Low-Loss-Spray-Application - The Scientific Basis

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Summary
Limited time frames caused by infection threat and weather demand for efficient pesticide application techniques in modern integrated and organic fruit farming. This demand is best complied by low volume spraying, since it minimizes traveling time and number of fillings per spray treatment, but also minimizes the probability of a contamination of the operator with concentrated pesticides. To obtain good spray deposition, low volume spray application demands small droplets which offer numerous benefits, but also carry a high drift potential. This feature threatened the technique, because no method for spray drift reduction has been available in order to make use of reduced buffer zones to water courses and non-target areas. A new method based on cross flow characteristics of the sprayer fan, canopy adapted forward speed and fan speed and a mixed set of hollow cone nozzles and air induction nozzles resulted in an approx. 85% reduction of particle drift deposits, so that the method has been registered in the official German list of drift reducing devices in the 75% drift reduction class. Besides drift reduction a canopy adapted fan speed also results in an enormous reduction of fuel consumption and noise emission as further environmental benefits of small droplets. An assessment of the influence of a canopy adapted forward speed and fan speed on spray deposit, relative spray coverage and droplet deposit density revealed a significant increase of the application efficiency, rising with decreasing canopy width and compensating a reduction of water volume and dose rate from canopy related dosing models. Testing a tower sprayer in orchards for use with reduced fan speed unexpectedly showed an unusable vertical air distribution. Alarmed by this finding, a subsequent testing of various fan types on a test bench disclosed a very unsatisfying vertical air distribution of many fan types and even within a production series the air distribution differed enormously. Especially an uneven horizontal reach of the air stream over working height is a major obstacle for a successful use of canopy adapted fan speed with all its benefits. Since a uniform vertical air distribution is the basic requirement for a highly efficient and environmentally safer spray application not only in terms of the potential to reduce pesticide consumption, but also for reducing fuel consumption and noise emissions, testing and adjusting fans of orchard sprayers on a test bench is urgently needed. Because of the importance of the topic, three fruit growers associations in Austria, Italy and Germany together initiated the development of a new test bench to measure vertical air distribution of orchard sprayers.

Introduction
In modern crop protection in integrated and organic top fruit growing with a few exceptions only protectant fungicides are used against apple scab (*Venturia inaequalis, Cke., Wint.*). These fungicides have to be applied as close as possible before a rain event to minimize leaf growth between the application and the rain event, which is crucial to maximize residual activity for covering as many infection periods as possible. Right before the onset of a rain event weather conditions with low natural wind are an additional factor which may limit the time window available for optimal fungicide application. In important European fruit growing regions very often the blocks are rather small and are spread within the vicinity of a fruit farm requiring a lot of extra time for traveling between the orchards and for sprayer filling. This may consume significant time in relation to the total time required for a fungicide treatment of all blocks of a fruit farm. As a last factor the number of fillings per spray round has to be minimized in order to minimize the chances of contamination of the operator with the concentrated pesticides.

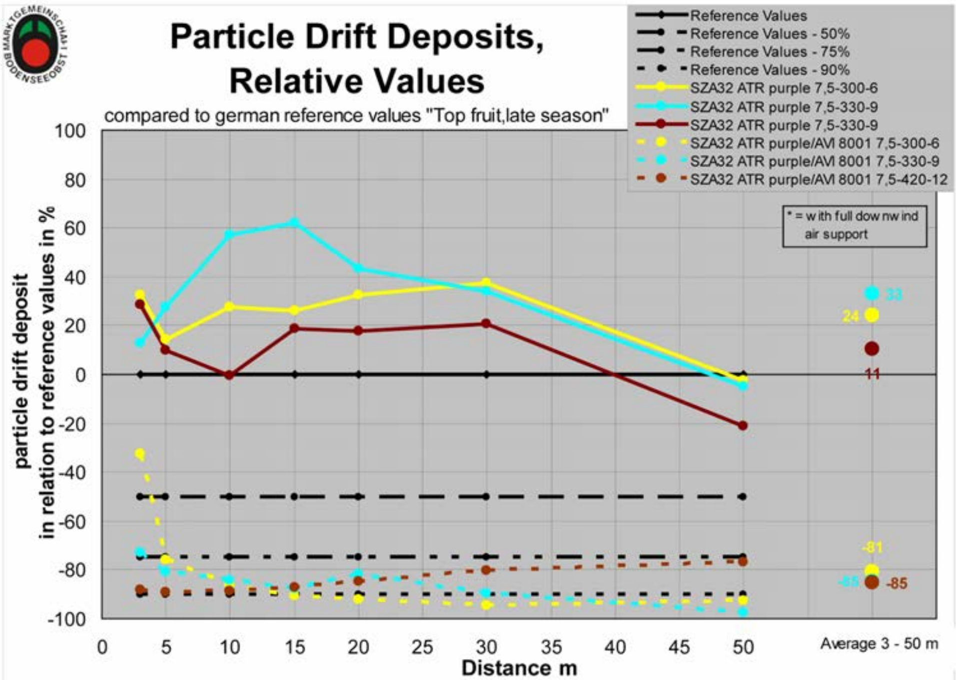
To maximize work rate under these constraints, low volume spray application with small droplet hollow cone nozzles (e.g. "Albuz ATR purple") has become standard in the late 1980ies in large fruit growing regions in the UK, The Netherlands, Austria and Germany. Further reasons to use small droplets have been low risks for visual spray deposits on the fruit and phytotoxicity, and a potential to reduce pesticide dose rates. Some innovative growers using tower sprayers with small droplet spay application since many years also adapted the fan speed to the canopy because this already visually seemed

