance, and more particularly:

- to analyse the effects of various operational parameters on spray recovery rate under static conditions;

- to test the sprayer in the vineyard, under actual field conditions, during the whole 2007 growing season, and to analyse the spray recovery rate at different growth stages and leaf densities of the vines.

Materials and methods

The two-row prototype tunnel sprayer consisted of two identical spraying units, carried by a tractor-mounted, over-the row structure, while the 100-L tank was placed on a separated, trailed unit (

Figure 1). Each of the spraying units, or tunnels (Figure 2), consisted of a couple of symmetrical shields (height: 1700 mm; length: 1180 mm), each including:

- an axial-flow fan (maximum air flow rate: 1.20 m^3/s), driven by an hydraulic motor;

- a vertical air duct (height: 1700 mm; diameter: 250 mm), fitted with six air jets (total outlet section: 61.2 cm^2), spaced at 216 mm intervals;

- a vertical boom with six hydraulic nozzles;

- a lamellate panel (height: 1700 mm; length: 670 mm; thickness: 150 mm; pitch: 40 mm), designed to separate the excess spray, not deposited onto the canopy, and to capture its liquid fraction while discharging the air flow to the outside;

- a recovery basin, connected to the recycling system of the sprayer, to convey the recovered liquid back to the tank.

The reciprocal position of the tunnels and of the shields could be adjusted by means of hydraulic actuators to fit the row distance of the crop (between 1.8 m to 3.6 m), and the width of the vine canopy (up to 1.0 m tunnel opening, as measured between the basins). Both the main air duct and the air outlets could be rotated in the horizontal or vertical plane, respectively, to adjust the directions of the outcoming air flows, relative to the canopy and/or

Figure 1. The prototype tunnel sprayer during application in the vineyard.

the separator panel. The tractor-mounted, main structure of the sprayer also included: the main circuit's membrane pump, fitted with a constant pressure regulator; the membrane pump of the recycling circuit, connected to the tank; suction filters before each pump; and a hydraulic power system, driven by the tractor's P.T.O. and used to operate the fans and the hydraulic actuators on the over-the-row structure.

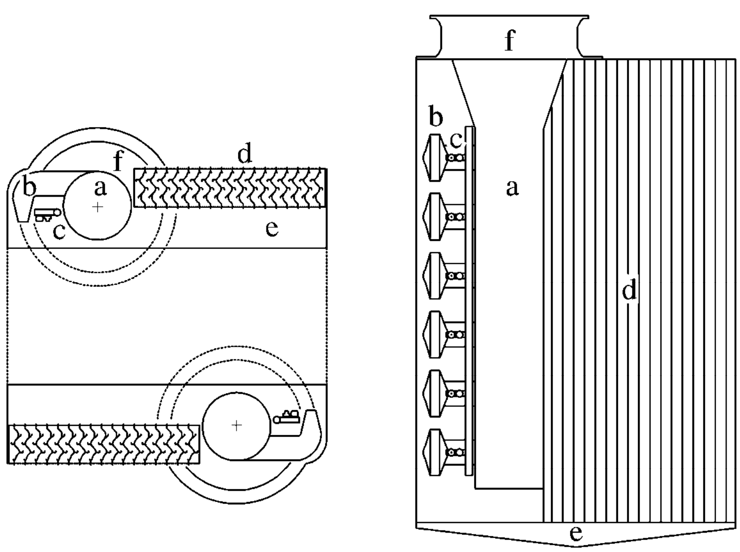
The performance of various configuration of the sprayer was evaluated on the basis of spray recovery trials, performed with water only under static conditions, and in the absence of vegetation. The sprayer was fitted with 12 Albuz ATR brown hollow cone nozzles (Very Fine BCPC spray quality at 10 bar), and the total flow rate was 7.92 l/min (at 10 bar pressure) in all experiments. The spray recovery rate was measured by collecting the water flow from the tube of the recycling system, previously disconnected from the tank. This involved: adjusting the operational parameters of the sprayer; starting the sprayer, and waiting until the water flow from the recycling pipe became steady; placing the end of the tube in a container (volume capacity: 50 l), so as to collect the water flow; after four minutes, removing the tube's end, and measuring the volume of water collector using graduated cylinders. In each test, the machine was let to spray for at least five minutes before taking the first measurement, in order to completely soak all inside surfaces.

Four different tests were performed. Test No. 1 was a factorial experiment, in which the following settings were compared:

- tunnel opening: 0.50 m, 0.75 m and 1.00 m;
- outlet angling: 10°, 20° and 30°; both air booms were symmetrically rotated towards the centre of the tunnel, clockwise as seen from above;
- fan speed: 36.1 rev/s, 46.8 rev/s and 52.4 rev/s (at 350, 450 and 540 rpm of the tractor's P.T.O., respectively; corresponding to air flow rates of 1.46 m^3/s, 2.05 m^3/s, and 2.40 m^3/s, respectively).

In test No. 2, the effect of different outlet orientations (10°, 15°, 20°, 25° and 30°) was further analysed at medium fan speed and three tunnel openings.

Figure 2 - Schematic views of the prototype. Left: from the top; right: from the (inner) side. (a) main air duct; (b) air jets; (c) nozzles; (d) air/droplet separator; (e) basin; (f) fan.



Tests No. 3 and No. 4 were conducted to quantify the potential advantages of the prototype, relative to different possible configurations, such as:

- tunnel sprayer without air-assistance;
- tunnel sprayer with air-assistance, but with full walls and no air/droplet separators.

In test No. 3, the fans were shut off, and this adjustment compared with the medium fan speed, in order to assess the effect of air-assistance on the spray recovery rate. Six measurements were performed (two fan settings combined with three tunnel openings as above). Finally, in test No. 4 the separator panels were made ineffective by covering their inner or outer side with plastic foils in the inside or in the outside, so as to simulate a tunnel sprayer with full containment walls, in order to assess the effect of the spray separating system on the recovery rate.

Further tests were performed with the tunnel sprayer in motion at 6.2 km/h forward speed along a 250 m long, smoothly paved lane. Tunnel opening was adjusted at 0.50 m, and the fan speed was set to the maximum (52.4 rev/s, giving a 2.40 m^3/s air flow rate). Outlet orientation was initially set at 25° backwards (front boom) and 25° forward (rear boom). Preliminary visual observation suggested that the spray and air flows generated by the nozzles and air outlets were, by some extent, being deflected backward by the additional flow of air, entering the tunnel from the front opening owing to motion. This was causing a relatively small, but clearly visible loss of droplets from the rear opening. In order to compensate for this effect, additional runs were made after rotating either the front or rear outlets towards the back of the tunnel, in steps of 5°, and repeating the procedure until no further improvement in the spray recovery rate was recorded.

The measuring procedure was the same as described above, except for the following. Two separate containers (volume capacity: 20 l each) for liquid recovery were used, and placed in a metallic frame, fitted in the back of the tank trailer. After the water flow from the recycling pipe had become steady, the sprayer was put in motion; liquid recovery was started as soon as the forward speed of the sprayer had stabilised, and was stopped after two min. The same was done during a second run in opposite direction, to compensate for the effect of the wind. At the and of both runs, the volume of water collected was measured, and the spray recovery rate was assessed.

During 2007, the tunnel sprayer was used for pesticide application in a commercial vineyard estate, located in San Martino al Tagliamento (PN, N.E. Italy). The vineyard (cv: Merlot) was trained to a spur-pruned low cordon, with planting distances of 2.4 m between the rows, and 0.8 m between the vines). Standard canopy management was performed, including side and top trimmings, and vertical shoot positioning using movable catch wires, which helped to limit the canopy width to 0.5 m or less at all growth stages.

Six treatments against powdery mildew and downy mildew were performed. After each application, six vines were randomly chosen in the vineyard for the assessment of the leaf area index (LAI); all their leaves were counted, and one leaf every five was taken. The area of the leaves sampled were measured with an area meter (Model LI-3100C, LI-COR Inc.). Based on the number of leaves per vine and their mean area, the total leaf area (S, in m^2) were determined for each sample vine.

The leaf area index (LAI) was then calculated as:

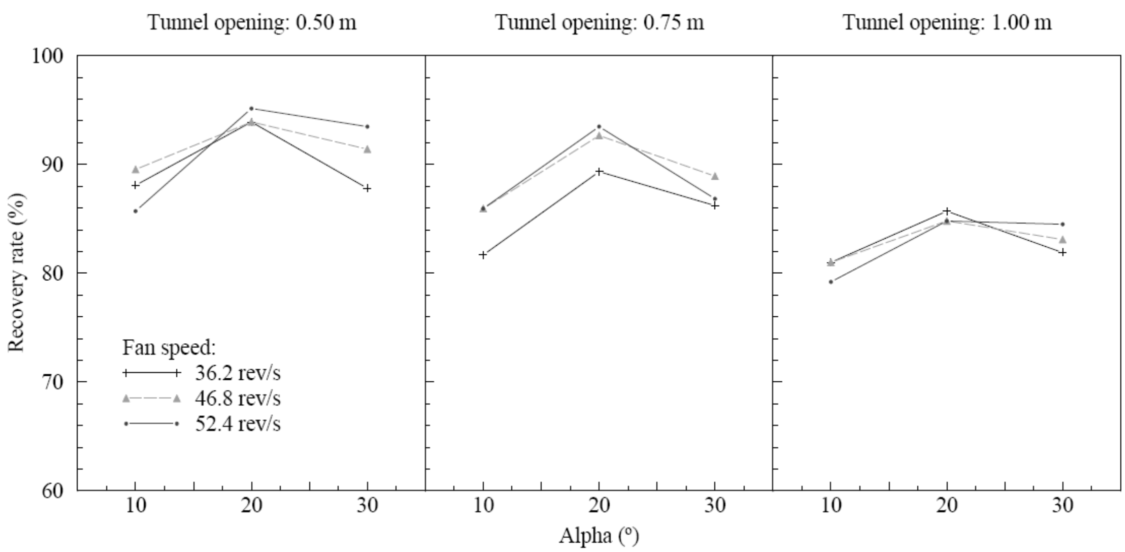
$$LAI = \frac{S}{xb}$$

where: x, in m, is the planting distance between the vines length (0.8 m); and b, in m, is the row spacing (2.4 m).

Results

The maximum recovery rate in static test No. 1 (95.1%; Figure 3) was recorded after adjusting the distance between the tunnel's walls at the minimum distance, 0.50 m, the outlet orientation at 20°, and the fan speed at the maximum. The reduction in the recovery rate at increasing distances between the tunnel's walls was largely expected. However, this effect was very small at the 0.75 m tunnel opening (maximum recovery: 93.5%; at the same outlet and fan speed adjustments as above), while clearly visible at the 1.00 m distance (85.7%; same outlet orientation, but at the minimum air flow rate, 1.18 m^3/s).

Figure 3. Static test No. 1: effect of tunnel opening, fan speed and outlet orientation on spray recovery rate.



The spray recovery rate was little affected by the air flow rate adjustments. This was indeed a good result, since it suggested that it would be possible, during spray application in the vineyard, to choose the correct air flow rate in order to obtain sufficient penetration into the vine canopy, without affecting the spray recovering and recycling potential of the sprayer.

Also the effects of different outlet orientations were comparably small. In general, the best angling of the air outlets was 20°, so as to point towards the middle of the opposite separator panel. At 10° inclination, in fact, part of the spray plume was not completely captured by the separator panel, but visibly escaped through the front and rear openings of the tunnel. On the other side, the 30° inclination of both air booms towards the centre of the tunnel visibly increased the turbulence of the air flows, particularly at the minimum distance between the shields (0.50 m, Figure 3), and this may have reduced droplet penetration through the separating panels.

Test no. 2 allowed a more complete analysis of the effects of outlet orientation. In fact, the best angling was different, depending on the distance between the air outlets and the opposite separator panel, and was 15°, 20° or 25° for openings of 1.00 m, 0.75 m and 0.50 m, respectively. This was consistent with the fact that, for a given angle of inclination, the air flow would impact the separator panel in slightly different points, depending on the distance between the shields.

Test No. 3 showed that air-assistance was important to improve the recovery rate. In the no-fan treatment, in fact, part of the droplets did not even have sufficient energy to reach the

Table 1. Static test No. 3: no fan versus medium fan speed (46.8 rev/s).

Tunnel opening, m	Recovery rate, %	
	No fan	Medium fan speed
0.50	74.6	94.2
0.75	71.7	92.5
1.00	61.8	84.7

separator panel at the facing tunnel wall, and were mainly lost through the opening at the bottom of the tunnel. As a consequence, the recovery rate was decreased at 61.8% to 74.6%, depending on tunnel opening (Table 1).

Test No. 4 showed that a similar reduction could be expected from a tunnel sprayer fitted with air-assistance and full containment walls (60.6% to 79.9%).

The dynamic tests performed with the sprayer in motion at 6.23 km/h showed that the orientation of the air outlets, and particularly the front ones, needed to be differently adjusted, in order to compensate for the effect of the additional flow of air, entering the tunnel from the front opening. In fact, the symmetrical rotation by 25° of both air booms, giving a 95.0% recovery under static conditions, resulted in a substantially lower recovery rate (83.8 %; Table 2) at 6.23 km/h forward speed. This was associated with a relatively small, but clearly visible loss of droplets from the rear opening. The best outlet orientation found in these tests was: 5° backwards and 25° forwards (front and back air booms, respectively), giving a recovery rate of 87.4% (Table 2). Thus, complete compensation of the effect of motion was therefore not

Table 2 . Dynamic tests: effect of outlet orientation.

Outlet orientation, degrees		test conditions	Recovery rate, %
front air boom (forwards)	rear air boom (backwards)		
25	25	static	95.0
25	25	dynamic, at 6.23 km/h forward speed	83.8
5	25		87.4
0	25		86.7
0	30		79.6

Table 3. Static test No. 4: effect of separator panel covering.

Tunnel opening, m	Outlet orientation, degrees	Recovery rate, %		
		panels covered at the inside	panels covered at the outside	panels not covered
0.50	25	77.7	79.9	93.3
0.75	20	70.6	72.0	92.1
1.00	15	60.6	62.1	86.3

Table 4. Amount of spray recycled by the tunnel sprayer in 2.71 ha Merlot vineyard during 2007

Trial Date (2007)	LAI	Tunnel opening, m	Recovery rate, %	Open nozzles per side	Volume sprayed, l/ha	nozzle type
3-April	0.00	0.60	77	3	319	ATR brown
3-May	0.33	0.55	40	2	219	ATR orange
9-May	0.53	0.60	47	3	323	ATR orange
21-May	0.46	0.60	47	3	323	ATR orange
31-May	0.61	0.60	50	4	444	ATR orange
8-June	0.96	0.65	40	5	555	ATR orange
11-July	1.79	0.65	34	6	433	ATR yellow

possible; and this may suggest that the prototype could be somewhat improved by increasing the air flow rate, or by using additional air jets to better shield the front opening from the incoming air flux.

Spray recovery in the vineyard was 77% at beginning of season (April 3, before bud break) to 34% on July 11 (full foliage development; Table 4). This was largely expected, since the increase in the leaf area index of the crop also increased the fraction of spray retained by the canopy, and decreased the amount of spray that could be recovered by the tunnel sprayer. However, the recovery rate was relatively constant between May 3 and June 8 (40% to 50%), despite an increase in the LAI by nearly three times (from 0.33 to 0.96).

Conclusions

These preliminary tests showed that the choice of using an air-assistance system, combined with a lamellae separator wall, allowed to obtain a high recovery rate from the tunnel sprayer. In fact, maximum potential recovery under static conditions was 95.1% or 93.5%, at 0.50 m 0.75 m tunnel openings, respectively, but clearly decreased at 1.00 m, suggesting that better performances are to be expected when using the tunnel sprayer in vineyards with thin canopies, and in VSP (vertical shoot positioned) training systems such as Guyot or Low Spur Cordon.

Under dynamic conditions, however, the maximum spray recovery rate decreased, owing to the effect of the additional flow of air, entering the tunnel from the front opening at 6.23 km/h forward speed. Adjusting the orientation of the air outlets to 5° backwards (front air boom) and 25° forward (rear boom) could partially compensate for this effect, resulting in a recovery rate of 87.4%. This suggested that the prototype could be possibly improved by increasing the air flow rate of the fans, or by using additional air jets to shield the front opening from the incoming air flux.

The actual recovery rate in the vineyard was maximum before bud break (77%), but still very good during the whole growing season of the vines (34% to 50%), and was relatively little affected by the LAI development. These values were generally better than those reported in the literature from tunnel sprayers both without air-assistance (Bäcker and Rühling, 1990; Siegfried and Raisigl, 1991; Siegfried and Holliger, 1996), or fitted with centrifugal fans (Baraldi et al., 1994; Planas et al., 2002).

These preliminary tests were also useful to set up the tunnel sprayer for further analyses, in order to assess the spray distribution over the foliage, penetration into the canopy and coverage of the under side of the leaves. The objective of further research will be to determine whether the new air-assistance system, developed for this sprayer, will be efficient in improving spray distribution uniformity, which has often been reported as unsatisfactory from most models of experimental or commercial tunnel sprayers proposed so far (Siegfried and Raisigl, 1991; Siegfried and Holliger, 1996; Viret *et al.*, 2003; Planas et al., 2002).

References

Bäcker G., Rühling W. (1990): Reduction of environment pollution by recycling of chemical in application of space cultures. International Conference on Agricultural Engineering, Berlin 24-26 October 1990, 160-161.

Planas S., Solanelles F., Fillat A. 2002. Assessment of recycling tunnel sprayers in Mediterranean vineyards and apple orchards. Biosystems Engineering 82:1, 45-52.

Schmidt, K. 1990. JOCO-Tunnelspritzgerät. Besseres Obst 35(6), 10-11.

Siegfried W., Holliger E. 1996. Application Technology in Fruit-Growing and Viticulture. Report, Swiss Federal Research Station, Wädenswill, Switzerland.

Siegfried W., Raisigl U. 1991. Erste Erfahrungen mit dem Joco-Recyclinggerät im Rebbau. Schweizer. Zeitschrift für Obst- und Weinbau 127(6), 154-160.

Viret O., Siegfried W., Holliger E., Raisigl U. 2003. Comparison of spray deposits and efficacy against powdery mildew of aerial and ground-based spraying equipment in viticulture. Crop Protection 22:8, 1023-1032.

Occupational and environmental risks caused by bio-aerosols in and from farm animal houses

Hartung J., Schulz J.
Institute of Animal Hygiene, Welfare and Behaviour of Farm Animals, University of Veterinary Medicine Hannover, Bünteweg 17p, 30559 Hannover, German, telephone +49 (0)511 953-8832, telefax +49 (0)511 953-8588, itt@tiho-hannover.de

Abstract
The air in modern animal production systems contains a large variety of aerial pollutants which are widely recognised as detrimental for the respiratory health of animals kept in these facilities and the work force working regularly in this atmosphere. Primary and opportunistic microbial pathogens may cause directly infectious and allergic diseases in farm animals, and chronic exposure to some types of aerial pollutants may exacerbate multi-factorial environmental diseases. There are, however, few international field surveys paying attention to the health of the farmers and the farm personnel working in animal houses, and to the spread of pathogens from farm buildings. Studies reveal that up to 20 % of farmers and farm workers complain about symptoms of respiratory affections such as coughing, sputum, wheezing and others. Some develop asthma, others develop diseases which are described as e.g. ODTS (organic dust toxic syndrome). There are indications that various pathogens can survive in an air-borne state for several minutes and can be distributed over long distances in the ambient air of farms, e.g. foot and mouth virus can travel aerially more than 50 km. In a recent study it was shown that *Staphylococcae* can be found in significant concentrations (4000 cfu/m³) in about 500 m down wind of broiler barns. A future-oriented sustainable farm animal production should enhance - beside the topics of animal welfare, consumer protection and economy - also standards to improve occupational health and to prevent or reduce the spread of pathogens via the air.

Keywords: air pollutants, animal farming, disease transmission, occupational health.

