The application of pesticides has been of concern for many years, particularly methods of reducing drift and improving deposition. There are many interrelated factors which affect spray application depending upon the target, the efficacy of the spray, the attitude of the operator, the standard of management, the weather etc.

In modern vineyards there are numerous row widths, varieties, plant spacing and variations in canopy shape and style. Canopy characteristics (height, width and density) also change as the growing season progresses.

Good disease and insect control is dependent upon the correct amount of pesticide being applied at the correct time. Incorrect application may result in pest resistance, poor pest or disease control, increase costs for the grower, and an increased risk of chemical contamination in the environment.

The operation of the sprayer often leaves much to be desired. Most growers know that there are three factors which affect application rate: forward speed, nozzle size and system pressure; but often overlook the factors which help get the spray onto the target: airflow, liquid flow, forward speed and canopy structure. Progress lies in the direction of a better understanding of the factors involved in getting the spray from the tank to the vines. Adjusting airflow and liquid flow to match the growing canopy as the season progresses is the key.

Landers (2016) describes real-time adjustment of the operating parameters (air flow, pressure, active nozzles, etc.) according to the target density as an important goal for canopy spraying systems. Keeping the spray cloud within the canopy is the goal resulting in reduced spray drift and increased deposition.

Fruit sprayers comprise two systems. The first system is the liquid spray and the second and, equally important for vine crop applications, is the airflow. The liquid flow is based upon nozzles and pressure, the airflow is based upon a fan to provide air for canopy penetration.

Airflow
The purpose of the air is to carry the droplets from the nozzles to the target as well as create a small amount of turbulence within the canopy to aid penetration. Too much air blows the spray through the canopy onto the ground or into the air (drift) or dislodges the droplets previously deposited into the canopy when the other side of the row was sprayed. Many vineyard sprayers use some form of air assistance from fans which are frequently too large for modern, well-pruned training systems; the large diameter fan creates too much air for the target canopy. The ideal air volume should match the canopy volume. Canopies vary along the row therefore the ability to vary airflow accordingly is important.
Trials with various types of vineyard sprayers have been conducted at Cornell University to study how changes in fan speed affect air speed, volume and direction. For some years we have shown growers that reducing airflow via a reduced air intake design will improve deposition in the canopy. A simple device, the “Cornell doughnut”, is made of plywood or metal. It is the same size as the fan intake with a hole 1/3rd, ½ or 2/3rds of the air intake cut in the centre, Figure 1. The doughnut reduces air intake and the operator selects the larger sized holes as the canopy develops.

We have also recently developed an adjustable air outlet for airblast and tower sprayers, Figure 2. An electric actuator moves an adjustable louvre allowing the operator to change air volume to match the changing canopy and reduce drift by as much as 71% in vineyards in early season application. Where the air blows the droplets will surely follow. Therefore, if drift is reduced, deposition within the canopy is improved, Table 1.

Adjusting airflow by using the CU adjustable louvre, Figure 3, increases deposition whilst reducing drift. Note, in Table 1 below, that airflow is needed in full canopy to get improved penetration and deposition.
Table 1. Drift reduction and deposition increase using the Cornell University adjustable airflow louvre in c.v Vignoles

Traditional airblast sprayers with a fan rotating in a counter-clockwise direction, move air downwards on the left-hand side of the sprayer and vice-versa on the right-hand side. The result is often a large plume of spray going upwards and outwards on the right hand-side of the sprayer and uneven application within the canopy. This does nothing to help public perception of the application of pesticides to fruit crops!

Airblast sprayers fitted with towers, adjustable air outlets or multi-head fans provide better airflow characteristics, and therefore better deposition into the canopy than do traditional designs. Our trials have shown up to 30% better deposition throughout the canopy by using tower sprayers. Adjustment of top and base deflector plates on traditional air blast sprayers should also be carried out to direct the air towards, and confine it to, the target canopy.

Adjusting the airspeed can improve deposition considerably. Field trials were conducted using a sprayer fitted with airshear nozzles operating at two fan speeds, 2076 rpm (540 rpm PTO) and at a 25% reduced speed of 1557 rpm (405 rpm PTO). Drift was detected using water sensitive cards and then analyzed using image analysis software. At the higher fan speed of 2076 rpm, drift was detected up to 24m from the target row where 10% card coverage occurred. Reducing fan speed by 25% with a slower PTO speed resulted in considerably less drift, with card coverage at 24m being 0.20%.

A number of manufacturers now offer adjustable airflow. For example, some adjust the airflow by changing fan blade pitch or altering hydraulic or electricity flow to multi-head fan sprayers.