to keep a higher amount of the spray mist in the canopy, assuming that it might improve spray deposition and reduce spray drift. These growers also reported a significant reduction of fuel consumption and noise emissions from a reduced fan speed.
With the appearance of large droplet nozzles in order to reduce particle drift deposits as a basic requirement to legally reduce buffer zones to water courses for the application of pesticides, low volume spray application was endangered to be no more applicable for efficient crop protection. Therefore an alternative method for spray drift reduction that maintains the enormous benefits of low volume spraying technique with small droplets had to be developed, combining the needs of growers with official demands to minimize particle drift deposits.

Spray drift reduction with small droplet nozzles

Since spray drift trials with small droplets are rare, it has been necessary to check the status quo of spray drift from small droplet nozzles. From this starting point new drift reducing methods should have been developed for its reduction. The aim was a particle drift reduction that allowed a registration at least in the 75% - drift reduction class of the official German list of spray drift reducing devices of the JKI at Braunschweig. The basic idea to achieve this reduction was an adaptation of the reach of the air stream from fans with cross flow characteristics to the canopy so that only very little spray mist passes the canopy, moving into the next alley way and being released into the atmosphere above the canopy.
A trial, based on the official German protocol for particle drift deposit trials was carried out to assess the effect of a cross flow fan and reduced fan speed at various forward speeds in combination with the hollow cone nozzle "Albuz ATR purple" on particle drift deposit.
A "Wanner N36-A" axial fan was used as a reference to test the effects of three combinations of fan speeds and forward speeds to compare with the "Wanner SZA32" axial fan with cross flow characteristics, where the downwind facing air outlet was not closed by the deflector plate. In a first treatment at a forward speed of 6 km h^{1} the effect of replacing the axial fan by an axial fan with cross flow characteristics at identical settings of forward speed and fan speed was evaluated. Further treatments were carried out at a forward speed of 6 km h^{1} while reducing fan speed to 420 min^{1} and finally to the canopy related value of 300 min^{1}. The tests have been repeated with further combinations of forward speeds and canopy adapted fan speeds (9 km h^{1} at 330 min^{1} and 12 km h^{1} at 420 min^{1}).
Compared to the German reference values, the axial fan produced an average particle drift deposit 4,1-fold above the German reference value "top fruit; late season". The axial fan with cross flow characteristics with every other settings remaining unchanged yielded a value 2.4-fold higher than the reference, reducing particle drift deposits by 42% compared to the axial fan. Reducing fan speed to 420 min^{1} of the cross flow fan resulted in a value 1.5 fold above the reference analogical an extra 36% reduction from the previous value. The canopy adapted PTO speed of 300 min^{1} finally resulted in a particle drift deposit 24% above the reference values. This complies to a 94% reduction compared to the axial fan at nominal PTO speed (540 min^{1}).