Introduction

The air in modern animal production systems contains a large variety of air pollutants such as gases like ammonia and carbon dioxide, dust, micro-organisms and endotoxins. These pollutants, also addressed as bio-aerosols, are increasingly regarded as a source of air pollutants which can be both aggravating and environmentally harmful. The pollutants give cause for concern for several reasons. (1) Animal respiratory health may be compromised by pollutants such as gases, dust, microorganisms and endotoxins (eg Baekbo, 1990). (2) The second reason concerns the environment. There is vast knowledge that the livestock buildings, manure storage facilities, manure spreading and even free range systems are major sources of gaseous pollutants such as ammonia, methane and nitrous oxide which contribute to soil acidification and global warming (eg Jarvis and Pain, 1990; Hartung et al. 1990). (3) The third concern is farmer's health. There is epidemiological evidence that the health of farmers working in animal houses may be harmed by regular exposure to air pollutants like ammonia, dust, micro-organisms and endotoxins (Donham, 1987; Whyte et al., 1994, Donham, 1995, Radon et al., 2002, Hartung, 2005). Providing a safe and healthy work environment for employees is an important aspect of any industry – including animal farming (Cargill and Hartung 2001). (4) A major reason for concern are the bio-aerosol emissions such as dust and micro-organisms from buildings which are supposed to play a role in respiratory affections in people living in the vicinity of animal enterprises (Müller and Wieser, 1987, Hartung, 1995, Seedorf, 2004) and which can be transmitted by way of the air between farms (Schulz et al., 2005). Scientific assessment of the risk of aerial transmission of pathogens between flocks is hampered by the fact, that there is still little knowledge about the nature and composition of bio-aerosols, the tenacity (resistance) of bacteria and viruses in an airborne state and their survival times in ambient air.

This paper briefly defines the term bio-aerosol, gives some quantitative data of air pollutants in poultry houses, shows examples of health effects of this pollution on man and animals, discusses survival times of bacteria and viruses in air and their possible travel distances in the surrounding of farms and reflects on "safe distances" between flocks.

Common pollutants found in farm animal houses and definition of bio-aerosol

The key pollutants recognised in the airspace of livestock buildings are particles including dust, microorganisms and their toxins, and gases such as ammonia, carbon dioxide and more than 100 trace gases e.g. like volatile fatty acids (Table 1). Under commercial production conditions the airborne particles will contain a mixture of biological material from a range of sources, with bacteria, toxins, gases and volatile organic compounds adsorbed to them. Because of their complex nature these airborne particles are also addressed as bio-aerosols (Seedorf and Hartung 2002). The typical character of bioaerosols is that they may affect living things through infectivity, allergenicity, toxicity, pharmacological or other processes. Their sizes can range from aerodynamic diameters of 0.5 to 100 µm (Hirst, 1995).

Table 1. Common air pollutants in animal houses

Gases	Ammonia, hydrogen sulphide, carbon monoxide, carbon dioxide, 136 trace gases, osmogens
Bacteria/Fungi	100 bis 1000 cfu/l air 80 % staphylococcaceae/streptocococcaceae
Dust	e.g. 10 mg/m³ inhalable dust organic matter approx. 90 %, antibiotic residues
Endotoxin	e.g. 2 µg/m³ in piggeries

Several studies have recorded concentrations of key components of bio-aerosols in farm animal buildings, but with particular high amounts in poultry production (e.g. Seedorf et al., 1998).

Table 2 summarises the results of a broad EU-wide study on bio-aerosols in pig, cattle and poultry farms. The results show that the lowest concentrations were found in cattle production and the highest in poultry houses (Seedorf et al., 1998). However there are existing considerable differences between production systems within one species. The highest dust concentrations regularly occur in aviaries for laying hens. These concentrations often exceed the occupational health limit at the work place of 4 mg/m³ (for Germany) particularly at times of high animal activities (Saleh, 2006). These pollutants are emitted into the environment by way of the exhaust air through the ventilation system.

Table 2. Bioaerosol Concentrations in Livestock Buildings

		Cattle	Pig	Chicken
Inhalable Dust	mg m-3	**0.38**	**2.19**	**3.60**
Respirable Dust	mg m-3	**0.07**	**0.23**	**0.45**
Total Bacteria	log CFU m-3	**4.4**	**5.2**	**5.8**
Total Fungi	log CFU m-3	**3.8**	**3.8**	**4.1**
Inhalable ETOX	ng m-3	**23.2**	**118.9**	**660.4**
Respirable ETOX	ng m-3	**2.6**	**12.0**	**47.5**

ETOX: Endotoxin, 1 ng equals approx. 10 EU (endotoxin units)
CFU: Colony forming units
(Seedorf et al. 1998, Takai et al. 1998; modified)

Health effects of bioaerosols at the work place in farm animal houses

The number of farmers and employees complaining about respiratory symptoms during and after work in animal houses has risen in recent years. The number of obstructive airway diseases caused by allergic compounds rose from about 90 in the year 1981 to approximately 700 in 1994, a slightly smaller increase from 8 to 50 was observed for obstructive diseases caused by chemical irritants or toxic compounds (according to the statistic of the occupational health board in agriculture, 1996). In a study comprising 1861 farmers in the north of Germany about 22 % of the pig farmers, 17 % of the cattle farmers and 13 % of the poultry farmers displayed airway problems (Nowak, 1998). The data are detailed in Table 3.

Numerous studies have demonstrated links between dust and human health in a number of livestock related industries (Donham, 1995). A survey of 69 full-time poultry stockmen found that although levels of exposure to respirable dust were within occupational health and safety guidelines, 20% were exposed to levels of dust 2.5 times the figure of 10 mg/m^3 recommended under occupational health and safety guidelines (Whyte et al., 1994). Findings such as these have led to the introduction of strict codes to protect people involved in the intensive livestock industries in several countries including Denmark and Sweden. Guidelines have also been recommended to the Australian pig industry (JACKSON and Mahon, 1995).

First reports indicating significant health hazards for humans working in intensive livestock production systems were published 30 years ago (Donham et al., 1977). A number of syndromes have been recognised in workers in the intensive animal industries. They range from an acute syndrome that develops within a few hours to days of exposure to animal sheds, and which is accompanied by a variety of clinical signs including lethargy, a mild febrile reaction, headaches, joint and muscle aches and general malaise to more chronic responses. In some cases, the initial attack is so severe that the employee terminates their employment within a matter of days. In general, episodes last 12 to 48 hours with chronic fatigue and congested respiratory passages being reported as the most common clinical signs. The condition has been referred to as Organic Dust Toxic Syndrome (ODTS) or toxic alveolitis. The prevalence of ODTS has been quoted as ranging from 10 to 30% of workers, depending on the type of intensive animal production and the facilities used (Donham, 1995).

Table 3. Frequency of workplace-related respiratory symptoms in livestock farmers/employees in Lower Saxony, Germany (Nowak, 1998)

Animal Species		Number of Persons	Percentage (%) of complaints
Pig	Sow	619	22,7
	Fattening	799	21,9
	Weaner	551	23,0
Cattle	Cow	1245	17,4
	Beef	895	17,2
	Calf	1190	17,8
Laying hen		279	14,7
Broiler		47	12,8

A range of acute respiratory symptoms, described by employees following contact with their work environment, but not necessarily associated with a generalised clinical syndrome, have also been documented (Brouwer et al., 1986). The more common clinical signs include an acute cough, excess sputum or phlegm, a scratchy throat, discharging or runny nose and burning or watery eyes. Other more generalised clinical signs that may or may not be present include headaches, tightness of the chest, shortness of breath, wheezing, and muscle aches.

Exposure to dust produces a variety of clinical responses in individuals. These include occupational asthma due to sensitisation to allergens in the airspace, chronic bronchitis, chronic airways obstructive syndrome, allergic alveolitis and organic dust toxic syndrome (ODTS) (Iversen, 1999).

The suggestion that the primary clinical problem is an obstruction of the airways is supported by various studies in which workers have been subjected to lung function tests. Although the forced expiratory volume-in-one-second (FEV_1) was not changed in most people studied, decreases in the FEV_1/forced vital capacity (FVC) ratio and flow rates support this hypothesis. In a series of studies of workers over a period of time, the greatest decrease (4 to 12%) occurred in forced expiratory flow rates (Hagland and Rylander, 1987). In both Swedish and American workers, significant changes were also recorded in FEV_1 and flow rates. Although the changes reported in these studies were modest on a population basis, a significant clinical reduction in FVC was recorded in 14% of Canadian workers (Dosman et al., 1988) and 20% of Dutch workers (Brouwer et al., 1986).

Exposure to bio-aerosols has also been shown to cause a broncho-constriction, hyper-responsiveness and increased inflammatory cells in bronchial alveolar lavage fluids in naïve subjects (Malberg and Larsson, 1992). It is assumed that broncho-constriction followed by reduced ventilation of the lungs can be caused by inhaled endotoxin. Experiments using nasal lavage show that pig house dust containing different concentrations endotoxins increases the inflammatory reaction of the nasal muceous membranes of humans distinctly (Nowak et al., 1994). The broncho-constrictive effects of bioaerosols have also been demonstrated in guinea pigs (Zuskin et al., 1991) as well as stockpersons in Sweden and North America (Donham, 1995).

Further studies are required to understand the building features and animal husbandry practices that increase the concentration of airborne pollutants in buildings housing animals and to determine the key pollutants involved. The evidence collected in farm animal buildings suggests that issues such as hygiene and stocking density (kg biomass/m^3) are key factors but that the composition of pollutants or bioaerosols may vary significantly from shed to shed depending on a range of factors (Banhazi et al., 2000). These include hygiene, dietary composition, as well as the type of bedding and effluent disposal system used. The composition of bioaerosols might be more important for severity of specific occupational health problems than just the concentration of airborne particles within an animal house atmosphere.

Transmission distances of bio-aerosols

There are only few experimental data available on transmission distances of bioaerosols from animal confinement houses. From epidemiological studies it is known that FMD-virus can travel over distances of more than 50 kilometres (Gloster et al., 2005). Experiments around farms revealed elevated levels of dust particles and bacteria in comparison to reference point measurements between 50 and 115 m and 50 and 300 m, respectively. These figures are far from being safe distances because they do not reflect the spread of specific pathogens or allergenic components (e.g. feather fragments) which may be transported much longer distances, and which can develop health risk even in small quantities.

Most important for a possible transmission of a pathogen is its ability to survive in an airborne state over a longer period. Micro-organisms in an air-borne state are strongly influenced by environmental conditions such as temperature and humidity of the air. Other factors are radiation, sun light and additional chemical compounds in the air.

Recent investigations in and around broiler houses showed that the travel distance of *Staphylococcae* downwind can be at least 500 m from the source. Under stable wind conditions more than 4000 cfu/m³ were found 477 m downwind the barn (Figure 1). *Staphylococcae* are typical bacteria in broiler house air. They can probably serve as indicator bacteria for the bacterial pollution because they do usually not appear in relevant concentrations in normal outside air.

These results show that there is a considerable distribution of micro-organisms from poultry production in the vicinity of livestock houses.

Strategies to minimise the risk for employees and animals

Several approaches aimed at reducing air pollution in animal houses and protecting employees on the job are available. These include wearing protective gear, reducing exposure levels within the buildings, and eliminating pollutants at source. Employees should be encouraged to wear dust masks and eye protection when working in sheds, particularly in straw based shelters when handling or moving animals. As a minimum, a mask that can be shaped for individual nasal structures with two head straps (above and below the ears) should be used. A reliable protection is realized by ventilated masks only. The disadvantage is the weight of the helmet with the filter system and the battery powered ventilator. Employees who wear glasses may need to consider contact lenses while wearing a mask and eye protection. A recent survey is given in the book KTBL Schrift 436 (Anonymus, 2005).

Various strategies have been recommended for reducing the concentrations of airborne pollutants in animal houses. These include management measures as well as strict hygienic rules and direct reduction techniques such as fogging sheds with oil and water (Pedersen, 1998, Banhazi et al., 1999). All these methods have carefully to be investigated whether they may display side effects on the animals, the environment or on meat quality (Cargill and Hartung, 2001). Also end-of-pipe techniques such as bio-filters and bio-scrubbers are recommended in some countries which filter the exhaust air and reduce the pollution of the surrounding of the farm. These techniques are however still rather expensive and presently more restricted to sensitive situations when e.g. farms are in very close neighbourhood to residential areas.

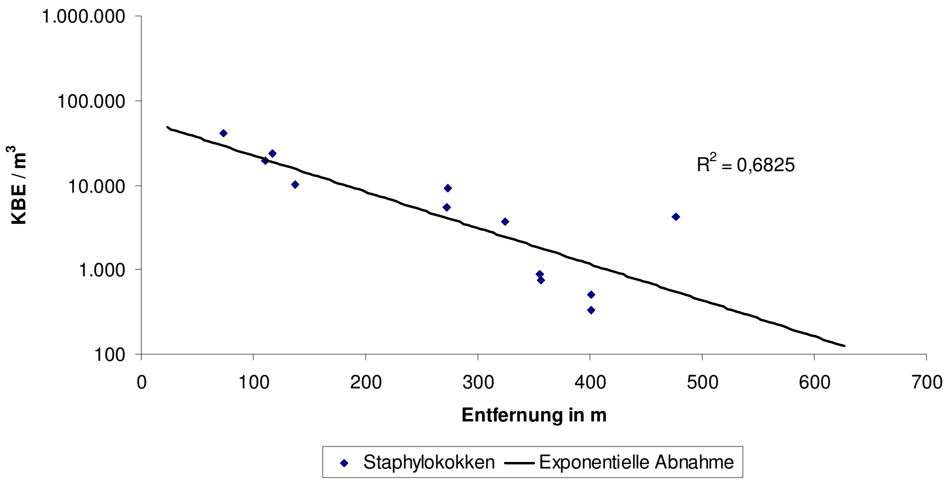


Figure 1: Decreasing concentrations of Staphylococcae with increasing distance downwind a broiler barn with 30,000 birds. Sampling 1.5 m above ground. Animals in second half of production cycle. Air temperature about 16 °C, wind speed between 1.7 m/s and 6.3 m/s. n = 12.

Reducing air pollutants in animal houses is an urgent demand for the development of future production. It will provide a safer and healthier work environment for employees and a better atmosphere for the animals improving their health, welfare and performance. Reducing emissions will at the same time reduce the risk of transmission of pathogens indoors as well as between neighbouring farms. A future-oriented sustainable farm animal production should enhance - beside the topics of animal welfare, consumer protection and economy - also standards to improve occupational health and to prevent or reduce the spread of pathogens via the air.

References

Anonymus, 2005. Luftgetragene biologische Belastungen und Infektionen am Arbeitsplatz Stall. KTBL-Schrift 436. Kurat. Technik u. Bauwesen Landwirtschaft, Darmstadt, p. 1-201.

Baekbo, P. 1990: Air quality in Danish pig herds. Proceedings 11th Congress of the International Pig Veterinary Society 1-5 July 1990, Lausanne, 395.

Banhazi, T., O'Grady, M., Cargill, C., Wegiel, J., Masterman, N. 1999. The effects of oil spraying on air quality in straw based shelters. In: Manip. Pig Prod. VII Ed Cranwell, P.D., 28.

Banhazi, T, Cargill, C, Payne, H. and Marr, G. 2000. Report on national Air Quality Survey to Pig research and Development Corporation, Kingston, ACT.

Brouwer, R, Biersteker, K, Bongers, P, Remin, R and Houthuijs, D. 1986. Respiratory symptoms, lung function and IgG_4 levels against pig antigens in a sample of Dutch pig farmers. American J Industrial Med, 10, 283-285.

Cargill, C., Hartung, J. 2001. Air quality – from an OH&S perspective. In: Proceedings Australian Association of Pig Veterinarians, Pan Pacific Conference on Consistent Pork, Melbourne, 14.05. – 15.05.01, 93-101.

Donham, K. J, Rubino, M.J, Thedell, T.D. and Kammermeyer, J. 1977. Potential health hazards of workers in swine confinement buildings. J Occupational Medicine,19, 383-387.

Donham, K. J. 1987. Human health and safety for workers in livestock housing. In: Latest developments in livestock housing. Proceedings of CIGR, Illinois, USA, 86-95.

Donham, K. J. 1995. A review - The effects of environmental conditions inside swine housing on worker and pig health. In Manipulating Pig Production V; D. P. Jennessy and P. D. Cranwell, Eds., 203-221.

Dosman, J. A, Grahm, B. L, HALL, D, Pahwa, P, McDuffice, H, Lucewicz, M. 1988. Respiratory symptoms and alterations in pulmonary function tests in swine producers in Saskatchewan: results of a farm survey. J Occupational Medicine, 30, 715-720.

Gloster, J., Freshwater, A., Sellers, R.F., Alexandersen, S. 2005. Re-assessing the likelihood of airborne spread of foot-and-mouth disease at the start of the 1967-1968 UK foot-and-mouth disease epidemic. Epidemiol. Infect. 1-17.

Hartung, J., M. Paduch, S. Schirz, H. Döhler, H. Van den Weghe 1990. (Hrsg): Ammoniak in der Umwelt. Gemeinsames Symposium von KTBL und VDI in der FAL Braunschweig, 10-12 Okt. 90., LANDWIRTSCHAFTSVERLAG GMBH, Münster**,** 670 Seiten.

Hartung, J. 1995. Gas- und partikelförmige Emissionen aus Ställen der Tierproduktion. Dtsch. tierärztl. Wschr., 102, 283-288.

Hartung, J. 2005. Luftverunreinigungen in der Nutztierhaltung. In: Luftgetragene biologische Belastungen und Infektionen am Arbeitsplatz, KTBL Schrift 436, Darmstadt, 7-19.

Haglind, P. and Rylander, R. 1987. Occupational exposure and lung function measurements among workers in swine confinement buildings. J Occupational Medicine, 29, 904-907.

Hirst, J.M. 1995. Bioaerosols: Introduction, retrospect and prospect. In: Bioaerosols Handbook, C.S. Cox and C.M. Wathes (eds.)**,** CRC Press, Boca Raton.

Iversen, M. 1999. Humans effects of dust exposure in animal confinement buildings. Proceedings of the "Dust control in animal production facilities" International Symposium, Jutland, Denmark, 131-139.

Jackson, A.; Mahon, M. 1995. Occupational Health and Safety for the Australian Pig Industry," PRDC and Queensland Farmers' Federation.

Jarvis, S.C., Pain, B.F. 1990. Ammonia volatilisation from agricultural land. Proceedings Fertiliser Society, Peterborough, U.K., 298.

Malberg, P, and Larsson, K. 1992. Acute exposure to swine dust causes bronchial hyperresponsiveness. Stokloster Workshop 3, Stoklostwer, Sweden. April 6-9 1992.

Müller, W. AND Wieser, P. 1987. Dust and microbial emissions from animal production. In: Strauch, D. (ed.), Animal Production and Environmental Health. Elsevier, Amsterdam, Oxford, New York, Tokyo, 47-89.

Nowak, D.; Denk, G.; Jörres, R.; Kirsten, D.; Koops, F.; Szadkowski, D.; Hartung, J.; Magnussen, H. 1994. Endotoxin-related inflammatory response in nasal lavage fluid after nasal provocation with swine confinement dusts. Am. J. Resp. Crit. Care Med., 149, A401.

Nowak, D. 1998. Die Wirkung von Stalluftbestandteilen, insbesondere in Schweineställen, aus arbeitsmedizinischer Sicht. Dtsch. tierärztl. Wschr.,105, 225-234.

Pedersen, S. 1998. Staubreduzierung in Schweineställen. Dtsch. tierärztl. Wschr., 105, 247-50.

Radon, K., Monso, E., Weber, C., Danuser, B., Iversen, M., Opravil, U., Donham, K., Hartung, J., PEDERSEN, S., Garz, S., Blainey, D., Rabe, U., Nowak, D. 2002. Prevalence and

risk factors for airway diseases in farmers – summary of results of the European farmers´ project. Ann Agric Environ Med., 9, 207-213.

Saleh, M. 2006. Untersuchungen zur Luftqualität in verschiedenen Systemen der Geflügelhaltung mit besonderer Berücksichtigung von Staub und Luftkeimen. [Air quality in different housing systems for poultry with special reference to dust and airborne microorganisms.] PhD-These, Tierärztliche Hochschule Hannover

Schulz, J., Seedorf, J., Hartung, J. 2005. Estimation of a „safe distance" between a natural ventilated broiler house and a residential dwelling. In: Krynski, A., Wrzesien, R. (eds.): Proc., Volume 2, XIIth Internat. Congress on Animal Hygiene of the ISAH (International Society for Animal Hygiene) "Animals and Environment", Warsaw, Poland, 04.-08.09.05, 41-45.

Seedorf, J. 2004. An emission inventory of livestock-related bioaerosols for Lower Saxony, Germany. Atmospheric Environment, 38, 6565-6581.

Seedorf, J., Hartung, J., Schröder, M., Linkert, K.H., Phillips, V.R., Holden, M.R., Sneath, R.W., Short J.L, White, R.P., Pedersen, S., TAKAI, T., Johnsen, J.O., METZ, J.H.M., Groot Koerkamp, P.W.G., Uenk, G.H., Wathes, C.M. 1998. Concentrations and Emissions of airborne Endotoxins and Microorganisms in Livestock Buildings in Northern Europe. In: Journal of Agricultural Engineering Research, 70, 97-109.