Liquid flow and canopy structure
There are two main aspects to consider when applying liquids, the volume of product and the volume of water. Many growers typically apply X L/ha pre-bloom and then Y L/ha post-bloom with the intention of getting good leaf coverage. Unfortunately poor spray coverage is a major factor contributing to poor insect and disease control. Better coverage leads to better control and a thorough application of an effective material is required. Uneven coverage increases the amount of pesticides that must be applied in order to provide adequate control on poorly covered areas and can increase the number of sprays required if it allows insects or a disease to become established. Applying the correct amount of spray at the correct time to the correct target is good advice.

Canopy size and shape will affect application volume and there are as many dangers in not applying enough spray as there are in applying too much. There is an optimum quantity required for a thorough coverage of the target. The old addage that you should spray until the leaves drip is misplaced; likewise lowering spray rates to below the minimum which offers control is also misguided advice. Increasing spray application volumes leads to higher losses to the ground and lower deposition on foliage.
The tunnel or recycling sprayer provides the ultimate in both drift control and canopy sensing. As the vine only intercepts the spray required, excess is returned to the tank providing savings of up to 75% in spray use in early season and average of 30% over the whole season.

There are a number of new techniques to assess canopy volume or area being investigated or practiced. Unit Canopy Row from Australia uses canopy volume and Leaf Wall Area in Europe are both recently-devised methods being used to assess the volume of liquid required to give satisfactory coverage without applying and transporting vast quantities of liquid around the vineyard. What is the optimum amount? The aim of good pesticide application is to provide many small/medium droplets that will stick to the surface of the leaf and, as every canopy is different, due to growth stage, variety, trellis and climate etc., the only way to know is to look at the canopy. Growers can use a variety of safe methods using clean water and:

- Water sensitive cards and strips, attached to the leaves with paper clips or staples as long as the canopy is dry and the user wears rubber gloves. They are quite expensive but show where water droplets have hit the upper or lower leaf surfaces and how close the water deposits are to the grape cluster.

- High quality photographic paper cut into 50mm x 25mm strips attached to the leaves and used in conjunction with a readily available kitchen food dye. Quality photo paper can be purchased at office supply shops for printing digital photos. Alternatives include plain glossy business cards or file cards.

- Surround as a tracer. Surround, an organic insecticide, based upon Kaolin clay, is highly visible on most green vine leaves and grapes. It should be premixed in a bucket before putting into the spray tank, otherwise it will block the filters. Keep the tank agitation working. The spray will dry rapidly on a summer day and in approximately 10 minutes you will see all the droplets over the leaves and grapes.

- Fluorescent tracers and an ultra violet (black-light) lamp provide an excellent means of seeing where the droplets have landed, Figures 3 and 4. Figure 4 shows excessive application leading to run-off. Growers have to wait until dark to see the droplets in the canopy or remove leaves to view in a darkened area. Inexpensive blacklights are available on the internet.

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*Figure 3 Coverage 350 L/ha at 4.8km/h*  
*Figure 4 Coverage: 700 L/ha at 4.8 km/h*
Nozzles
When applying pesticides, growers know that small or fine/medium droplets give the best coverage, as large droplets (in excess of 300 µm) will bounce off the leaves onto the ground. Good coverage is critical for all contact pesticides. Unfortunately small or fine droplets (less than 150 microns) are drift-prone if they don’t become attached to the target leaf, insect or clusters. Directed deposition is needed if pesticide is to be applied to the target zone. Drift results watercourses and an unintentionally reduced rate of application to the target crop, thus reducing the effectiveness of the pesticide. Pesticide drift also affects neighbouring properties, often leading to public outcry. Air induction nozzles can be used in the canopy sprayer to reduce drift considerably. They can reduce drift from occurring as far as seven rows away down to one or two rows and are ideal when spraying next to sensitive areas.

Droplets under 150 microns generally pose the greatest drift hazard; droplets less than 50 microns have insufficient momentum for impact as they remain suspended in the air indefinitely or until they evaporate. Deposition efficiencies may be as low as 55% of the applied spray from an airblast sprayer, suggesting that 45% of pesticide hits the ground contaminating the soil and goes up into the air. Trials at Cornell University, using Albus, Lechler and TeeJet air induction nozzles, can reduce drift by at least 50-65 percent. They work well with systemic products and are also ideal for use in weed sprayers.

The operator
Correct filling routine, personal protective clothing and calibration should be standard practices. Calibration of vineyard sprayers can be seen on the internet at You Tube, showing both measuring liquid flow and also nozzle selection. Sprayer operators need to remain alert, checking changing weather conditions and the use of a hand-held anemometer is recommended.