Seedorf, J., Hartung, J. 2002. Stäube und Mikroorganismen in der Tierhaltung. KTBL-Schrift 393, LANDWIRTSCHAFTSVERLAG GMBH, Münster, 166 Seiten

Takai, H., Pedersen, S., Johnsen, J. O., Metz, J. H. M., Groot Koerkamp, P. W. G., Uenk, G.H., Phillips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schröder, M., Linkert, K. H., Wathes, C. M. 1998. Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. Journal of Agricultural Engineering Research, 70, 59-77.

Whyte, R. T.; Williamson, P. A. M.; Lacey, J. 1994. Air pollutant burdens and respiratory impairment of poultry house stockmen. 709-717.

Zuskin, E, Kanceljak, B, Schlachter, E, Mustajbegovic, J, Giswami, S, Maayani, S, Marom, Z and Rienzi, N. 1991. Immunological and respiratory findings in swine farmers. Environmental Research, 56,120-130.

Reducing pesticide-related water pollution by improving crop protection practices: the use of embedded ICT technologies

Douchin M., de Rudnicki V., Ruelle B., Bellon-Maurel V., Pasi L.[1]
Cemagref – UMR ITAP- 361 rue J.F. Breton 34196 Montpellier France www.lifeaware.org
Tel +33 04 67 04 63 00 Fax +33 04 67 16 64 40
[1]*Consorzio CISA s.c.ar.l. - ARPA Agrotecnica soc coop, P.zza Indipendenza 5, 00185 Rome Italy - +39 348 5650369 lucianopasi@arpacoop.it*

Abstract

The AWARE project shows that the optimisation of the pesticides application techniques can limit the pollution of surface water and help farmers to respect the environmental requirements of the CAP. It has 4 main actions:

1-Developing tools and a methodology to reduce the environmental impact of pesticides

- **by setting up geo-referenced data-recorders embedded on sprayers, which gives real time control of the applied pesticide and the production of an objective traceability book;**
- **by improving equipments: collective filling stations for sprayers which fulfil environmental standards, rinsing tanks and devices and sprayers adjustment;**
- **by implementing a plan of practices' improvement based on measured data**

2-Extending the results to other contexts thanks to the modeling of pesticides transfer.

3-Assessing the feasibility of knowledge transfer through implementation of the methodology in others European contexts (Spain, Italy);

4-Transferring the experience and the acquired knowledge to the european farmers and to the general public. The tests of the Aware sensing device lasted almost two years on 15 different sprayers on the Neffiès (Montpellier) river basin, showing that:

- **the system can be implemented on different type of vineyard sprayers;**
- **the devices were used for sprayer tuning and for spraying monitoring by the farmers;**
- **the device outputs can be used for generating traceability records, error free;**
- **the maps and graphs generated from the data can help improving agricultural practices and lead to the use of lower quantities of pesticides;**
- **these devices have been very well accepted by farmers**

Keywords: CAP, pesticides, health, environment, traceability.

Introduction

Context

The European Water Framework Directive sets the goal of achieving a "good status" for all of Europe's surface waters and groundwater by 2015. In France, studies carried out by the French Institute for the Environment (IFEN) show that the whole territory is concerned by water pollution. Both underground and ground water masses are affected, especially at locations where human activity is important. In 2004, the contamination levels are significant: 49% of ground water samples were graded "average to bad" quality, 27% of underground water would need to be processed for being made potable.

The Aware project, co-funded by the European Union and 9 partners in France, Spain and Italy, focuses on the impacts of agricultural activity on water resources in rural areas. It has been build up to demonstrate how the optimisation of agricultural practices and equipments related to pesticide spraying in viticulture helps the farmers to preserve the quality of water entities and to maintain a high quality of products.

The project is coordinated by the Cemagref (French agricultural and environmental research centre), and is based on a partnership between state-owned company (Conseil Général de l'Hérault (France), Chambre d'Agriculture de l'Hérault (F)), public research and training centres (Montpellier SupAgro(F), INRA(F), IRTA(Spain)) and private companies (Voe Développement(F), Ereca(F), CISA (Italy)).

Life Aware is a three years project which takes place in the Vaillèle catchment basin of the French town of Neffiès, in the south of France, where the only crop is grapevine. 15 winemakers, members of the cooperative or having their own winery, have accepted to participate actively to the project.

Environmental concerns increasingly play a role in the Common Agricultural Policy: the agri-environmental strategy of the CAP is aimed at enhancing the sustainability of agro-ecosystems. Since the Agenda 2000 CAP reform, cross compliance has been established, becoming compulsory in 2005, see C.Reg. 1782 and Comm. Reg. 796 : this is the principle that farmers should comply with environmental protection requirements as a condition for benefiting from market support. If farmers do not respect the environmental requirements, appropriate sanctions are to be applied, which may include the reduction or even the withdrawal of direct aids.

Statutory Management Requirements (in Italy "Criteri di Gestione Obbligatori" or CGO) are specific European legal requirements applicable to farmers. They comprise a number of articles from 19 EU Directives and Regulations which address the environment, public, plant and animal health, and animal welfare. In particular, there are specific CGO with regard to water protection from pollutants.

Good Agricultural and Environmental Conditions (in Italy "Buone Condizioni Agronomiche e Ambientali" or BCAA) are domestic legal requirements requiring farmers to keep their soils in good condition, and to maintain a range of habitat and landscape features which are important to the countryside. They either reinforce existing national laws or were already established good practice. As such, it is only natural that they have a very technical nature, specific to particular environments and to climate conditions: this is the reason for their definition at a regional level.

There is a specific EU regulation, see C. Dir. 414/1991 and Dir. 8/1998, finalized to minimise the detrimental environmental impact of pesticides. They have been previously regulated in most EU member states, mostly regarding their production, distribution and end-of-life stages.

Under the cross compliance regime, with regard to GAEC, the ACT B9 reminds producers and distributors of the legal requirements concerning the supply of pesticides to the market; the ACT B11 sets requirements for the use of pesticides that must be satisfied in order for farmers to get the aids from the PAC: this is linked with public health targets and mainly concerns the traceability along the food chain. Each farmer has to keep track of a series of data regarding crop treatments.

In spite of these efforts, according to official sources, as a result of misuses of pesticides, including overuses, the percentage of food and feed samples in which residues of pesticides exceed maximum regulatory limits, has not decreased over the last ten years.

Since July 2002, with the introduction of the sixth environment action programme, the European Commission adopted a document on the Thematic Strategy on the sustainable use of pesticides which is targeting specifically the use-phase of plant protection products. The Strategy addresses the threats of pesticides to human health and the environment and will ensure coherence of rules across member states. It will concern the temporary storage of pesticides at farm level, the management/calibration of application equipment, the protection of operators, the preparation of the spraying solution and the application itself.

We think that our project, both via the new equipment and thanks to the procedures set up during our tests, anticipates some of the solutions to these problems:

- precise control of sprayed quantities, of their distribution across fields and of the metereological conditions;
- the ability to speed up the processes required by traceability, with an almost automatic production of the relative records.

It is possible that member states would consider giving a special low risk status with regard to the Integrated Administration and Control System's (IACS) procedures, to those farmers equipped with sprayers having this kind of capabilities.

Last but not least, the results from our research on modeling the catchment basin can greatly improve the understanding of the dynamic of pollutant: this in turn can lead to regional raccomandation being integrated in the existing GAEC.

Objectives

The first objective of this project is to test the capacity of information and communication technologies to help farmers reducing the total amount of pesticides released during the crop protection process. We install high quality equipments (embedded data-recorder on sprayers, a collective filling station which fulfil environmental standards, rinsing tanks on sprayers) and organize training sessions to support them in the daily use of these equipments.

The second objective is to study the relation between this decrease of pesticides quantities on a given catchment basin and the actual improvement on the water quality in the basin outlet. We try to assess the sensitivity of the water system to the variations of the total amount of molecules released.

Finally, we aim to extend the method and results to other contexts thanks to the modeling of pesticides transfer, and to assess the feasibility of knowledge transfer through implementation of the methodology and ICT recording system in others European countries (Spain, Italy).

Communication towards the wider range of stakeholders is a key issue of the project: we target farmers, advisers, research centres, students, companies involved in plant health protection, etc. We use several communication tools in order to fulfil this goal: booklets, website, reports, interactive film, and the participation to international congresses.

Materials and methods

1 Embedded data-recorder on sprayers

The Aware device aims at measuring a number of data relevant for the spraying operation and delivering them to the farmers of the Cooperative. It is made up of two parts:

- The Aware mobile device is an embedded electronic system which measures and records spraying parameters.
- The Aware Server is the processing and display unit, located at Neffiès wine cooperative.

Aware mobile consists of embedded electronics on the tractor (MPU) and on the sprayers (APU). Data recorded by the Aware Mobile are the following:

- meteorological data: temperature, humidity, wind direction and speed
- tank level
- right and left flows of the sprays,
- Geographical position and tractor speed by GPS sensor.

Figure 1

Figure 2

The MPU (Fig. 1) manages the GPS referencing, the climate data, the data display and man-machine interface (for manual data input), so as the WiFi interface to data transfer. The APU (Fig.2) deals with acquisition of data related to tank level and right / left flows.

The Aware Server unit is aimed at:

- recording and processing the data of each tractor in order to compute trajectories and to merge data;
- generating information related to the sprayed plots and to the various processing dates.

A Geographical Information System (GIS) has been implemented for gathering and process all terrain data (tractors trajectories, topography, hydrography, vineyard plots etc).

The sensors have been implemented on the sprayers of 15 vineyard growers, representing 80% of the vineyard plots of the river basin. These sprayers were all of different brands and models and the setting up has been realized without any major problem (Fig 3).

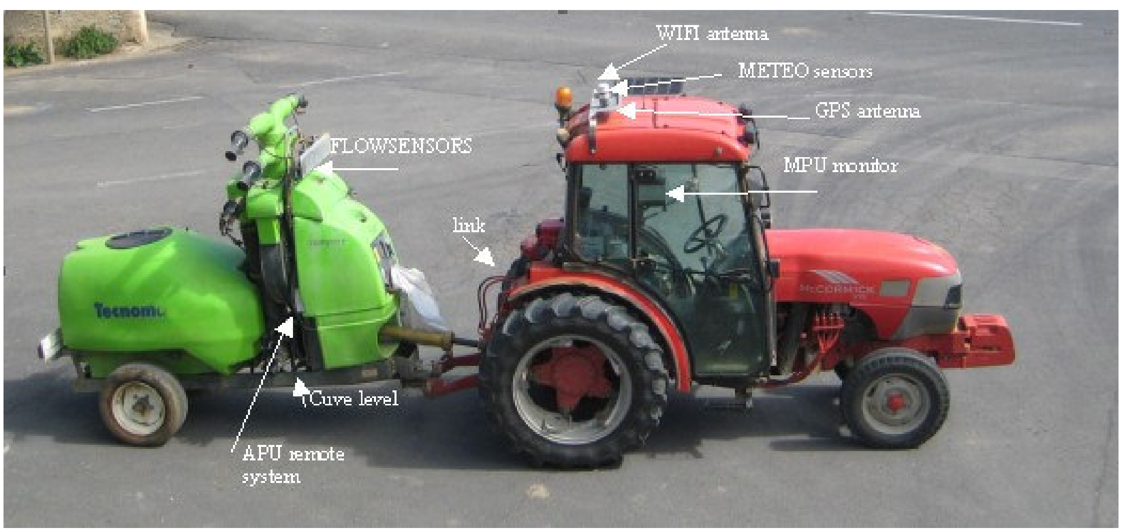


Figure 3

Both the Mobile and the Server Aware units have been developed in order to be as user-friendly as possible: the Aware project also deals with assessing the acceptation of the device by vineyard growers. Two training sessions have been organized, one in July 2006 and the other one in October 2006, in order to carry out a first return on experience from the farmers.

One campaign was carried out in 2007 with these 15 sensing devices. At the beginning of the season all sprayers have been cleaned and tuned. Various parameters are checked during the training sessions: the nozzle orientation, the cleaning up and the maintenance of the sprayer between two spraying operations; the tuning of the right and left flows.

In parallel to the spraying data recorded by the Aware device, the farmers are invited to fill up a "spraying book", in which all data dealing with spraying are theoretically written.

2 The catchment basin approach - impacts on water

2a Equipments

Several equipments were installed to study the catchment basin system. At the outlet of the basin, across the river, a crest has been fit out with measuring and sampling devices so that

- the river flow is measured and recorded at different time steps.
- water samples are automatically taken during floods

The water samples are analysed by an independent laboratory which looks for the presence of a wide range of pesticides (fungicides, acaricides, insecticides, weed control molecules). A weather station in the middle of the catchment basin records the climate parameters every 10 minutes, such as rain intensity and wind speed. The former measure is a key data for analysing the hydrological response of the basin to heavy rainfalls. The later helps the farmers to decide whether to spray or not, depending on the wind speed.

2b Modeling the hydrological system

One of the goals of the project is to evaluate the relation between the amount of pesticides released in the plots and the concentration of molecules found in the river at the outlet of the catchment basin as in Voltz (2003). Since the Aware project lasts only 3 years, and considering the significant climate variability in the south Mediterranean context, we chose to use modeling tools to study the way rainfalls and agricultural practices influence the level of the water pollution: the modeling is based on the deposits over crops and ground and on the rainfalls. The partner Lisah has been developing the hydrological model Mhydas on another close catchment basin (Roujan) for 15 years. This model was then calibrated on our experimental site in Neffiès. The whole area has been parted into homogeneous hydrological zones (at ground and underground level). We can apply a rainfall quantity and pesticides quantities on each plot and let the model calculate the river flow and the concentration of pesticides molecules in the river (or everywhere else in the area). Basically, we use Mhydas to test different scenarios of agricultural practices in various climate conditions. We focus our work on the following aspects of the river pollution:

- The impact of the geographical position of each plot considering the distance to the river
- The role of a controlled grass between the vineyard rows
- The impact of the time between the pesticide application and the following rainfall
- The sensibility with regard to the amount of pesticides sprayed

We can use this tool to show stakeholders what progress are made depending on the climate, the organization of vineyards, the pesticides used by farmers, the quantities involved.

Results

1 Agricultural practices

1a The role of the Aware devices for sprayer tuning

The Aware sensing devices were used at two stages by farmers, in an on-line configuration:

First, during the filling up: the tank level sensor is very useful to the farmer as it allows him to stop the filling when necessary. This operation was much less comfortable when using the sprayer embedded level sensors and the Aware sensor is more accurate. The farmer can precisely adjust the water volume needed for the set of plots he planned to work on.

Second, during the spraying, when the farmer can monitor the spraying and external parameters and therefore adapt his speed or detect any dysfunction (ex: stuck nozzle…). The displayed parameters are: the right and left flows (in l/min.), the tank level and the weather parameters (the farmer can stop if the wind is strengthening or above the allowed threshold).

1b The role of Aware devices for farmer practice improvements

All the data recorded during spraying operations are processed and organized in an easy and readable format. They are turned into graphs and maps, which can be used by farmers and advisers as a base for training sessions or self-improvement.

For instance, a graph can show a lack of balance between left and right sprayer arms. The regular flow drops can indicate that the farmer systematically switch off the flow when arriving at the plot border. We can graph the wind force, and check if the application has been done under the upper authorized speed, i.e. 19 km/h (in France).

Maps are also very informative for farmers and they can get involved into a self-teaching scheme. We can map the total flow (addition of right and left flows) sprayed on a plot, clearly showing such things as:

- the farmer switching off at the border of the plot between each row;
- overlapping that caused some over-dosing.

1c The role of Aware devices for traceability improvement

Data can also be organised in order to fill up automatically a "traceability book", similar to the one that is filled compulsorily by the farmer but with objective information : see Fig. 4.

First comparisons made with the manual traceability books show several discrepancies, often due to farmer errors (caused by a delay in filling up the book, by writing errors…).

	Traçabilité automatique	Traçabilité papier	Comparaison
Date du traitement:	2007-06-25	2007-06-19	Dif
Parcelle traitée	13B (surface déclarée=0.85Ha, interrang=2.25m,intercep=1.0m)		
Produits utilisés			
Produit 1:	None : None	**sirbel** (2000160) à **1.3** l/ha	
Produit 2:	None : None	**collis** (2060085) à **0.4** l/ha	
Produit 3:	None : None	() à	
Produit 4:	None : None	() à	
Produit 5:	None : None	() à	
Produit 6:	None : None	() à	
Caractéristiques du traitement			
Vitesse de fonctionnement	4.7 km/h	4.6 km/h,	2.17 %
Débit gauche de fonctionnement	2.93 L/min	différence gauche-droite: -0.1	
Débit droit de fonctionnement	3.03 L/min		
Débit total de fonctionnement	5.97 L/min	5.87	1.7 %
Passe tous les :	1.8 rangs	2 rangs	-10.0 %
Volume de bouillie pulvérisé	152.52 L	-	
Surface traitée	0.93 / 0.97 Ha	-	
Volume de bouillie par hectare	164.0 L/ha	170.0 l/ha,	-3.53 %
Conditions météorologiques			
Force du vent moyen	5.0 km/h (1.4)	2 - legere brise	dif=-0.6
Force du vent maximum	11.8 km/h (2.5)	-	
Température moyenne	19.0 °C	-	
Température maximum	20.2 °C	-	
Humidité moyenne	59.0 %	-	
Humidité minimum	54.0 %	-	

Figure 4

2 Impacts on water quality

2a Understanding of the catchment basin hydrological behaviour

The data from the devices installed in the outlet and in the weather station shows that the catchment basin rapidly responds to heavy waterfalls; as in many Mediterranean basin rainfalls are rare and heavy, mostly concentrated in spring and autumn.

The time between the flood and the return to the initial water level is due to a water table situated at the top of the catchment basin. This explains also why we constantly have water in the river, even during very dry periods in summer.

The analysis of the samples of water taken in the outlet reveal the presence of several molecules, mainly fungicides and herbicides (diuron, glyphosate, aminotriazol, terbuthylazin desethyl). We studied the trend of the concentration of one molecule found in every water sample from the beginning of the project. It comes from the terbuthylazin, an herbicide which is not used in France since 2004 in vineyards. Our result is related to the pesticides life cycle: the molecules are stocked in the soils during their use and progressively released and transported by the combined action of the physical and chemical processes. This example emphasizes the fact that a long-term survey must be done on each catchment basin to follow the evolution of the concentrations year after year.

Since Aware lasts only 3 years, we use the modeling tool Mhydas to study the evolution of the pollution by pesticides molecules in a middle and long-term approach.

2b First results on modeling the catchment basin

The whole study will be completed during the year 2008. The first results come from the sensitivity modelling done on Mhydas for the following types of model inputs. We observe how one variation of each model input influence the outputs of Mhydas (river flow rate, concentrations of molecules, volume flowed, mass of molecules)

- Meteorological parameters: the main processes to take into account are the rainfall intensity and the soil water content before the rainfall.
- Cultural parameters: the initial state of the soil surface is a key parameter. It is conditioned by the practice of the farmer about weed control. In case of ploughing, the soil surface will be modified and the transport of pesticides decreases. On the contrary the use of herbicides does not change the soil properties. The other important parameters are the amount of pesticides sprayed on the plot, and the delay between the spraying and the following rainfall.
- Physicochemical characteristic of each pesticide are not very sensitive compared to the previous one.

Conclusions

Lowering the pollution of the water masses by pesticides is a challenge for the farmers. In order to lead pertinent studies on catchments basin, and to propose to farmers several way of amelioration, scientists and agricultural advisers need to develop tools to measure the real quantities of chemical released in the environment and to deduce the risk of pollution for the close rivers and ground waters.

The Aware project combines the recording of objective traceability data by embedded systems, the numerical modeling of pesticides pollution (Mhydas) and the training offered to the farmers based on the results.

The originality of the Aware project lays on all the data collected automatically from the wine growers' sprayers. We can lean upon objective and accurate data, and we gain a great comprehension of the farmers' behaviour by comparing what they thought to be doing and what was eventually done.The first results on modeling the catchment basin help to prioritize the different parameters involved in pesticide transfer on a given area with a given climate. We then can choose which practices must be changed first, and what is the breathing space.

The Aware sensing device has been tested during almost two years on 15 different sprayers on the Neffiès river basin. This experiment has shown that:

- these systems can be easily implemented on different type of vineyard sprayers;
- during operations the devices were used by farmers for sprayer tuning, and for spraying and filling up monitoring
- the device outputs is used for generating automatic traceability books;
- the maps and graphs generated from the sensor can be used by advisers for training farmers, in order to improve agricultural practices. In most cases, lower quantities of pesticides can be used thanks to the better knowledge of the sprayers' behaviour.
- these devices had been very well accepted by the farmers

The next stage is to assess the feasibility of transferring the methods and results in other contexts, and in other countries which are partners of the Aware project, i.e. Spain and Italy.

At the end of the project, we will write a "book of good practices" in order to help the stakeholder to combine a high quality production level and the lowest impact possible on the environment.

Acknowledgements

The Life Aware project is co-funded by the Life Environment tool of the European Commission

References

Commission Regulation (EC) No 796/2004 of 21 April 2004

Council Directive (91/414/EEC) of 15 July 1991

Council Regulation (EC) No 1782/2003 of 29 September 2003

Directive 98/8/EC of the European parliament and of the Council of 16 February 1998

Giles, D. K., Downey D. 2003. Quality control verification and mapping for chemical application, in Precision Agriculture: Volume 4, Number 1, 103-124.

Giles, D. K. 2007. Precision Spray Equipment to Reduce Pesticide loading, unpublished paper

Life AWARE project web site. 2006. http://www.lifeaware.org

Tisseyre, B., Ojeda H., Taylor J. 2007. New technologies and methodologies for site-specific viticulture, in J. Int. Sci. Vigne Vin, 2007, 41, 2, 63-76

Voltz M., Louchart, X., Andrieux, P, Lennartz, B. 2003. Processes of pesticide dissipation and water transport in a Mediterranean farmed catchment, in Hydrology of the Mediterranean and Semiarid Regions IAHS Publl. no. 278 , 422-428.

PM_{10} and fine particulate matter concentration and emission from three different type of laying hens houses

Costa A., Guarino M.
Department of Veterinary and Technological Sciences for Food Safety, Faculty of Veterinary Medicine, Università degli Studi di Milano, via Celoria 10, 20133 Milan, Italy, Tel: 0039.02.50317909, Fax: 0039.02.50317909, annamaria.costa@unimi.it

Abstract

The aim of this study was to evaluate PM_{10} concentration in three different laying hens houses (traditional battery cages with aerated open manure storage, *free range* and vertical tiered cages with manure belts with forced air drying) and to evaluate particulate matter emission into atmosphere during one year of observation. Internal and external temperature and relative humidity, ventilation rate, PM_{10} concentration have been continuously monitored in order to evaluate particulate matter concentration changes during the day and the season and to define PM_{10} emission. PM_{10} concentration was corrected by gravimetric technique to lower measurements error. Furthermore, in the free range house, TSP and fine particulate matter (particles smaller than 2.5 micron) concentration was measured. Average yearly PM_{10} concentration was remarkably higher in the free range house with 215 µg m^{-3} vs 108 m^{-3} for the ventilated belt house and vs 94 µg m^{-3} for the traditional battery cages house. Recorded values for PM_{10} emission were 0.441 mg h^{-1} hen^{-1} for battery cages housing type, 0.071 mg h^{-1} hen^{-1} for ventilated belt house, values lower than those available in literature, while the free range housing type showed the highest PM_{10} emission (1.230 mg h^{-1} hen^{-1}) with appreciable peaks during the morning, together with the increased animal activity and habitual farmer operations, as feed administration, cleaning and droppings removal.

Keywords: poultry houses, PM_{10}, continuous measurements.

Introduction

Concentrations and emissions of dust particles from livestock operations are generally determined by the characteristics of the respective housing system, specified e.g. by management, bedding materials, animal species, ventilation, as well as climatic inside and outside conditions (Takai et al., 1998), feeding practices and feeding type (Costa et al., 2007). The highest concentration of particulate matter is usually measured in swine and poultry houses (Takai, 1998), with appreciable increases in in both total and respirable dust (Pedersen, 1993, Costa et al., 2008 *in press*) associated with increased animal activity. Substances like dust, micro-organisms and endotoxins, which are also transported as bio-aerosols, are supposed to play a role in the prevalence of respiratory diseases in receptive humans as gathered from occupational health reports on farm workers in animal houses (Parry *et al.*, 1987). All these kind of bio-aerosols in animal houses are emitted in considerable quantities into the environment by ventilation systems and can consequently also affect the respiratory health of people living close to livestock enterprises (IPCC, 1997) and since these particles can carry diseases (for example, Newcastle disease), environmental conditions in enclosed laying houses must be strictly controlled (Carpenter, 1986).

The aim of this article was to evaluate the variability of dust concentration and its emission from three different types of laying houses which are fairly widespread in Italian poultry farms, through a long-term monitoring research funded by FIRST (Fondo Interno Ricerca Scientifica e Tecnologica, 2007).

Materials and methods

Locations

The measurements were taken in three commercial laying hen units located in Northern Italy, near Cremona and Brescia. The monitored techniques were:

1) Battery system with pit under cages and a scraper to remove manure
2) Free range house
3) Vertical tiered cages with manure belts with forced air drying.

Battery system: The house, with 11.000 hens lodged, is 14m wide x 70 m long. The house is ventilated by 4 fans of 116 cm of diameter, positioned on the longitudinal walls of the floor, the maximum ventilation rate is 42000 $m^3 h^{-1}$ for each fan. The air is collected from the upper floor, enters the house through a continuous longitudinal ridge chimney and is delivered into the hen space through continuous openings in the false ceiling over every row of batteries. The ventilation program is computer controlled and based on thermostatic regulation (the first group of fans are active for the minimum ventilation level, when temperature is higher than 15.4 °C, the following groups are switched on when temperature inside the barn reaches 22°C.

Free range house. The house, with 7500 hens lodged is 14m wide x 70 m long. The house is ventilated by 4 fans of 116 cm of diameter, positioned on the longitudinal walls of the floor, the maximum ventilation rate is 42000 $m^3 h^{-1}$ for each fan. As in the previous house type, described, the air is collected from the upper floor, enters the house through a continuous longitudinal ridge chimney and is delivered into the hen space through continuous openings in the false ceiling over every row of batteries. The ventilation program is computer controlled and based on thermostatic regulation (the first group of fans are active for the minimum ventilation level, when temperature is higher than 15.4 °C, the following groups are switched on when temperature inside the barn reaches 22°C. In this house hens are reared on the floor, a " flat deck" type, the nest for eggs deposition is located in the middle of the room. This housing type is endorsed by EU rules on animal welfare.

Ventilated belt house: it has 8 rows of 6-tier cages with 22000 hens lodged. Even in this case the length of the laying cycle is approximately 2 years, with the moult after 12 months. The droppings are collected on the manure-belts under each tier and an air jet dries the droppings. The manure ventilation system is designed so that maximum air velocity is at bird level, no higher than 2.0-2.5 $m s^{-1}$, to avoid disturbing the birds in the winter months. The house has 8 fans on the longitudinal wall, with a maximum ventilation rate of 32000 $m^3 h^{-1}$ each The ventilation program is always running. The manure is discharged every 3-4 days to sheltered external storage. The house has a tunnel ventilation system thermostatically controlled on a 4 step basis, with air inlets located on the opposite wall of the one with fans.

Dust concentration measuring equipment

In each of these facilities, the PM_{10} concentration was continuously monitored, with a frequency of one minute, using calibrated scatter light photometers (accuracy: ±3 μg m–3) (EPAM 5000, HAZ-Dust; Environmental Devices Corporation, Plaistow, NH). The instrument was also used in order to collect PM_{10} through traditional gravimetric technique.

This procedure was performed to adjust the particulate matter specific gravity of bio aerosol, typical and specific for every animal house. The mean value of dust amount collected on the membranes was utilized as a *correction factor* to be applied to the continuously collected data. PM_{10} was collected once in each housing type every 45 monitoring days(3 samples for day), using polytetrafluoroethylene (PTFE) membranes (47 mm of diameter and 2.0 μm of pore size, SKC). The membranes were weighed using a microbalance (0.000001 g) in a controlled humidity room before and after dust collection. The filters were dried in an oven at 100°C for four hour before weighing. In order to ensure isokinetic sampling conditions, the dust measuring instrument inside the building was positioned in such a way that the airflow rate, checked with an hot wire anemometer, was in general less than 0.5 m s^{-1}, as described by Haeussermann et al. (2008).

Table 1. Correction factor applied to on-line measured data

Housing type	**Correction factor**	**St. Dev.**
Ventilated belts	0.87	0.003
Free range	0.94	0.001
Battery system	1.02	0.001

For TSP and fine dust sampling, in the free range house, a sampling station was set up, consisting of a pump with a counterpositioned piston and a constant, pre-set airflow rate (8.85 l min^{-1}), connected to a system that controlled and recorded the volume of the aspirated air. The station was connected to a sampling instrument (Sioutas, Cascade Impactor) to separate and collect airborne particles in five size ranges: TSP, particles smaller than 2.5 μm, particles in the range from1.0 to 2.5 μm, from 0.50 to 1.0 μm, from 0.25 to 0.50 μm, and particles smaller than 0.25 μm. Samples were collected from 9.00 to 17.00 to study the amount of fine dust inhaled by operators during a working day. Filters used in this part of the study were 37-mm PTFE Teflon, prepared as described above for PM_{10} evaluation.

<u>*Emission rate calculation*</u>

Emission rate was calculated as the multiplication of pollutant concentration with the ventilation rate recorded in the same minute, as reported in the following equation.

$$E_i=C_i \ x \ V_i$$

Equation 1. Pollutant emission calculation
Where:
E_i = Pollutant Emission at time *i*, C_i = Pollutant Concentration at time *i*, V_i =Ventilation rate at time *i*, *i* = time (in minute)

Continuous monitoring of ventilation rate, improved pollutant emission factor accuracy reaching the value of 5 %, in that way, it was possible to reduce the error of the traditional method (around 30 %) to estimate pollutants emission, based on the estimate of ventilation rate through periodic measures.

Results

<u>*Environmental parameters and particulate matter*</u>

In table 1, the results of the monitoring year in the three houses are shown, subdivided in the periods between November 2006 and May 2007, and June and November 2007. In this table, data related to on-line PM_{10} concentration is corrected by gravimetric technique.

Table 2. Structural characteristic, environmental parameters, PM_{10} concentration and emission from the three hens houses

Building type		**Battery system cages**		**Free range house**		**Vertical tiered cages with ventilated belts**	
	Monitoring period	**November 2006 May 2007**	**June 2007 November 2007**	**November 2006 May 2007**	**June 2007 November 2007**	**November 2006 May 2007**	**June 2007 November 2007**
Structural characteristics	Ventilation system	4 Exhaust fans in the longitudinal wall		4 Exhaust fans in the longitudinal wall		8 Exhaust fans in the longitudinal wall	
	Number of animals	11.000		7500		22000	
	Dropping removal system	Dip pit with a scraper to remove droppings		Litter, a belt in front of the nest removes droppings		Manure belts under cages with forced air drying	
Internal Microclimate	Temperature (°C; min-max)	18.68 (11.24; 25.60)	19.31 (13.24; 27.32)	14.88 (9.72; 26.21)	21.42 (17.47; 26.53)	21.24 (18.07; 22.63)	20.06 (17.25; 23.46)
	Relative Humidity (%, min-max)	55 (24; 88)	56 (27; 86)	62 (28; 97)	46 (32; 58)	55 (28; 74)	56 (42; 67)
External Microclimate	Mean Temperature (°C, min; max)	12.41 (-1; 29)	19.34 (6.2; 32.3)	12.41 (-1; 29)	19.34 (6.2; 32.3)	14.91 (-3; 28)	18.11 (5.3; 36.7)
	Relative Humidity (%, min-max)	66 (25; 99)	55 (25; 93)	66 (25; 99)	55 (25; 93)	53 (25; 78)	53 (38; 89)
Ventilation rate	Mean $m^3 h^{-1}$	59481	65498	18892	72752	13672	22223
PM_{10} (corrected by gravimetric method)	Concentration mg m^{-3}	0.094	0.093	0.238	0.192	0.116	0.099
	Yearly mean concentration	0.094		0.215		0.108	
	Emission mg h^{-1} hen^{-1}	0.276	0.590	0.600	1.86	0.069	0.094
	Yearly emission factor	0.433		1.230		0.081	

PM_{10} Concentration

PM_{10} concentration, see Figure 1, was remarkably higher in the free range housing type with an average concentration of 215 µg m^{-3} vs 94 µg m^{-3} of the battery cages house and vs 108 µg m^{-3} of the ventilated belt house.

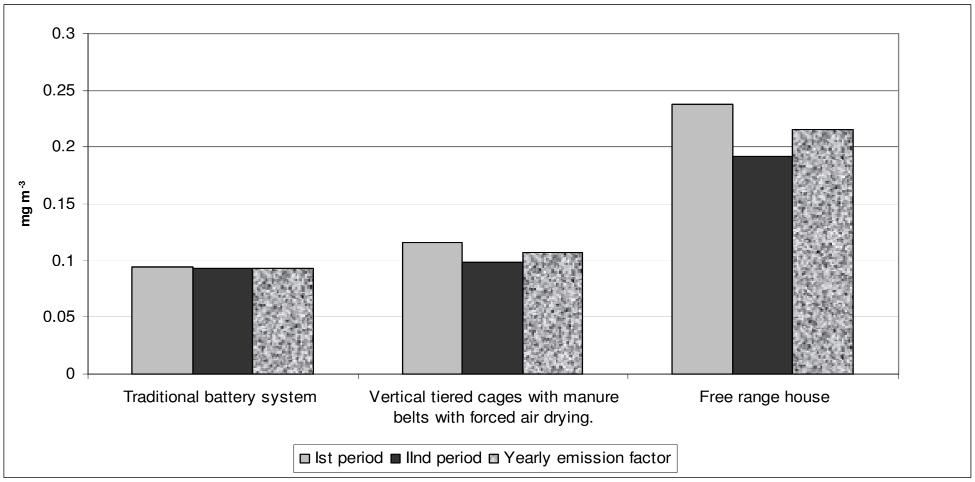


Figure 1. PM_{10} concentration in the three hens houses

PM_{10} Emission

The average emission factors calculated on yearly basis are 0.172 mg $h^{-1}hen^{-1}$ for the hens reared in vertical tiered cages on ventilated belts house, 0.265 mg $h^{-1}hen^{-1}$ for the hens raised in traditional battery cages, and 1.231 mg $h^{-1}hen^{-1}$ for the free range house. Values measured in the two first house type are however generally lower than those available in literature, for example, Zhao et al. (2005) found an emission factor of 0.830 mg $h^{-1}hen^{-1}$.

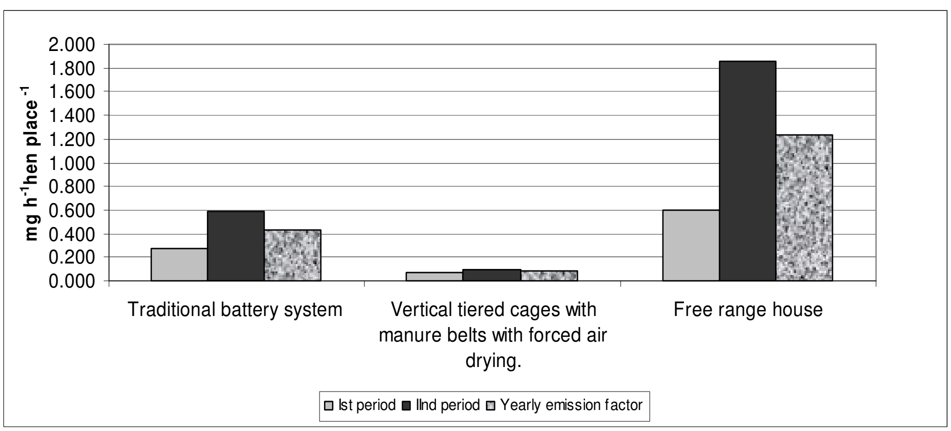


Figure 2. PM_{10} emission from the three hens houses

During all the monitoring year, the daily trend of particulate matter concentration, in the three houses, reached the maximum values in the first and central hours of the day. These increased values are related to an increase in animal activity occurring for feeding time and egg deposition, and to the increased activity of farmers (animals' inspection, eggs manual picking up, droppings removal) during the morning an in the central part of the day.

During the afternoon (between 13.00 and 17.00), dust concentration was usually low and uniform, in correspondence with the absence of men's and animals' activity (see Figure 3 and, more in details Figure 4).

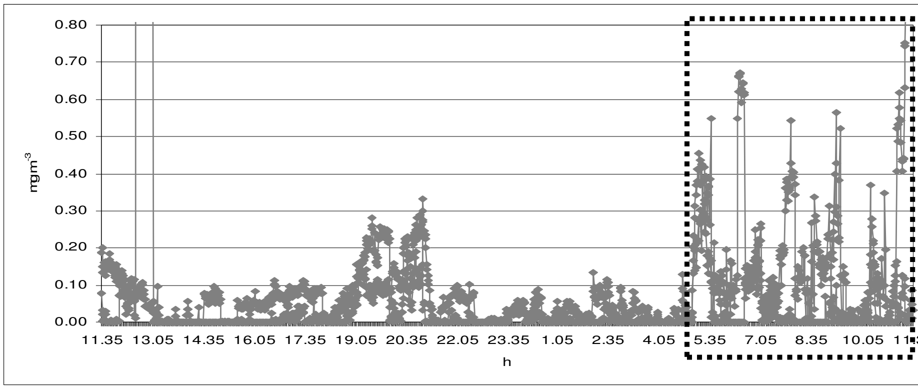


Figure 3. example of diurnal pattern of PM_{10} mean concentration in the free range house, in the bounded zone, particulate matter concentration peaks occurring in the morning

The following Figure 4 shows the PM_{10} average hourly ranges during the day, in absolute value.

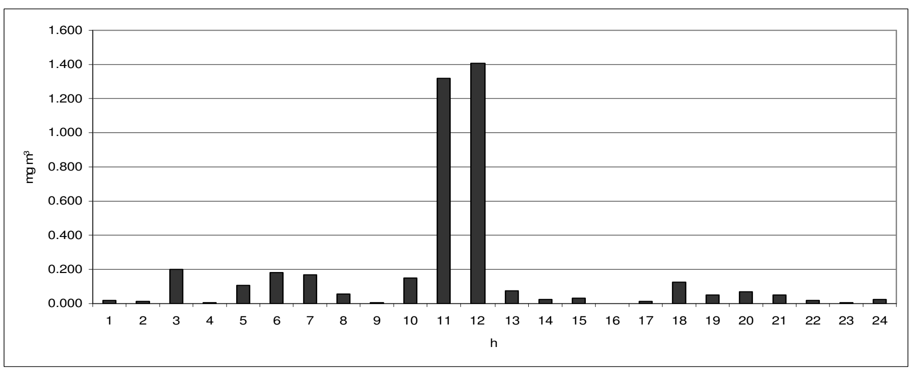


Figure 4. Hourly mean range (in absolute values) of PM_{10} concentration during the 24 hours in the free range house.

The highest hourly ranges, or variations, in PM_{10} concentration happened between 11.00 and 12.00 (1321 µg m^{-3}) and between 12.00 and 13.00 (with an average increase in PM_{10} concentration of 1409 µg m^{-3}), this results are reported in Figure 4. Table 3 shortly reassumes the quantitative subdivision of TSP and thin particulate matter: the amounts of $PM_{0.5}$ and $PM_{0.25}$ collected are a consistent portion of the dust sampled in the free range house. These results, when linked to the researches in industrial disease, highlight the existence of a severe working environment for men and animals. In studies conducted by Wang et al. to (1998) it was demonstrated that dust inhaled in animal houses can affect the concentration of β interleukin altering the respiratory functionality in human. In reference to Table 3, and, considering that a human being, with a normal respiratory frequency, can breath from 6 to 8 l min^{-1} of air, in an atmosphere with a $PM_{2.5}$ concentration similar to that one observed in this study, one could inhale, at a breathing rate of 6 l min^{-1}, up to 11.55 µg h^{-1}, or 92 µg of fine dust during 8 working hours. This aspect takes even more importance since particles smaller than 5 µm are rarely expelled from the lungs, causing allergic reactions (Rylander, 1986) and inflammatory processes in the pulmonary system (Thelin et al., 1984). From a recent study lead from Lagorio et al. (2003), a strong association between dust concentration variation, more than dust high concentration itself, and damages to the cardiac functionality was found.