Forward speed
The sprayer should be operated at a speed consistent with spray penetration into the canopy. Driving too slowly in a sparse, early-season canopy will result in spray blowing through the row; conversely, driving too fast in a full canopy results in poor penetration. Watching what is happening, along with checking on deposition as mentioned earlier, will result in the optimum speed. As with all farm operations, spraying requires thorough preparation, attention to detail, and constant vigilance if mistakes are to be avoided and an efficient application is to be made.

Automation
Llorens et al (2013) and Llorens and Landers (2014) developed a method of liquid control, adapting the Lechler Vario-Select (Lechler GmbH, Metzingen, Germany) nozzle system from horizontal boom sprayers and applying it to the vertical boom found on tower fruit sprayers. The Lechler Vario-Select comprises a cluster of nozzles, each nozzle being operated individually or in a combination thereof, allowing a wide range of outputs to be obtained. The Lechler system used compressed air to open and close the nozzles. This method allows the use of variable rate technology (VRT), a basic requirement in the precision farming concept.

Previous research, at Cornell University, lead to the development of an adjustable louvre to control the air leaving the sprayer, discussed earlier. When drift is reduced by adjusted air volume or speed, deposition within the canopy or on the fruit increases. Currently the sprayer operator manually adjusts the louvre via an adjustable stroke length actuator that moves the louvre, thus matching airflow to canopy size. Unfortunately in heavy canopies it is a challenge to see how far the spray cloud is passing through the canopy.
Llorens et al (2013) developed a system which measured the distance from the ultrasonic sensor to the edge of the vine canopy. The low cost system calculated canopy volume based upon the distance and time of the ultrasonic system and the centerline (trellis posts) of the canopy. The assumption being made that the rows of vines were in a straight-line and the tractor was being driven in a straight-line, neither being commonly found. The ultrasonic system detailed in previous work (Palleja & Landers, 2015) was used in the field trials. The canopy sprayer was a Berthoud S600 axial fan sprayer. It incorporates a set of 4 ultrasonic sensors (XL-MaxSonar MB7092) mounted on a 3 m long mast (Figure 5). The sensors are distributed along the mast according to the height of the vines. A microcontroller board was used to estimate the canopy density as a function of the ultrasonic echoes. It was tested as the growing season progressed and the data obtained was highly correlated with the season but it was not compared to actual canopy density. The sensor system was further modified to monitor canopy density and volume resulting in the ability to adjust the airflow actuator and the liquid flow from the nozzles based upon canopy density.

Point Quadrat Analysis (PQA) was used to compare the ultrasonic data with a scientifically accepted method to estimate canopy density, check if the data is correlated, and validate the ultrasonic system. Point Quadrat Analysis (PQA) is an acceptable yet simple field method to measure key parameters of the canopy characteristics. In PQA, a probe is passed through the canopy and any contact with biomass such as leaves or fruit are identified and recorded (Smart, 1985; Smart & Robinson, 1991). The canopy is sampled at specific heights, which is usually at the fruit zone, at consistent intervals along the row. Enhanced Point Quadrat Analysis (EPQA) was a further development of the PQA method by Meyers & Vanden Heuvel, (2008) and is a more descriptive system as it adds metrics which allow cluster exposure mapping and leaf exposure mapping to measure sunlight distribution.

Two plastic frames were built to perform PQA in the two vineyards (0.5x2 m, Figure 6). The frames have 4 horizontal bars, matching the ultrasonic sensors’ height. Each horizontal bar has 6 marks spaced 10 cm apart, indicating the position where the operator introduces the probe to count the number of leaf layers.
The experiments were conducted in fields belonging to Cornell University during the growing seasons of 2015 and 2016. Vineyards of *V. vinifera* cv. Vignoles and cv. Cabernet Franc grapevines were used. The field trial consists of using the ultrasonic system to scan both sides of a row at 4.6 km/h as well as perform PQA. The PQA frame has 24 different positions and it is moved along the row at 4 random locations, making a total 96 samples per row per week. The average 96 PQA samples, named |PQA|, is compared with the average of the 4 sensors’ $w_c$ (the average of the full sum of ultrasonic sound returns, Pallejà & Landers, 2016) along the row, named $|w_c|$. $w_c$ values are expressed in volts.

The ultrasonic system shows strong correlation to the acceptable, traditional method of Point Quadrat Analysis (PQA). This work shows that the ultrasonic canopy density method needs to be calibrated for each variety and plant type, in order to be used as a reference for adjustment of the sprayer’s parameters in real time, with the aim of improving deposition and reducing drift.

The ultrasonic system allows the rapid determination of canopy density, providing information to allow the variable application of pesticides in real-time. The ultrasonic system will also provide horticultural researchers with a fast method of comparing canopy density and growth stage for their field trials.

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References