Table 3. TSP and fine dust particles measured in the free range house

Particle size class, micron	Dust collected on filter, µg m^{-3}	P
0.25	19.996	NS
0.50	18.401	NS
1.00	6.866	NS
2.50	32.107	NS
TSP	444.353	NS

Balduzzi (2003) singled out a tight correlation between sanitary risk (infarct, cardiac pathologies generally) and increase in dust concentration, stating that a variation of 10 µg m^{-3} of PM_{10} concentration corresponds to the 0.6% increased mortality in human. The remarkable variation of PM_{10} concentration that usually takes place in the free rang house during the morning (up to 1.409 mg m^{-3}) highlights how this hens house type cannot guarantee a healthy working environment for operators.

Conclusions

Average yearly PM_{10} concentration was remarkably higher in the free range house with 215 µg m^{-3}, 108 m^{-3} for the ventilated belt house and 94 µg m^{-3} for the battery cages house. Recorded values for PM_{10} emission were 0.433 mg h^{-1} hen^{-1} for battery cages housing type, 0.081 mg h^{-1} hen^{-1} for ventilated belt house, values were lower than those available in literature.

The free range house showed the highest (1.230 mg h^{-1} hen^{-1}) PM_{10} emission with peaks during the morning, together with the increased animal activity and with farmer operations (up to 1409 µg from 12 A.M. to 13).

These critical environmental conditions are considered the primary source for respiratory affections and cardiac diseases, as heart attack and cardiac ischaemia, since every 10 µg of dust concentration variation, the risk of mortality in people is increased for 6 ‰.

Acknowledgements

The project was funded by FIRST (Fondo Interno Ricerca Scientifica e Tecnologica, 2007).

References

Berckmans, D., P. Vandenbroeck, and V. Goedseels. 1991. Sensor for continuous ventilation rate measurement in Livestock Buildings. Journal of Indoor Air, 3, 323-336.

Balduzzi M. 2003. Effetti biologici del PM_{10} rilevanti per la salute dell'uomo. Ann. Ist. Super. Sanità, 39(3), 411-417.

Carpenter, G.A. 1986. Dust in livestock buildings—review of some aspects. J. Agric. Engng Res., 33, 227–241.

Costa A., Guarino M., Navarotto P., Savoini G., Berckmans D. 2007. Effects of corn milling type on physical characteristics and on dustiness of swine diets. Transactions of the ASABE, 50(5), 1759-1764.

Costa A., Guarino M., Leroy T., Borgonovo F., Berckmans D. 2008. PM_{10} daily variation in pig buildings in relation to on-line monitored animal activity. AgEng 2008 International Conference on Agricultural Engineering & Industry Exhibition, 23-25 June 2008, in press.

Fabbri C., Valli L., Guarino M., Costa A., Mazzotta V. 2007. Ammonia, methane, nitrous oxide, carbon dioxide and particulate matter emissions in two different buildings for laying hens. Biosystem Eng., 97/4, 441-455.

Ferin J, Oberdoster G, Penney DP. 1992 Pulmonary retention of ultrafine and fine particles in rats. Am J Resp Cell Mol Biol., 6, 535-42.

Haeussermann A., Costa A., Aerts J. M., Hartung E., Jungbluth T, Guarino M., Berckmans D. 2008. Development of a dynamic model to predict PM_{10} emissions from swine houses. J Environ. Qual., 37(2), 557-564.

IPCC (Intergovernmental Panel on Climate Change). 1997. Revised 1996 IPCC. Guidelines for National Greenhouse Gas Inventories. Reference Manual. Paris, France.

Lagorio S., Forastiere F., Pistelli R., Iavarone I., Fano V., Incalzi R., Basso S., Benedetto R., Della Corte Am., Fuso L., Maiolo C., Sammarro S., Serra M., Spadaro S., Tramaglino L., Cattani G., Stacchini G., Marconi A., Ziemacki G., Ostro B. 2003. Inquinamento atmosferico e funzionalità cardiaca e respiratoria in tre gruppi di pazienti. Ann. Ist. Super. Sanità, 39 (3), 395-404.

Parry, R.R., Schlenker, E.H. and Feistner, R. 1987. Correlation of positive Farmer’s Lung serologies, respiratory symptoms, pulmonary function tests in non-smoking workers involved in confinement raising of livestock., Am. Review of Respiratory Disease, 135, A451.

Pedersen, S. 1993. Time-based variation in airborne dust in respect to animal activity. In Proc. 4th Intl. Livestock Environment Symp., St. Joseph, Mich.: ASAE, 718-725.

Rylander, R. 1986. Lung diseases caused by organic dusts in the farm environment. American Journal industrial Medicine, 10, 221-227.

Takai H. 1998. Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. J. Agric. Engeng Res., 70, 59-77

Thelin, A., Tegler, O. and Rylander, R. 1984. Lung reactions during poultry handling related to dust and bacterial endotoxin levels. European J. Respiratory Diseases, 65, 266-271.

Wang Z., Manninen P., Malmberg P., and Larsson K. 1998. Inhalation of swine-house dust increases the concentrations of interleukin-1 beta (IL-1beta) and interleukin-1 receptor antagonist (IL-1ra) in peripheral blood. Respiratory medicine, 92, 1022-1027.

Zhao L., Lim T. T., Sun H., Diehl C. A.. 2005. Particulate Matter Emissions from a Ohio Belt-Battery Layer Barn, 2005 ASAE Annual Meeting, Paper 054010.

Reduction of the pesticide losses and the improvement of spray deposit through the study of sprayer optimal air velocities in vineyard

Balsari P., Marucco P., Oggero G., Tamagnone M.
University of Torino. DEIAFA, Mechanics Section
Via Leonardo da Vinci, 44 – 10095 Grugliasco (TO), ITALY.
Tel 0039 0116708587, Fax 0039 0116708591, paolo.balsari@unito.it

Abstract
A two years study has been carried out in order to assess spray deposits on leaves, as well as ground and drift spray losses, according to the air volumes applied, taking into account different vegetation growth stages. In the first year of experiments, trials were carried out when the vegetation was fully developed (BBCH 77), applying always a volume rate of 230 l/ha, comparing the combinations of three different forward speeds (4, 6 and 8 km/h) and four different air velocities measured on the target (4.7, 7.0, 9.7 and 13.5 m/s). In the second year of the study, the same tests were made in the vineyard at the end of flowering growth stage (BBCH 69). Results pointed out that spray deposits on the leaves increased when low air velocities (5 m/s) and reduced forward speeds (4 or 6 km/h) were adopted. The use of reduced air volumes enabled also to limit drift losses.

Keywords: spray deposit on the leaf, drift losses, ground losses.

Introduction
Several studies have been carried out over the years with the aim to assess the most suitable volume application rates and spraying parameters for application in vineyards (Pergher and Gubiani, 1995; Balsari and Tamagnone, 1996). Nevertheless, only in recent years the adjustment of air flow rates and air velocities generated has become an important point of consideration (Balsari et al., 2001; Pergher, 2006; Cerruto, 2007). It is a fact that the regulation of the air generated by the sprayers' fans usually employed in vineyards is often neglected by farmers. This happens because often there are few options to adjust the air flow rate; typically it is possible only to change the rotation speed of the fan by a gear-box with two velocities (low and high). Moreover, in general terms, farmers do not consider the air adjustment as an instrument enabling to improve significantly the quality of spray distribution on the target. Sometimes they may consider reducing the air flow rate during the early growth stages, when there is only little canopy, mostly to avoid spray drift. Finally, there is a lack of guidelines for the correct air adjustment based on scientific data.

To investigate the effect of the air regulation on the quality of spray distribution in vineyards, a set of tests was carried out combining three different sprayer forward speeds and four different velocities of the air generated by the sprayer fan. Tests were made at two different vine growth stages, to examine the effect of canopy density on the outcome of the study.

Matherials and methods
Tests were carried out in a Barbera espalier trained vineyard, featured by a layout with 1 m distance between plants and 2.8 m distance between rows. In the first year of experiments, the trials were conducted when vegetation was at fully developed growth

stage (BBCH 77), when the canopy wall was on average 1.5 m in height and 0.4 m in width. In the second year, tests were made earlier, at the end of flowering growth stage (BBCH 69), when the canopy wall was on average 1.2 m in height and 0.25 m in width.
A lift mounted air-assisted sprayer (Unigreen Turbo Teuton), equipped with a 400 l main tank and a radial fan (500 mm in diameter, nominal air flow rate of 10400 m^3/h at PTO speed of 540 rev/min) was employed. The sprayer is equipped with a system of orientable air spouts (3 per side) connected to the fan by means of flexible air hoses, enabling to obtain an even vertical air profile (Fig. 1). All tests were carried out using hollow cone nozzles (Teejet TXA 01, 015 and 02), mounted on the air spouts. In both growth stages considered, twelve treatments were compared combining three different forward speeds (4, 6 and 8 km/h) and four different air velocities from the air spouts (4.7, 7.0, 9.7 and 13.5 m/s). In order to always apply the same volume rate (230 l/ha) under the same operating pressure (1.0 MPa), different sizes of hollow cone nozzles (Teejet TXA) were used while keeping the droplet sizes produced relatively the same (Tab. 1). The air velocity was measured by means of an anemometer (Allemano Testo 400) positioned at 0.5 m from the outlet of the air spout. This distance corresponds to that existing in practice between the air spout and the vine canopy external leaves. To obtain the different air velocities examined, the PTO rotation speed, the fan gear-box velocity and the position of an air discharge valve in the air conveyor system were opportunely combined (Tab. 2)

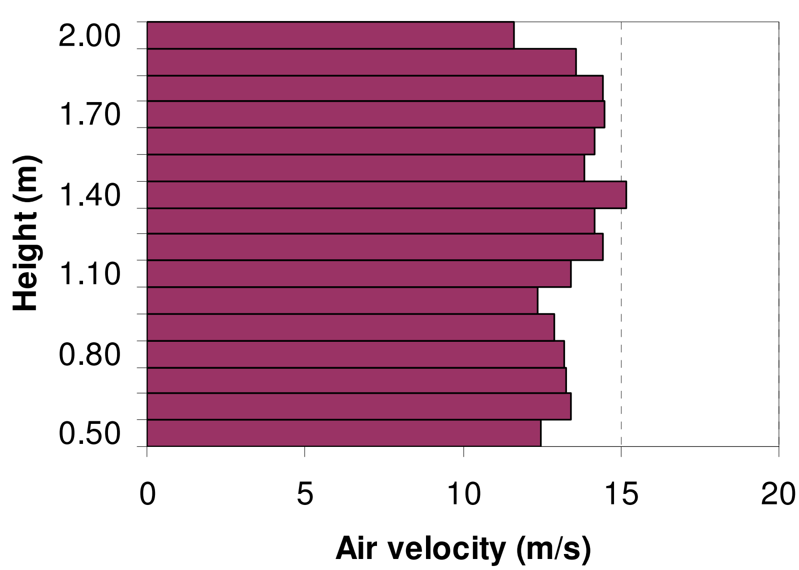


Figure. 1. Air velocities measured at 0.5 m away from the air spouts at different heights with the following operating parameters: PTO speed = 500 rev/min; fan gear velocity = high; air discharged valve = closed; fan rotation speed = 3350 rev/min.

Table 1. List of treatments examined in the experiments and corresponding spraying parameters.

Treatments	Forward speed (km/h)	Nozzle type	VMD (µm)	Air velocity (m/s)
1	4	TXA 8001	113	4.7
2	4	TXA 8001	113	7.0
3	4	TXA 8001	113	9.7
4	4	TXA 8001	113	13.5
5	6	TXA 80015	134	4.7
6	6	TXA 80015	134	7.0
7	6	TXA 80015	134	9.7
8	6	TXA 80015	134	13.5
9	8	TXA 8002	154	4.7
10	8	TXA 8002	154	7.0
11	8	TXA 8002	154	9.7
12	8	TXA 8002	154	13.5

Table 2. Fan parameters adopted to obtain the different air velocities tested in the experiments.

Air velocity (m/s)	PTO speed (rev/min)	Fan gear velocity	Air discharge valve	Fan rotation speed (rev/min)
4.7	250	Low	Open	1500
7.0	350	Low	Closed	2100
9.7	500	Low	Closed	3000
13.5	500	High	Closed	3350

Trials were conducted spraying a water solution of yellow Tartrazine E102 (5%v/v). For each test, the average amount of spray deposit on the leaves, the average amount of ground losses and that of losses in the air beyond the treated row were assessed. Sprayed leaves were sampled from the treated rows using a special frame (Fig. 2A), a 300 mm x 300 mm x 300 mm cube, that was inserted in the canopy. All the leaves included in the volume delimited by the frame were picked up, then washed in laboratory with a known volume of water and washings were analysed by a spectrophotometer (Jenway 6300). Five replications of this sampling were made for each treatment examined, and the average amount of spray deposited on the leaves, expressed in $\mu l/cm^2$ was then calculated. To estimate ground losses three arrays of collectors, 25 x 10 cm sized, made of cellulose material (Camfil CM 360), were placed in the adjacent inter-row area next to the sprayed row at distances of 45, 140 and 235 cm from the treated row, while to assess the spray losses in the air beyond the sprayed row, further collectors (always Camfil CM 360, 25 x 10 cm) were placed on the wires of the next row at three different heights from the ground: 90, 130 and 170 cm (Fig. 2B). Spray deposits on the collectors were then analysed with the same procedure adopted for the leaves. In order to compare the incidence of the ground losses and of the spray losses beyond the treated row between the treatments examined at the same vine growth stage, index values were used. Value 1 was assigned to the treatment with the lowest losses and the other values were calculated as multiples of this reference value.

A B

Figure 2. The iron frame used to define the portion of the row where to sample the sprayed leaves (A) and displacement of collectors on the ground and in correspondence of the second row to assess respectively ground losses and the amount of spray dispersed in the atmosphere beyond the treated row (B).

Results

In the trials carried out with the vegetation fully developed (BBCH 77), a low forward speed (4 km/h) combined with the lowest air velocity tested (4.7 m/s) produced the maximum amount of spray on the leaves (Fig. 3). Independent of the forward speed used, increments in the air velocity from the sprayer fan resulted in a reduction of the spray deposits on the leaves.

Concerning the incidence of ground losses, it was observed that, independently of the forward speed adopted, they generally decreased as the air velocity is increased (Fig. 4). On the other hand, as expected, higher air velocities resulted in higher deposits on the collectors placed beyond the treated row (Fig. 5), generating a higher risk of spray drift.

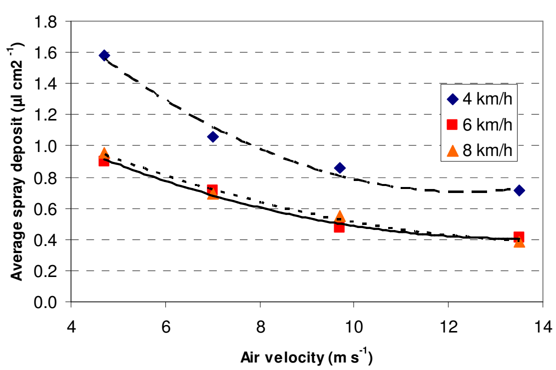


Figure 3. Effect of the air velocity generated by the sprayer fan on the average amount of spray deposit on the leaves, according to the forward speed adopted. Vine growth stage: vegetation fully developed (BBCH 77).

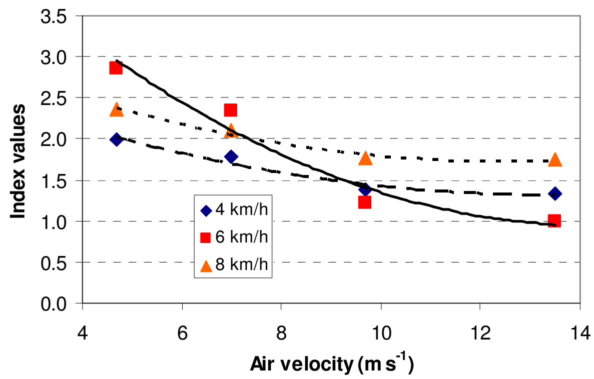


Figure 4. Ground losses registered in function of the air velocity used and according to the forward speed adopted (BBCH 77).

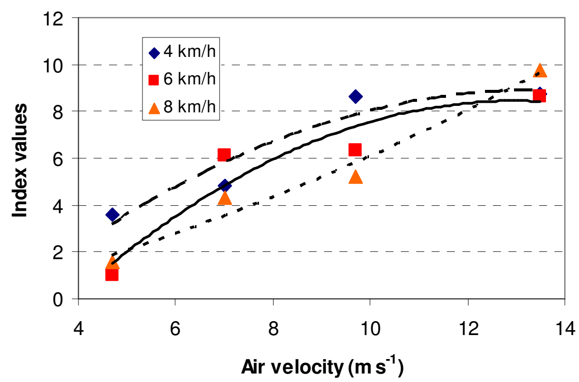


Figure 5. Airborne losses through the treated row registered as a function of the air velocity used and according to the forward speed adopted. Vine growth stage: vegetation fully developed (BBCH 77).

Test results obtained working at the end of flowering growth stage (BBCH 69) confirmed the general trend observed in the previous trials with regard to the effect of the air velocity on spray deposits on leaves (Fig. 6). Nevertheless, in this early growth stage, the best results were obtained adopting a forward speed of 6 km/h , thus applying a lower amount of air per hectare compared to the application at fully developed growth stage.

At the end of flowering growth stage, ground losses under different air velocities showed a similar trend with respect to that registered with the vegetation fully developed (Fig. 7 vs. Fig. 4): increasing the fan air velocity resulted in a decrease almost linearly of deposits on the collectors placed on the ground. Concerning the amount of spray that escaped the treated row and was detected in the second row, a dramatic increment of the values (up to 40 x) appeared as a result of increased air velocity (Fig. 8). This result is related to the fact that, as the vine canopy was still not fully developed, leaves could be easily rotated according to the air flow direction, therefore increasing the dispersion of spray through the treated row.

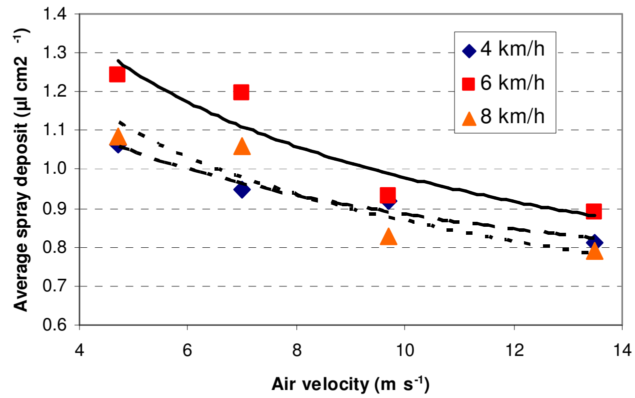


Figure 6. Effect of the air velocity generated by the sprayer fan on the average amount of spray deposit on the leaves, according to the forward speed adopted. Vine growth stage: end of flowering (BBCH 69).

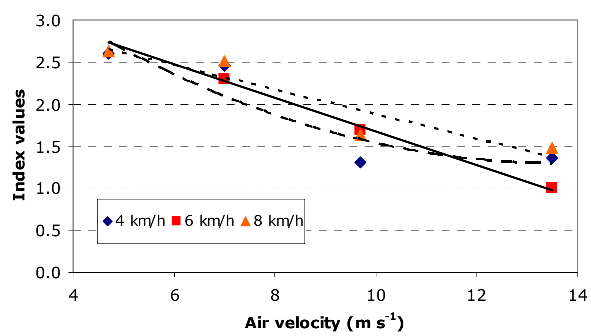


Figure 7. Ground losses registered as a function of the air velocity used and according to the forward speed adopted (BBCH 69).

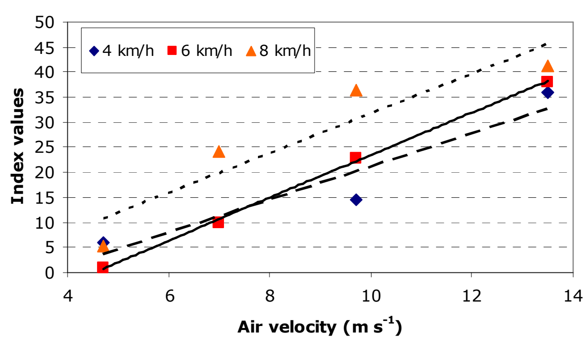


Figure 8. Airborne losses through the treated row registered as a function of the air velocity used and according to the forward speed adopted. Vine growth stage: end of flowering (BBCH 69).

Conclusion

Test results pointed out that, independent of the growth stage, working with high air velocities when spraying in vineyards do not produce higher average spray deposits on the leaves. Best results were obtained adopting an air velocity of around 5 m/s close to the external canopy. Results also showed that spray distribution within the canopy was better at low air velocities, as the coefficient of variation (CV) between the replications was lower than when using higher air velocities (Fig. 9).

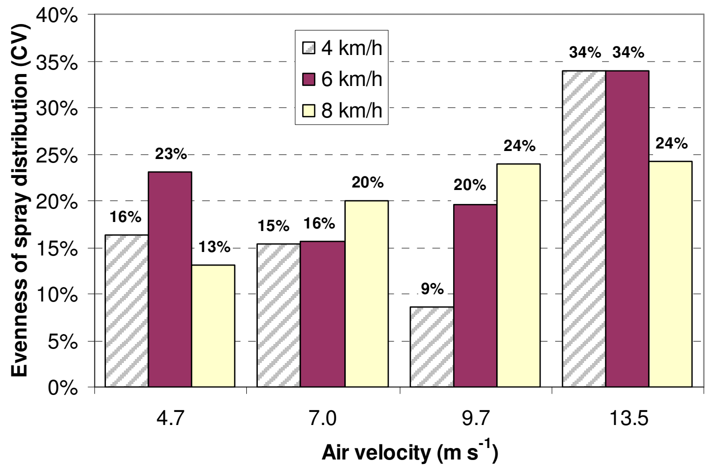


Figure 9. Coefficient of variation between the replications of samples calculated for the different combinations of air velocity and driving speed examined. Vine growth stage: vegetation fully developed (BBCH 77).

The use of high air velocities, moreover, severely increased the incidence of airborne losses, therefore enhancing drift risks.

These results are consistent with previous findings (Balsari et *al*., 2001), but it is to underline that, in order to be able to produce such a low air velocity (5 m/s), a relatively new model of air-assisted sprayer fitted with adjustable air spouts had to be used. The conventional and most commonly used axial fan air-assisted sprayers available on the market, in fact, are equipped with fans which generally produce unnecessarily high air velocities. By observing the current trend in sprayers sold, one can predict that the fan output is likely to continue to get bigger in the future.

It seems therefore necessary to push sprayer manufacturers to reconsider their opinions about air-assistance and to suggest them to provide their machines with finer adjustments of fans and air outputs, considering also the possibility to have different air velocities at different heights. The necessity to reach a good spray penetration into the bunches, for instance, may require higher air velocities only in correspondence of the grapes band. Further studies should be conducted to study the relationships between air velocities and efficient deposition of spray material on grapes.

References

Balsari P, Tamagnone M., 1996. Confronto tra diverse macchine e tecniche di distribuzione dei fitofarmaci alla vite. Proceedings on Giornate Fitopatologiche 1: 423-430.

Balsari P, Marucco P, Tamagnone M., 2001. Assessment of the most suitable setup of mistblowers in vineyards. Proceedings of the 6th International ATW Symposium "Technik im Weinbau", Stuttgart (Germany) 14-16 May 2001: 116-125.

Cerruto E., 2007. Influence of airflow rate and forward speed on the spray deposit in vineyards. Rivista di Ingegneria Agraria 38, 1: 7-14.

Cerruto E., 2007. Further studies on the variation of spray deposits in vineyards with airflow rate and volume rate. Rivista di Ingegneria Agraria 38, 1: 7-14.

Pergher G, Gubiani R., 1995. The effect of spray application rate and airflow rate on foliar deposition in a hedgerow vineyard. Journal of Agricultural Engineering Research 61, 3: 205-216.

Pergher G., 2006. The effect of air flow rate and forward speed on spray deposition from a vineyard sprayer. Rivista di Ingegneria Agraria 37, 1: 17-23.

Reduction of water contamination from pesticides through the application of the Best Management Practices defined by the TOPPS project

Balsari P., Marucco P., Oggero G.
University of Torino. DEIAFA, Mechanics Section
Via Leonardo da Vinci, 44 – 10095 Grugliasco (TO), ITALY.
Tel 0039 0116708587, Fax 0039 0112368595, progetto.topps@unito.it

Abstract

Point sources are considered the most relevant entry route of PPP into surface and ground water. To focus on them is important in order to prevent contamination risks and to avoid exceeding the admitted threshold for PPP residues in drinkable water (0.1 µg/l), stated by European Water Directive. TOPPS (training of Operators to prevent Pollution from Point Sources) is a European Life project aimed at identifying Best Management Practices to prevent point sources taking into account farmers' behaviour, equipment and infrastructure. Dissemination of TOPPS BMP through advice, training and demonstrations at a larger co-ordinated scale in Europe is the final project goal, which should lead to a consistent reduction of water contamination from pesticides.

Keywords: point sources, sprayer, remnants management.

Introduction

Several studies carried out in Northern Europe (Seel et al., 1996; Kreuger, 1998; Mason et al., 1999; Muller et al., 2002; Maillet-Mazeray et al., 2004; Bach et al., 2005; Neal et al., 2006) have pointed out that from 50% and up to 90% of water contamination from plant protection products (PPP) originates from point sources. Especially the phases of PPP mixture preparation and loading into the sprayer, as well as the management of the spray mixture residue at the end of the application and the cleaning of the spraying equipment are considered mainly responsible for PPP point sources.

As in 2000 the European Water Directive was adopted, stating that the maximum allowable threshold of PPP concentration in drinkable water is 0.1 µg/l, prevention of water contamination from pesticides came into particular focus. Exceeding the admitted threshold, in fact, could mean a ban for some pesticides from the market, hence reducing the range of available crop protection solutions for farmers.

In November 2005, a EU Life Project named "TOPPS" (acronym of Training the Operators to prevent Pollution from Point Sources) started. This project aimed at defining Best Management Practises to prevent water contamination from point sources and its final objective is to disseminate these BMP among European farmers, through advice, training and demonstrations.

PPP point sources

During the management of PPP in the farm, there are different phases that can be particularly at risk for water contamination. According to a TOPPS survey carried out among European farmers in 2007, especially the management of left over spray solutions at the end of the application, the cleaning of the spraying equipment and the filling of the sprayer are considered significant for the generation of PPP point sources. Typically, filling and cleaning of the sprayer are carried out always in the same area of the farmyard, close to the water source (well or water network). In most cases, as the TOPPS survey carried out in 2007 showed (Fig. 1), any precaution is taken to avoid that liquids containing pesticides - originating from spills, accidental overflows occurring during the sprayer filling process (Fig. 2) or from rinsing of the spraying equipment at the end of the application - percolate through the soil towards ground water table or run off towards surface water. As these operations of filling and cleaning sprayers are repeated several times during the season, there is a risk that a not negligible amount of pesticides is let in a reduced soil surface, originating water pollution phenomena.

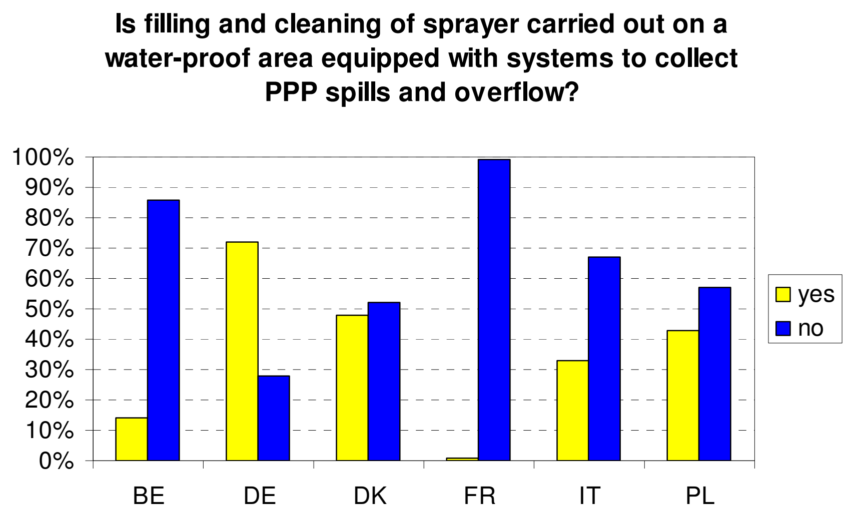


Figure 1. Use of an equipped sprayer filling/cleaning area in Europe (TOPPS survey, 2007).

Figure 2. Example of accidental sprayer overfilling.

Also the not correct management of remnants after the treatment, as the discharge of the PPP mixture residue still present in the tank at the end of spraying on a small surface area in the farmyard or close to a water course can originate point sources.

The TOPPS Project and the genesis of Best Management Practises

TOPPS is a three-year multi-stakeholder project funded by the European Union and by the European Crop Protection Association (ECPA) and involves 15 European countries structured in 4 Clusters (North, Midwest, South and East). DEIAFA - University of Turin is the Italian Partner in the project and co-ordinates the work within the South Cluster that includes Italy, Southern France, Spain and Portugal.

The first task of the project was to collect all existing materials (brochures, booklets, videos, articles, etc.) in the different European countries about the subject of PPP water contamination and about its prevention. These materials have been uploaded in a database available also on the project website (**www.topps-life.org**), and have constituted a basis for the development of Best Management Practices (BMP) guidelines. In a first phase, in each country BMP have been proposed and discussed with local stakeholders (representing farmers associations, environmental agencies, agricultural boards, sprayers manufacturers, crop protection industry), then the national proposals have been discussed at European level between Partners in order to find a "European BMP core" agreed. On February 7, 2007 the official presentation of TOPPS BMP guidelines agreed at European level took place in Bruxelles, in front of the main stakeholders delegated by each European country.

TOPPS BMP guidelines are structured on the basis of defined processes, which represent a sequence of steps in the use of plant protection products.
There are 6 main processes defined:

- Transport
- Storage
- Before spraying
- During spraying
- After spraying
- Remnant management

In the ambit of each main process, further sub-processes are then taken into account in order to better explain the different phases of PPP management in the farm: for instance, the main process of PPP transport is divided in four sub-processes: planning, loading/unloading, during and emergencies.

Based on these definitions the BMP guidelines have been developed in a two step approach (Table 1):
Statements = What to do
Specifications = How to do

Key elements that can improve the prevention of PPP point sources are based on farmer behaviour, on equipment and on infrastructure.

Table 1. Example of the structure of a TOPPS BMP guidelines.

Process	Sub-process	Statement	Specification
Transport	Planning	DO transport PPPs in their original containers with intact, readable label	Type approved [UN] packaging used by most manufacturers. Note: Individual containers taken from 'packs' (split-offs) may not conform; original approved containers and original label instructions.

The European TOPPS BMP guidelines are a selection of about 100 out of more than 400 statements which, during the development process, achieved a good level of consensus in the various discussions. The specifications given in the TOPPS BMP are to be considered as a proposal for the operators / advisors when no local regulations exist. Statements and specifications have been translated in the different languages of the European countries involved in the TOPPS project in order to facilitate their dissemination.

In Italy, two illustrated BMP booklets have been issued: one contains only the statements and is addressed to farmers (Fig. 3A), the second contains both statements and specifications and is addressed to advisors and experts. (Fig. 3B).

A B

Figure 4. Booklets in Italian language edited by DEIAFA concerning BMP guidelines: A) booklet addressed to farmers; B) booklet addressed to advisors.

Dissemination of TOPPS BMP is in course through training courses and demonstrations organised in the demofarms installed in some of the countries involved in TOPPS Project (in Italy the demofarm has been installed in Fontanafredda, Piemonte region), publications, and participations to fairs and exhibitions with TOPPS stands.

Main contents of TOPPS Best Management Practises

Transport

Guidelines concerning the transport of pesticides from the dealer to the farm concern recommendations about the use of adequate vehicles and boxes for transporting pesticides (e.g. van with driver cabin separated from loading area, or boxes for safe transport of PPP cans in the car, Fig. 5), checking of PPP packages integrity, the use of appropriate tools for loading and unloading pallets, the availability of emergency numbers and safety instructions to be used in case of accidents.

Figure 5. Example of safety box used for PPP transport in a car.

Storage

PPP have to be stored preferably in a dedicated room, locked and clearly identified with pictograms; the floor of the storage room has to be waterproof and equipped with a system to separately collect accidental chemical losses. If it is not possible to have a dedicated storage room, pesticides at least must be placed in appropriate metallic cupboards (Fig. 6), displacing powders on the top shelves and liquids on the low shelves in order to minimise risks of accidental spills. Absorbent material shall be always available in the storage room, to contain accidental leakages, and a clearly identified tank or can must be present to store PPP contaminated material (e.g. broken cans, absorbent material, etc.).

Figure 6. Example of cupboard to store pesticides, with powder displaced over liquids.

Before spraying

Before starting any spray application, a planning should be made in order to consider all sensitive areas within the treated area (wells, ponds, ditches, etc.) and then to define appropriate buffer zones to avoid direct contamination of surface water.

Preparation of spray mixture and filling of sprayer should be carried out on a paved area, waterproof and enabling to separately collect PPP spills and accidental overflows, in order to guarantee their proper disposal. The filling area should be placed close to the PPP storage room and far away from surface water and areas sensitive to pollution.

To facilitate the introduction of chemicals into the sprayer tank, the use of an induction hopper is recommended. This auxiliary device, which allows to make a first mixing of the concentrated PPP with some water and then to transfer the concentrated mixture directly into the main sprayer tank can be installed independent from the sprayer in the filling area and connected to the water network (Fig. 7). This solution enables to use the same induction hopper to fill different machines, avoiding the uncomfortable and risky practise to pre-mix chemicals in a pail and then to pour the concentrated solution from the bucket into the main tank opening.

Moreover, inside the induction hoppers there are rotating nozzles which for cleaning empty PPP cans, allowing to transfer the rinsing water directly in the sprayer tank.

Figure 7. Dedicated paved area for loading and cleaning of sprayers, equipped with a collecting system for PPP contaminated liquids and with an independent induction hopper for loading sprayers.

During spraying

TOPPS Best Management Practises concerning the phase of spray distribution in the field are focussed on recommendations to avoid the aspects which could originate point sources, such as the dripping of PPP mixture from hoses or nozzles (for example when the antidrip devices do not properly work), the dispersion of spray mixture when turns at the end of rows are made without stopping spraying, or the accumulation of spray mixture on a restricted area when priming is made with the static sprayer (Fig. 8).

Figure 8. Point source originating from priming operations carried out with the static sprayer.

After spraying

A key aspect to minimise risks of point sources is, first of all, to avoid high volumes of spray mixture residues in the sprayer tank at the end of the application; this goal can be reached assessing precisely the quantity of PPP mixture to apply on the crop surface and therefore filling the tank just with the exact volume necessary. Moreover, it is important to use certified sprayers whose design enable the sprayer pump to suck nearly completely the content of the main tank.

At the end of the application it is important to rinse the sprayer, internally and externally: if the sprayer is equipped with a clear water tank, these operations can be carried out directly in the field. Internal cleaning allows to dilute the residual spray volume still present in the main tank and the diluted mixture can be sprayed on the crop (Fig. 9A); the external cleaning is aimed at removing the amount of spray deposited on the outer parts of the machine and can be done also in the field, changing the cleaning place from treatment to treatment, just connecting a spray lance to the clear water tank (Fig. 9B).

Even if the clear water tank is not originally available on the sprayer, it can be easily added, simply connecting a plastic auxiliary tank to the sprayer circuit (Fig. 10).

Cleaning of sprayer in the farm has to be made on a equipped area (Fig. 11), analogue to the one used for filling, enabling to collect rinsing water separately, in order to allow its subsequent correct disposal and/or treatment.

A

B

Figure 9. A) Application in the field of the diluted mixture obtained after the internal sprayer cleaning; B) external cleaning carried out in the field.

Figure 10. Sprayer equipped with an added auxiliary clear water tank.

Figure 11. Sprayer cleaning made in the farm on equipped area.

Remnant management

Solid and liquid wastes produced at the end of spray applications must be properly managed in order to avoid environmental contamination. For example, empty PPP cans should be collected in dedicated boxes and then delivered to specialised companies for their disposal. The PPP contaminated liquid (originating from spills, overflows, sprayers rinsing procedures, etc.) can be stored in appropriate tanks for delivery to specialised disposal companies or can be treated directly in the farm, for instance using biofilter systems. In this latter case, liquids containing pesticides are poured on farm soil layers (Fig. 12), where the microbial activity degrades PPP active ingredients, allowing to obtain as a final result a "purified" water that can be reused for subsequent treatments.

Figure 12. Biofilter installed in Fontanafredda demo farm

Conclusions

There are several devices and technical solutions able to prevent water contamination from PPP originated from point sources. Most of them have been well defined by the European Life Project TOPPS through the TOPPS BMP guidelines. It is now necessary to promote and to spread the use of these Best Management Practises all around Europe by means of specific training courses and economical subsides to increase the use of the necessary adequate equipment. In this sense, useful information can be downloaded from the TOPPS website: www.topps-life.org

References

Bach, M., Röpke, B. and Frede, H-G. 2005. Pesticides in rivers – Assessment of source apportionment in thePesticides in rivers – Assessment of source apportionment in the context of WFD; European Water Management Online, Official Publication of the European Water Association (EWA).

Kreuger, J., 1998. Pesticides in stream water within an agricultural catchment in southern Sweden, 1990-1996. The Science of the Total Environment 216, 227-251.

Maillet-Mezeray J., Thierry J., Marquet N., Guyot C., Cambon N., 2004. Bassin versant de la Fontaine du Theil – Produire et reconquérir la qualité de l'eau: actions et résultats sur la période 1998-2003. Perspectives Agricoles 301:4.

Mason, P.J., Foster, I.D.L., Carter, A.D., Walker, S., Higginbotham, S., Jones, R.L., Hardy,I.A.J., 1999. Relative importance of point source contamination of surface waters: River Cherwell catchment monitoring study. Proceedings XI Symp. Pest. Chem. Cremona, Italy, 405-412.

Müller, K., Bach, M., Hartmann, H., Spiteller, M., Frede, H.G., 2002. Point and non-point source pesticide contamination in the Zwester Ohm Catchment (Germany). J. Environm. Quality, 31(1), 309-318.

Neal C., Neal M., Hill L., Wickham H., 2006. River water quality of the River Cherwell: An agricultural clay-dominated catchment in the upper Thames Basin, south eastern England. The Science of the Total Environment 360 (1-3), 272-289.

Seel, P., Knepper, T.P., Gabriel, S., Weber, A. and Haberer, K. 1996. Kläranlagen als Haupteintragspfad von Pflanzenschutzmitteln in ein Fließgewässer – Bilanzierung der Einträge. Vom Wasser, 86, 247-262.

A Prototype of Self-Propelled Sprayer to Reduce Operator Exposure in Greenhouse Treatment

Balloni S., Caruso L., Cerruto E., Emma G., Schillaci G.[1]

Dipartimento di Ingegneria Agraria (DIA), Via S. Sofia 100, 95123 Catania, Tel. +39 0957147512, Fax +39 0957147600, Italy, giampaolo.schillaci@unict.it

Abstract

This paper reports the results of some trials aimed at measuring the dermal operator exposure during spray applications to full developed tomato plants, comparing a conventional handheld spray lance and a prototype of self-propelled sprayer suitably designed to properly work in greenhouses.

The spray lance was 0.97 m long, with 4 steel nozzles 0.21 m spaced, suited to spray plants up to 3 m high. The prototype of sprayer consisted of a little tracked tractor powered by a gasoline engine with continuous power of 2.6 kW at 3000 rpm, carrying a 120 L main tank, a volumetric pump, and two vertical spray booms 1.5 m long, each with four nozzles.

Dermal exposure was assessed by means of the spectrophotometric technique: delivering a mixture containing 2% of food dye Red Poinceau as tracer, the deposit on the protective personal equipment worn by the operator was calculated.

The results showed a large reduction in operator dermal exposure using the prototype with respect the spray lance. Normalising the deposits at the common volume rate of 1000 L/ha, the operator body collected 1653 mL/h with the spray lance, mainly located on the chest and on the right side, and only 11 mL/h with the prototype. These results should promote the prototype development, assessing its performance, work capacity, quality of spray deposition on the plants, adaptability to different greenhouse structures.

Key words
Spray lances, Water-sensitive papers Optical analysis.

Introduction

Several studies (Cerruto *et al.*, 2007; Sánchez-Hermosilla *et al.*, 1998; Ergonen *et al.*, 2005) have pointed out that greenhouse crops are characterised by a large use of plant protection products (PPP). The most widespread sprayers for pesticide applications are simple handheld high pressure spray lances and spray guns, which subject operators to high risks of dermal and respiratory exposure. Moreover, the peculiar climatic conditions inside greenhouses (high temperatures, high relative humidities), make unpleasant to wear proper personal protective equipment (overall, gloves, boots, face mask, helmet), so the risk of exposure increases.

Some Authors (Cerruto *et al.*, 2008; Bjugstad and Torgrimsen, 1996; Tuomainen *et al.*, 2002) report high values of dermal exposure while spraying in greenhouses using hand-held spraying equipment. The exposure can be greatly reduced using manually moved trolley with vertical spray booms or self-propelled sprayers as the "Fumimatic" (Nuyttens *et al.*, 2005) or the "Fisher Turbomobil" (Planas de Martí *et al.*, 2001), suitably designed to operate in greenhouses. They are not yet commercially widespread, but their performances are quite

[1] The Authors equally contributed to the present study.

promising.

A similar little tractor equipped with a spraying system is also at an advanced stage of development thanks to a close cooperation between the Mechanics Section of the Department of Agricultural Engineering (DIA) of the University of Catania and the manufacturer. The tractor comes from a tracked platform moved by an electric motor and developed for service purposes in greenhouse, which we hope to automatize thanks to a cooperation with the Dipartimento di Ingegneria Elettrica Elettronica e dei Sistemi (DIEES) of the University of Catania.

In this paper we discuss the results of some trials aimed at evaluating the operator dermal exposure during a simulation of a treatment of full developed tomato plants, comparing this prototype of sprayer and a standard spray lance.

Materials and methods

Plant and greenhouse features

The experimental trials were carried out in a tomato greenhouse located in the province of Ragusa (Sicily). The plants, cv *Tyty*, full developed, Y-shaped, were arranged in twin rows, with distance between rows of 0.56 m, distance between twin rows of 1.40 m, and row spacing of 0.70 m. The plant density was therefore about 14600 ha^{-1}.

The plants were geometrically characterised measuring minimum and maximum height of the foliage to be sprayed, and the thickness at two heights. Measurements were carried out on 16 plants of 8 twin rows.

The greenhouse had a metallic structure, covered with plastic film. The minimum height was 2.70 m, the maximum 4.50 m. It had 15 spans, each 29 m long and 8 m wide, so the total surface was some 3600 m^2. A lateral aisle 1.10 m wide provided for internal movements of operators during crop activities.

Spraying equipment

Spraying tests were carried out with the prototype of sprayer (Figure 1) and with a spray lance (Figure 2), used as reference.

Figure 1. Prototype of sprayer.

Figure 2. Handheld spray lance.

The prototype consists of a little tracked tractor powered by an air cooled, 4-cycle, single cylinder, gasoline engine. Continuous and maximum power are 2.6 and 4.2 kW at 3000 and 4000 rpm, respectively. The tractor carries a 120 L main tank, a volumetric pump, and two vertical spray booms 1.5 m long, each with four nozzles, 0.5 m spaced. The main dimensions, including the tank, are: length = 1650 mm, height = 1100 mm, and width = 730 mm. Driver seat and spray booms are suitably apart, so to keep the driver away from the spray jet and then to reduce his exposure. Spray booms height and reciprocal distance, as well as nozzles direction, can be suitably adjusted according to the crop needs.

Experimental tests were carried out using turbulence Albuz ATR yellow nozzles (orifice dimeter = 1.2 mm) at the pressure of 1.5 MPa. The flow rate was calculated connecting each nozzle to graduated cylinders by means of flexible pipes and measuring the delivering time.

The spray lance, 0.97 m long, had 4 steel nozzles, 0.21 m spaced. This long model was chosen to better reach the high parts of the plants canopy (Figure 3). The flow rate was measured at the pressure of 1.5 MPa. A pressure gauge installed near the helve allowed for checking the effective pressure value during spraying (Figure 2).

Experimental plan

The experimental trials with the spray lance consisted in a path (outward and return, 56.6 m long) between two twin rows, replicated three times (Figure 4). The operator walked forward, as in an ordinary pesticide application. Measuring the spraying time and knowing row length and flow rate at the nozzles, walking speed and volume application rates were also calculated (Table 1).

The experimental tests with the prototype consisted in spraying six twin rows, as depicted in Figure 5. Given the different flow rate at the nozzles and forward speed, the volume rate was 1070 L/ha (Table 1).

Figure 3. Spraying tests with the spray lance.

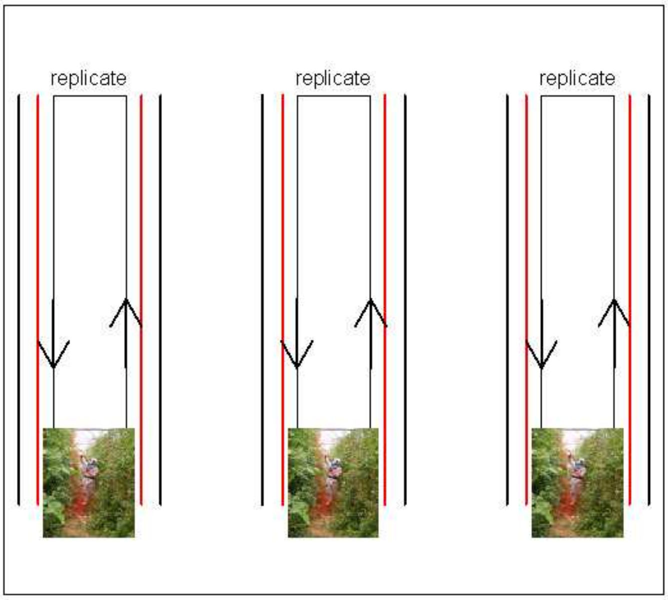


Figure 4. Experimental layout of the spraying test with the spray lance.

Spraying tests were carried out delivering a water solution with 2% of food dye Red Poinceau used as a tracer, to which a surfactant was added. During the spray, the operator was wearing protective personal equipment (PPE) consisting in a polypropylene disposable overall, completed with cover shoes, air forced full-face helmet, and latex gloves (Figure 6). Five water-sensitive papers were applied to the helmet (front, back, left, right, and top) to evaluate the head exposure.

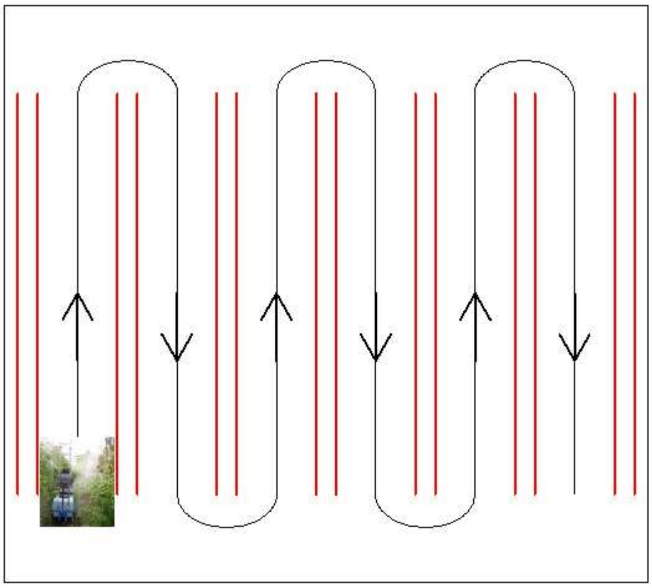


Figure 5. Experimental layout of the spraying test with the prototype of sprayer.

Figure 6. PPEs during spraying.

Table 1. Experimental plan.

Sprayer	Pressure, MPa	Flow rate, L/s	Speed, m/s	Volume rate, L/ha
Prototype	1.5	0.15	0.74	1070
Lance	1.5	0.06	0.85	700

After spraying, the overall was cut in several pieces (chest, back, legs, arms, hands, and feet) and the contamination of each piece was measured in laboratory by means of a spectrophotometer (Jenway model, Jenway Ltd), according to the following procedure:

1. Wash each overall piece with a known quantity V_c (mL) of distilled water in order to extract the dye;
2. Measure the absorbance A_c of about 5 mL of the solution by means of the spectrophotometer. The wavelength (511 nm) to which carry out the readings was previously experimentally determined as that corresponding to the maximum absorption;
3. Measure the absorbance A_m of the mixture delivered in field;
4. Calculate the volume of mixture deposited on each overall piece as:

$$v_c = \frac{A_c}{A_m} V_c$$

5. Calculate the unitary contamination as:

$$d_c = \frac{v_c}{S_c}$$

where S_c is the surface of each overall piece. To compensate for the differences in the volume rates, all values were normalised to the common volume rate V_N=1000 L/ha according to the equation:

$$d_n = \frac{V_N}{V_d} d_c$$

where V_d is the actual volume rate.

The water-sensitive papers were studied acquiring their image by means of a scanner with a resolution of 800 dpi and then analysing the images by means of a suitable software (the open source ImageJ 1.38x). For each image, surface coverage, number of particles per square centimetre (impact density), and particle size were evaluated. To account for the different sprayed area, surface coverage and impact density were expressed per twin row.

All computations, statistical analysis, and graphical representations were performed by means of the open source software R.

Results and discussion

Plant features

Table 2 reports the main geometrical characteristics of the plants canopy to be sprayed. The greatest variability was observed in thickness at 1.90 m and in minimum height of the foliage, whereas the maximum height was quite constant. Moreover, given the maximum height of about 2.80 m, to use a long spray lance model was preferred (Figure 3).

Table 2. Main geometrical features of the plants canopy.(1)

	Minimum height	Maximum height	Thickness at 1.40 m	Thickness at 1.90 m
Mean, m	0.68	2.81	0.41	0.36
Standard deviation, m	0.21	0.18	0.08	0.12
CV, %	31	6	20	34

(1) Average of 16 measures.

Operator exposure

The whole operator exposure was some 1653 mL/h of mixture with the spray lance and only 11 mL/h with the prototype. The great contamination measured with the spray lance provides evidence for the risks taken by the operator during pesticide applications in greenhouses, if not properly protected. This value (1653 mL/h) was much higher than that (223 mL/h) reported in Cerruto *et al.* (2008) because of the differences in plants and spray lance characteristics.

The ratio 1653:11 (~150:1) is comparable with the value 200:1 reported by Nuyttens using the Fumimatic, confirming as self-propelled sprayers can greatly reduce operator exposure compared to spray lances and improve safety and work productivity. Moreover, the value of 11 mL/h was lower than 26 and 40 mL/h measured with the spray lance when the operator walked backwards (Cerruto *et al.*, 2008). So, this prototype of sprayer seems to ensure an exposure always lower than that given by spray lances.

When using spray lances walking forward, the operator chest resulted more exposed than the back (258 vs. 55 mL/h, Figure 7): this because the operator, moving forward, partly hit the sprayed cloud with his one's body. In addition, the operator right side resulted more exposed than the left side (55% vs. 26%), confirming the results reported in Cerruto *et al.*, 2008. This because, being the exposure mainly due to the contact with the sprayed plants, when the operator walked forward between two twin rows, he scraped its right side against a sprayed row during both outwards and return path, whilst its left side only during the return path. As a consequence, right arm and right leg were the body parts more exposed, accounting for 21% and 16% of the total contamination respectively.

With the prototype (Figure 8), a little contamination was observed on the right hand (2.5 mL/h, 23% of the total dermal exposure), due to a running repair of the machine, and on the back (2.3 mL/h, 21%), the body part nearest to the nozzles.

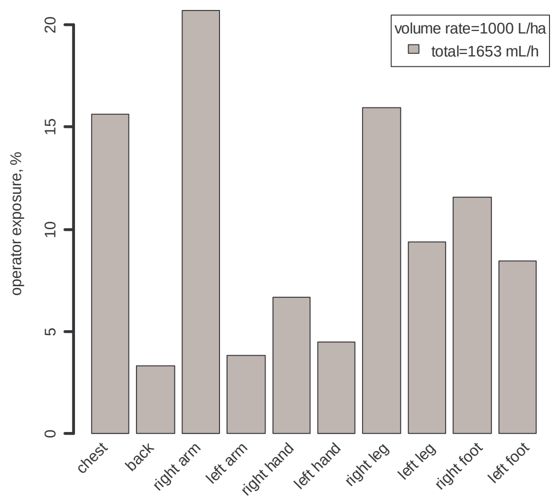


Figure 7. Percentage subdivision among the body parts with the spray lance.

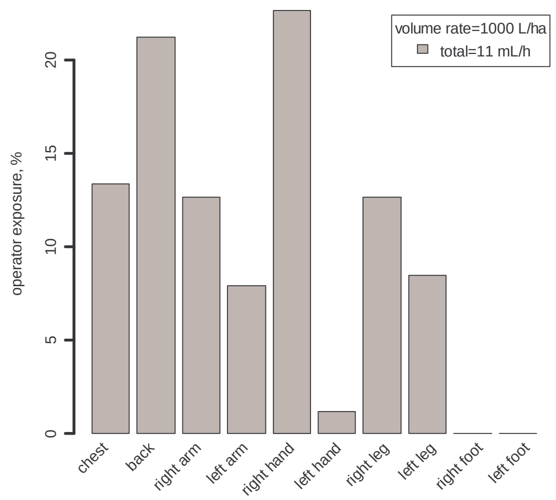


Figure 8. Percentage subdivision among the body parts with the prototype.

Using the spray lance, the weighted mean unitary exposure was 0.907 $\mu L/cm^2$ (Figure 9); the greatest value was on the right hand, which held the spray lance (3.955 $\mu L/cm^2$), followed by the right foot (3.315 $\mu L/cm^2$), which intercepted also part of the ground losses near the sprayed rows. The great specific exposure of upper (hands) and lower limbs (feet) should convince workers to always wear proper PPEs (gloves and boots) during spray applications.

With the prototype (Figure 10), the unitary exposure was much lower (weighted mean = 0.004 $\mu L/cm^2$), mainly concentrated on the right hand (0.052 $\mu L/cm^2$). Even if these values are negligible with respect the spray lance, nevertheless the operator should always wear proper PPEs, as unforeseen events could be noxious.

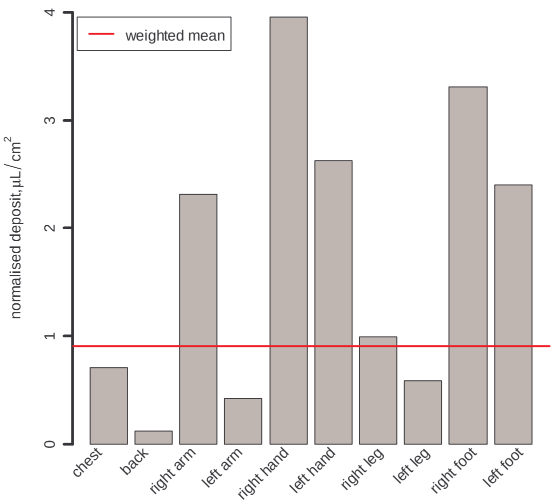


Figure 9. Unitary deposits with spray lance.

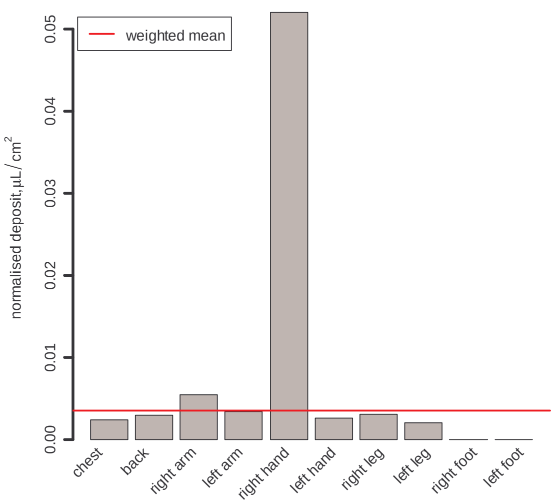


Figure 10. Unitary deposits with prototype.

Water-sensitive papers analysis

The water-sensitive papers produced results in agreement with the deposition measurements. In fact, the average covered surface was 22.9% for the spray lance and only 0.10% for the prototype (Figure 11). With the spray lance, the greatest coverage was recorded on the front (56.60%) and on the top (44.73%) of the helmet. Similarly, the average impact density was 148 cm^{-2} for the spray lance and 4 cm^{-2} for the prototype (Figure 11). The greatest values using the spray lance were again recorded on the top (309 cm^{-2}) and on the front (293 cm^{-2}) of the helmet.

These results reaffirm the great reduction in exposure working with the prototype, as well as the need to always properly protect the head.

Finally, Figure 12 reports the particle size distribution recorded by the water-sensitive papers, expressed as equivalent diameter, i.e. the diameter of the circle with the same area. Using the spray lance, the mean particle equivalent diameter was 299 µm, while using the prototype was 169 µm. The range was quite different: 36-732 µm for the prototype and 36-1551 µm for the spray lance.

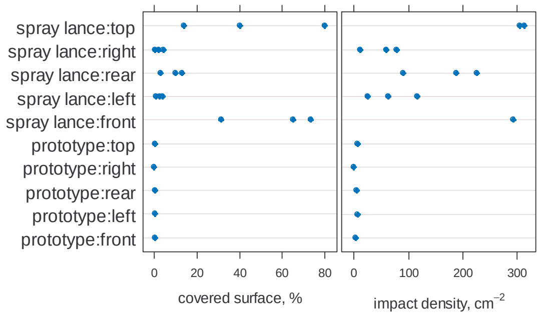


Figure 11. Percentage of covered surface and impact density.

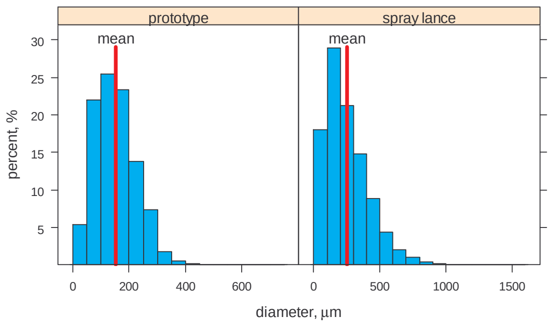


Figure 12. Equivalent diameter distribution.

Conclusions

Handheld high pressure spray lances are the most common equipment for spray application to greenhouse crops (Cerruto *et al.*, 2007). Given the usually high volume rates and the high frequency of application, operators are at high risk of dermal and respiratory exposure if not properly protected with adequate personal protective equipment.

In this research we measured the operator dermal exposure while spraying full developed tomato plants, comparing a conventional handheld spray lance and a prototype of self-propelled sprayer suitably designed to properly work in greenhouses. The results showed a dramatic reduction in operator exposure using the prototype: with a reference volume rate of 1000 L/ha, the operator body collected 1653 mL/h with the spray lance and only 11 mL/h with the prototype. If considered necessary, further reductions can be achieved installing a transparent screen rear the seat driver, so limiting that drifting droplets can reach the back of the operator. The experimental trials gave also some suggestion about the air forced, full-face helmet, which seems well endured by the operator when he was walking or driving the tractor, even if more focused researches are necessary.

These results demonstrate that operator safety during pesticide application to greenhouse crops can be greatly improved. Nevertheless, the operator should always wear proper PPEs against dermal and respiratory exposure. Moreover, these results should encourage further studies on the prototype development, assessing its performance, the quality of deposition on the plants, and improving its adaptability to different greenhouse structures.

References

Bjugstad N., Torgrimsen T. 1996. Operator safety and plant deposits when using pesticides in greenhouses. J. Agric. Engng Res., 65, 205-212.

Cerruto E., Balsari P., Oggero G., Friso D., Guarella A., Raffaelli M. 2007. Operator safety during pesticide application in greenhouses: a survey on Italian situation. GreenSys 2007, Naples, in press.

Cerruto E., Emma G., Mallia I., Manetto G. 2008. Evaluation of dermal exposure to pesticides in greenhouse workers. Innovation Technology to Empower Safety, Health and Welfare in Agriculture and Agro-food Systems, Ragusa (Italy), September 15-17, 2008.

Ergonen A.T., Salacin S., Hakan Ozdemir M. 2005. Pesticide use among greenhouse workers in Turkey. Journal of Clinical Forensic Medicine, 12, 205-208.

Nuyttens D., Windey S., Sonck B. 2005. Comparison of operator exposure for five different greenhouse spraying applications. XXXI CIOSTA-CIGR V Congress "Increasing Work Efficiency in Agriculture, Horticulture and Forestry", September 19-21, 2005, University of Hohenheim, Stuttgart, Germany, ISBN 3-00-016346-8, 98-105.

Planas de Martí S., Fillat Morata A., Escolà Agustí A. 2001. Advances on pesticide application in covered crops. AIIA 2001: Ingegneria Agraria per lo sviluppo dei paesi del Mediterraneo, Vieste (Fg), 11-14 settembre 2001, paper on CD-ROM.

R Development Core Team. 2007. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, URL http://www.R-project.org.

Rasband W.S., ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2007.

Sánchez-Hermosilla J., Pérez R., Díaz M. 1998. Study of labour risks due to the application of phytosanitary products protected crops. Ageng 98, Oslo, paper no. 98-G-033.

Tuomainen A., Mäkinen M., Glass R., Kangas J. 2002. Potential exposure to pesticides in nordic greenhouses. Bull. Environ. Contam. Toxicol., 69, 342-349.

POSTER PRESENTATION

Evaluation of respirable dust exposure during hazelnut and chestnut mechanized harvesting

Monarca D., Biondi P., Cecchini M., Santi M., Guerrieri M., Colantoni A.
Dept. Gemini, University of Tuscia, via San Camillo de Lellis – 01100 Viterbo, Italy, tel. +39 0761 357357, fax +39 0761 357453, e-mail: ergolab@unitus.it

Abstract

Atmospheric dust is defined in different ways but the most used classification are "total suspended dust" (T.S.D) and "particulate matter" (P.M.). A further distinction within the T.S.D. is about inhalable and respirable dust. Inhalable dust has an aerodynamic diameter between 5 and 10 μm, while respirable dust presents a diameter between 0,5 and 5 μm.
Beside the dimension, the danger about dust regards other factors, like: concentration, chemical composition, individual absorption characteristics and exposure time.
The mechanized harvesting of nuts, like hazelnuts and chestnuts, is carried out with specific machines that can be classified in three different types: pulled vacuum harvesters with aspirating tubes; pulled or tractor mounted harvesters with automatic picking system; self-propelled harvesters (aspirating or picking). In spite of installation of dust limitation devices, some studies have shown that dust concentration is still more elevated (up to 10 times) than the maximum limits indicated by the American Conference of Governmental Industrial Hygienists (A.C.G.I.H.).
The objective of the present study is to evaluate the level of risk at which operators, during nut mechanized harvesting and using modern machines, are really exposed.
In order to carry out this survey the data have been collected among some farms of the province of Viterbo (Italy); the farms selected have heterogeneous characteristics so that it is possible to obtain representative results for each type of working site and ground.

Keywords: health at work, dust exposure, respirable dust.

Introduction

The agriculture, despite all the transformations and technological evolutions, has preserved peculiar and well differentiated characteristics from all the other productive sectors. The multiplicity and the heterogeneity of the different cultural operations, the variety of the forms of management of the firms, the pulverization and dispersion of these in the territory, the variability of the ground (especially in reference to slope and physical-chemical characteristics), the land setups, the working age of the employees, constitute the principal determinants of the multiplicity and heterogeneity of the situations of risk for the agricultural operators.

The laws about operational safety and health impose the assessment of the risks for the operators who are exposed and the realization of prevention and protection measures to improve working conditions. Besides, the whole process of prevention, from the identification of the dangers to the measures of improvement, must be based on the consultation and the share of all the working subjects in the work place.

The present study intends to analyze one of the principals risks derived by the mechanized harvesting of hazelnuts and chestnuts, that is the workers' exposure to inorganic breathable air-spread particles [3-7].

It talks, in substance, of the dust that is absorbed during the respiration and that can not be expelled through cough or secretion of mucous, which is composed by particles that are not intercepted to the level of the first respiratory ways and which, therefore, reach the bronchial and pulmonary hollows.

The nature of these pollutants can be the most varied: silicium, zinc oxide, carbonaceous particles, combustion smokes, radioactive substances, asbestos, insecticides, organic substances as well as those that derive from the cereals, etc. With concentration is meant the quantity of particles in suspension in one cubic meter of air: it is generally expressed in mg/m^3, in $\mu g/m^3$ and in ppm (parts per million: volume of the contained particles in 10^6 volume unit).

The granulometry points out the dimensions of the particles: a diameter d is defined, expressed as the arithmetic average of the three dimensions of the particle (length l, width b and thickness s).

In the study of the dangerousness for inhalation, great importance however has the subdivision between breathable dust and non breathable dust, depending on the aerodynamic diameter.

This represents the diameter of a sphere of unitary density (1 g/cm^3) that has the same terminal speed of sedimentation of the particle in examination. The well known PM10 (particulate matter, with an aerodynamic diameter inferior to 10 μm) represents the dust able to penetrate into the superior part of the respiratory apparatus; while the PM 2,5 represents the dust able to penetrate into the inferior part of the respiratory apparatus (pulmonary alveoluses).

These last ones are the most dangerous because they are able to deposit themselves in the pulmonary system provoking inflammations, fibrosis and neoplasms.

The dusts with pathological action in humans are classified in two categories: pneumoconiogenic dusts and not pneumoconiogenic dusts [8].

The first ones are those that expound their action to the level of the respiratory apparatus provoking pneumoconiosis which consists of an accumulation of dusts in the lungs and consequent reaction of the pulmonary tissue.

The pneumoconiogenic dusts, in their turn, can be divided in inactive and fibrogenic dusts. The first ones don't alter the structure of the respiratory apparatus causing reactions that can modify the tissue in a potentially reversing way; the second ones can provoke more serious alterations modifying the structure of the alveoluses and provoking a fibrogenic reaction of the tissue [4].

These pathologies are subject to further worsenings, even after the exposure, up to the appearance of illnesses as silicosis (provoked by dusts of dioxide of silicium), asbestosis (provoked by asbestos dusts) and bissinosis (provoked by cotton dusts).

Also the not pneumoconiogenic dusts however can result as harmful because they bring particular substances or active principles able to pass into the circulation of the organism through the emo-lymphatic system. Given the dangerousness of the aforesaid dusts, in the last years (and it is predictable also for the next ones) there has been an increase of studies, researches, normative with the purpose to avoid, to prevent or to reduce the harmful effects on the health and on the environment.

The threshold limit values (TLV) find their application in the sector of the work hygiene.

They are fixed and annually adjourned by the A.C.G.I.H. (American Conference of Governmental Industrial Hygienists) and indicate the atmospheric concentrations of the principal harmful substances to which workers can repeatedly be exposed to, without negative effects.

There are three categories of TLV:

- threshold limit value - time-weighed average (TLV-TWA): the average concentration under which most people can work consistently for eight hours, day in, day out, with no harmful effects. Gas or vapors are expressed in *parts per million* (ppm), while solids, mist or floating dust particles are expressed in milligrams per cubic meter (mg/m^3);
- threshold limit value - short-term exposure limit (TLV-STEL): is the maximum concentration permitted for a continuous 15-minute exposure period. There may be a maximum of four such periods per day, with at least 60 minutes between exposure periods, and provided the daily TLV-TWA is not exceeded;
- threshold limit value - ceiling exposure limit (TLV-C) - an exposure limit which should not be exceeded under any circumstances.

Material and methods

The tests have been effected near different hazelnut and chestnut farms in the center of Italy (province of Viterbo), and have currently concerned the harvest with all the principals models of harvesting machines in use.

Pulled harvesters are equipped with one or two aspirating tubes from 100 to 140 mm in diameter. The harvesting is executed by walking operators, which pass the tubes over fruits that are usually piled or aligned in rows. Aspired fruits arrive in a sedimentation chamber where the heaviest particles (small clods, pebbles, twigs), carried together with fruits by blown air, fall on the bottom and are expelled. A further cleaning is provided by another fan and by a rotating sieve. Fruits are transported on a conveyer belt to a sack or directly to a pulled trailer.

The traditional system need a lot of workers, at least 1 operator at the tractor and 3 alternating operators at the two tubes, besides other workers responsible for carrying in and out the empty and full trailers. In the earliest models, the fan-blown air was expelled directly outside. The dust concentration in the air was so elevated that in 1986, in order to limit health risks for operators and even for residents, the use of hazelnut harvesters without dust limitation devices was forbidden.

In the late 80's, some Italian designers started to plan self-propelled harvesters. These machines are produced in different models where the harvesting technique (aspirating or picking) varies together with the engine power [3].

The samplings of dust have been effected using personal samplers built by the English SKC: particularly the model Sidekick© has been used at constant flow during the samplings (figure 1), with its pump set to a flow of 1,9 l/minute through a bubble flowmeter and cyclone SKC (figure 2) for the selection of the respirable convention as defined by the EN 481 standard "Workplace atmospheres. Size fraction definitions for measurement of airborne particles".

Figure 1. SKC Sidekick Pump™

The cyclone is realized in conductive plastics and it exploits a system of removable and reusable cassette sampling; inside the cassette the filter is supported on a homogeneous grilled surface, to exploit in a uniform way the filtering surface and at the same time to facilitate the manipulation of the filter before and after the sampling.

Filters have been employed in cellulose nitrate with a porosity of 0,8 μm and a diameter of 25 mm. The filters have been weighted, before and after the reliefs, through an analytical Gibertini scale mod. E42-B, with precision equal to 0,1 mg and a maximum of 120 g (figure 3).

Before weightings, for every filter a conditioning of 24 hours in a checked environment has been anticipated.

Figure 2. SKC cyclone for respirable fraction

The samplers have been submitted to the workers during the normal harvesting job, positioning the orifice of entrance of the sampler parallel to the body and at the same height of the respiratory zone.

Figure 3. Analytical Gibertini scale

The times of sampling have been timed and verified with the times pointed out by the counter in endowment to the pump. The choice of the duration of the samplings is founded on the observation of the membranes filtering there: particularly the sampling was concluded when on the membranes a light visible layer of dust resulted, without reaching excessive accumulations of particles that during the transport of the filters would have been able to cause a loss of part of the samples and consequent under-estimation of the concentration values.

For the transport of the samples a stuffed handbag has been used, to guarantee an elevated protection against the bumps that would have been able to provoke the separation of the particles sampled by the membranes (events that would have distorted the results of the tests); the handbag was maneuvered with particular attention.

Given the time of sampling t_c (min), the volume flow rate of sampling Q (m^3/min), the initial mass of the filter M_i (mg) and the mass of the dust-filled filter M_f (mg) (values gotten after the conditioning of the membranes) the value of the concentration of dust Ct_c is gotten through the formula [9]:

$$Ct_c = \frac{(M_f - M_i)}{Q \times t_c} \qquad (mg/m^3) \qquad (1)$$

The dust samplings, for the following analyses of the concentrations and exposures of the workers, have been effected during the harvest of hazelnuts and chestnuts in different farms in the province of Viterbo, using different models of machines.

Particularly the study has been effected on different fields in which the following harvesters were used:

- pulled vacuum harvester Cimina 300, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 160 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 180 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 200 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 300 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 380 S, produced by the firm Facma;
- pulled vacuum harvester Facma Cimina 200 T, produced by the firm Facma;
- tractor mounted picker Jolly 2800, produced by the firm GF;
- self-propelled picker Perla 55, produced by the firm Agrintem.

Regarding the times of exposure (to the aerodisperse dusts) of the workers employed in the harvest, a fundamental factor for the evaluation of the risk, it's necessary to underline that these are influenced by the dimensions of the surfaces to be picked up, the orografic characteristics, the conditions of the ground and the order of orchards.

Nevertheless in all the examined farms an exposure time practically coincident with the whole working shift is noticed, (equal to the 8 daily hours). This has allowed to be able to directly compare the average values of concentration noticed with the limits defined by the ACGIH.

Results

The values of concentration noticed, as said, coincident with the values of respirable dusts exposure of the workers employed to the harvest, is brought in table 1.

The aforesaid values have been compared with the limit values defined by the A.C.G.I.H. in 2007.

The A.C.G.I.H. identifies specific limits for coal dust, dust of cereals, dust of glass fibers, wood dust and cotton dusts. Other dusts are gathered under the name "(insoluble) particles not otherwise classified" (P.N.O.C.) and for these the A.C.G.I.H. nowadays speaks of "guidelines", rather than of TLV; in the past, TLVs fixed for the P.N.O.Cs have been used wrongly and applied to any non available particle in the lists.

Table 1. Concentrations of the respirable dusts found in the different examined firms, defined for every single machine (rate flow of sampling: 1,9 l/min) (TWA-A.C.G.I.H. limit value = 3 mg/m^3)

Tested Machine	Sampling time [min]	Volume aspirated [l]	Dust concentration [mg/m^3]
Species: hazelnut			
pulled vacuum harvester Facma Cimina 300	124	236	**21,8**
self-propelled vacuum harvester Facma Cimina 160 S	82	156	**13,4**
self-propelled vacuum harvester Facma Cimina 180 S	65	124	**14,6**
self-propelled vacuum harvester Facma Cimina 200 S	83	158	**20,5**
self-propelled vacuum harvester Facma Cimina 300 S	90	171	**24,7**
self-propelled vacuum harvester Facma Cimina 380 S	62	118	**25,0**
tractor mounted picker GF Jolly 2800	47	89	**21,3**
tractor mounted picker GF Jolly 2800	69	131	**18,8**
Species: chestnut			
pulled vacuum harvester Facma Cimina 200 T	52	99	**4,6**
self-propelled picker Agrintem Perla 55	52	99	**0,98**

The A.C.G.I.H., today, specifies that the recommended limits for the P.N.O.Cs are applied to particles that:

- have not a specific applicable TLV;
- are insoluble or poorly soluble in water (or, preferably, in the pulmonary fluids if available data have been given);
- have low toxicity.

For the aforesaid particles (in 2007) limits of air concentration of 3 mg/m^3 in the case of the respirable particles and 10 mg/m^3 in the case of the inhalable particles are recommended.
From the analysis of the data gathered in table 1 it is noticeable that in all the 8 fields of hazelnut harvest dust concentrations expose the workers to values above the limits of

respirable dusts defined by the ACGIH.

Conclusions

From the data shown in table 1, a constant trespassing of the limit values defined by the ACGIH is deduced, for hazelnuts harvesting, although the technologies used for the mechanized harvest of these shell fruits result to be characterized by a high degree of innovation [1].

The average concentration of dusts found in the tests is equal to 20 mg/m^3 (with a standard deviation equal to 4,25 mg/m^3), against a value defined by the "guidelines" recommended by the ACGIH equal to 3 mg/m^3.

The situation improves for chestnut harvesting, generally effected in the month of October, when the grounds are mostly damp (besides it needs to be underlined that generally chestnut orchards present well more grass covered grounds in comparison to those of the hazelnuts): in fact values of exposure are also gotten below the limits suggested by the ACGIH. Nevertheless the results related to chestnut harvesting cannot be considered indicatives, because the bad meteorological conditions during the harvesting season have not allowed the execution of a sufficient number of samplings.

Besides this the research has also analyzed the importance of the variables in play during a typical harvest: particularly the dampness of the ground assumes a notable influence, while other variables as the order of the orchards, the dimension of the fields, the organization of the work, primarily affect on the exposure times to the specific agent of risk.

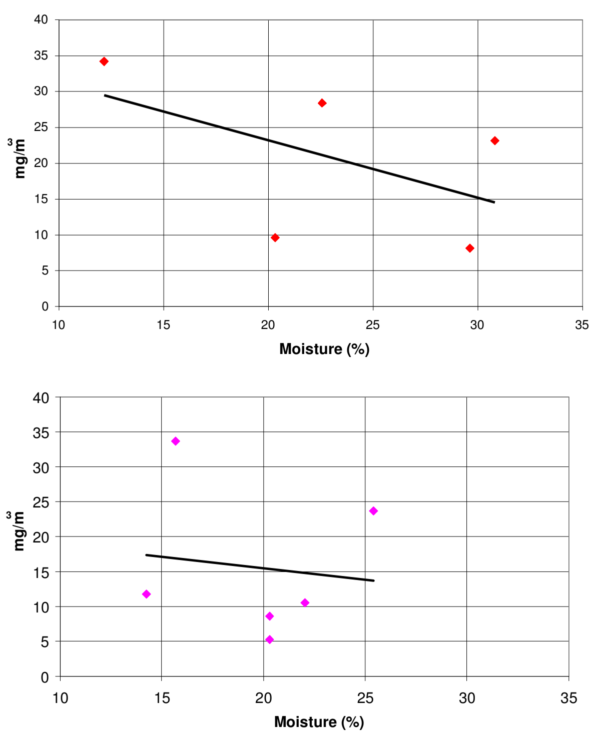


Figure 4. Course of the concentration of breathable dusts in relation to the moisture of the ground [6]

Previous researches, as it is deduced by the graphics brought in figure 4, underline the relationship between the ground moisture and concentrations of the aerodisperse dusts (Cecchini et al. 2005): obviously a great quantity of water in the ground reduces the concentration of particles, but this would seem more evident for the picking machines in comparison to the vacuum machines.

Anyway, in the hazelnuts harvesting, to avoid the onset of possible illnesses of the respiratory apparatus of the workers the use of individual protection devices (IPD - instruments of protection of the respiratory ways) is fundamental.

The choice of a fit individual protection device of the respiratory ways necessarily has to keep different factors in mind: the only criterion of choice in fact cannot be only the evaluation of the level of protection offered. Other aspects not to be underestimated are: the convenience, above all if the device must be worn for long periods, and the correct use.

For the choice of the IPD the norm EN 529:2005 "Respiratory protective devices - Recommendations for selection, use, care and maintenance - Guidance document." is adopted [9].

To be protected by the inorganic dusts the adoption of respirators is enough to filter against particles: facial anti-dust filters, or facial filtering.

The anti-dust filters (characterized by the white color code) and the respirators with anti-dust filter are divided in the following classes:

- low efficiency (filters P1 - respirators FFP 1, THP 1, TMP 1);
- medium efficiency (filters P2 - respirators FFP 2, THP 2, TMP 2);
- high efficiency (filters P3 - respirators FFP 3, THP 3, TMP 3).

The "nominal factor of protection" of a device (NPF) is the relationship between the concentration of the contaminant in the environment (C_{ext}) and its concentration inside the facial (C_{int}) one. The simple formula that ties the factor of protection to the filtering efficiency is the following:

$$NPF = \frac{C_{ext}}{C_{\text{int}}} \qquad (2)$$

The factor of nominal protection declared by the producer is given by measurements in the laboratory. In a work environment the conditions of use of the device can be very different: insofar, to the practical goals, more than the factor of nominal protection interests the "operational factor of protection". This last one can be considered, for devices with average efficiency, equal to 10.

From the results of the present study, therefore, considering that the workers' exposures during hazelnut harvesting are always revealed ten times above the TWA limit of the ACGIH, they would result to be fit facial filtering FFP 2 or P 2 filters fitted on masks.

However, for the reduction of the risks it seems evident the benefits brought by solutions like for instance: the substitution of the technique of the tilled soil with that of the natural cover crop, the reduction of the number of employees (with passage from the traditional system with hauled machines and three or four employees to the harvest, to the self moving ones usable by a single operator), while the employment of picking machines rather than vacuum machines doesn't appear as an evident system of prevention anymore [5].

More drastic solutions to the problem such as the adoption of semi-cab machines, even though desirable, result difficult as an application for the peculiarities of the work (necessity to pick up under the tree).

References

[1] ACGIH (2007), Valori limite di soglia. Indici Biologici di Esposizione, ACGIH 2007. Giornale degli Igienisti Industriali, AIDII, Milano, luglio 2007.
[2] Biondi P., Monarca D., Maraziti F. (1997), Il rischio da polvere in campo agricolo. Rivista di Ingegneria Agraria 4/1997: 226-236.
[3] Biondi P., Monarca D., Zoppello G. (1992), Il problema delle polveri nella raccolta delle nocciole con macchine aspiratrici. Rivista di Ingegneria Agraria 23 (4), 228-236.
[4] Biondi P., Monarca D., Zoppello G. (1993), Il problema delle polveri nella raccolta delle nocciole. Macchine e Motori agricoli, 50 (4), 63-69.
[5] Biondi P., Monarca D., Zoppello G. (1994), Dust control in hazel harvesting with vacuum harvesters. Atti III International Congress on Hazelnut, Alba 14-18 settembre 1992. Acta Horticulturae, gennaio, 351, 513-519.
[6] Cecchini M., Monarca D., Biondi P., Colantoni A., Panaro A. (2005), Il rischio da esposizione a polveri per gli addetti alla raccolta delle nocciole. Convegno AIIA2005: l'ingegneria agraria per lo sviluppo sostenibile dell'area mediterranea. Catania, 27-30 giugno 2005.
[7] Monarca D., Cecchini M., Antonelli D. (2005). Innovations in harvesting machines. Acta Horticulturae. vol. 686, pp. 343-350 ISSN: 0567-7572.
[8] Monarca D., Zoppello G. (1993), Il problema delle polveri e dei rumori in ambiente agricolo. Atti del V Convegno nazionale AIGR. Maratea 7-11 giugno 1993, (4) 383-390.
[9] EN 529:2005 "Respiratory protective devices - Recommendations for selection, use, care and maintenance - Guidance document"

The contribution to the programming and executing of this research must be equally divided by the authors.