Since forward speeds of 9 and 12 km h^{1} produced particle drift deposits of 33% and 11% above the reference value, it may be concluded that tower sprayers with a full set of the hollow cone nozzle "Albuz ATR purple" at canopy adapted fan speed produces approximately the same spray drift at any forward speed between 6 and 12 km h^{1}. Replacing the three topmost hollow cone nozzles with two air induction nozzles "Albuz AVI 8001" and operating the tower sprayer with the same settings as before, reduced particle drift deposits between 81% and 85% below the reference value (**graph 1**). These results allowed the listing of those sprayers in the 75% drift reduction class of the official German list of drift reducing devices.Repeating the trials with the mixed nozzle set and the same canopy related settings of forward speed and fan speed under hail net, raised particle spray drift reduction to values between 95% and 96% so that the system of a fan with cross flow characteristics, canopy adapted dosing and spray application in combination with a hail net may be listed in the 90% drift reduction class.



Graph 1. Particle drift deposits in relation to reference values "top fruit - late season" from an tower sprayer with canopy adapted fan speed at 6,0, 9,0 and 12,0 km h-1. Upper graphs: 16 x hollow cone nozzle "Albuz ATR purple"; lower graphs: mixed nozzle set of 12 x hollow cone nozzle "Albuz ATR purple" and 2 x AVI 8001.

The effects of a canopy adapted fan speed on spray cover

With the possibility of reducing particle drift deposit by at least 75% without any constructive modifications of the sprayer fan, it was interesting to assess the influence of a canopy adapted spray application on spray cover parameters as there are spray deposit, relative coverage and droplet deposit density. A "Wanner SZA32" tower sprayer, fitted with 2 x 8 hollow cone nozzles "Albuz ATR purple" has been used for the trial work. Spray deposit has been analyzed fluorometrically while image analysis has been used to assess relative coverage and droplet deposit density, each separately on the upper and lower leaf surface. For covering the range of canopy structures in modern commercial fruit farms, a three row bed, a slender spindle and a super spindle orchard has been chosen where the classical method of spray application (constant water volume, relatively low forward speed at nominal fan speed) has been compared with the results of the MABO dosing model (canopy adapted values of water volume, forward speed and fan speed) (**tab.** 1).

Tab. 1. Treatments for assessing spray cover on apple leaves

Treatment	Canopy system	Method of dosing and application	Spray liquid pressure	Water volume	PTO-speed*	Forward speed
			bar	l ha^{1}	min^{1}	km h^{1}
I	3-row-bed	„grower“	16.5	200	540	6.7
II	3-row-bed	„model“	7.5	237	460	3.8
III	Slender spindle	„grower“	9.0	200	540	8.0
IV	Slender spindle	“model”	7.5	153	330	9.0
V	Super spindle	„grower“	11.0	200	540	9.0
VI	Super spindle	„ model“	7.5	114	290	12.1

Operating a tower sprayer with an almost horizontal air stream equipped with small droplet hollow cone nozzles with canopy adapted forward speed and fan speed, resulted in a general increase of the application efficiency in all three canopy structures, increasing as canopy width decreased. For the spray deposit on the entire leaf area, this increase in efficiency (calculated as µg cm^{2} l^{1}) ranges from 14% in the bed system, 29% in the slender spindle to 35% in the super spindle orchard. Specific relative coverage (% l^{1}) on the upper leaf surface revealed a decrease of 29% in efficiency in the bed system, but an increase of 26% in the spindle and 67% in the super spindle orchard. Assessing droplet deposit density on the upper leaf surface, disclosed an increase of application efficiency (n l^{1}) beginning with a slight decrease of 5% in the bed system, increasing from 27% in the spindle and 55% in the super spindle canopy (**tab.** 2).

Tab. 2. Changes in average efficiency of spray deposition of “model” in relation to “grower” in three different canopy systems

	3-row bed	Slender spindle	Super spindle
Spray deposit (entire leaf)	14%	29%	35%
Relative coverage (upper leaf surface)	-29%	26%	67%
Relative coverage (lower leaf surface)	-27%	-3%	7%
Droplet deposit density (upper leaf surface)	-5%	27%	55%
Droplet deposit density (lower leaf surface)	17%	28%	27%

The results clearly show that canopy adapted spray application using fans with cross flow characteristics does not only reduce particle drift deposits when fitted with small droplet nozzles, but also increases spray deposition efficiency significantly on the upper leaf surface, when compared to classical spray application with relatively low forward speed and nominal fan speed. This increasing efficiency in the “model” treatment completely compensated a reduction of water volume and pesticide dose rate of 25% in the slender spindle and a reduction of 43% in the super spindle to an extent of 77%.

On the lower leaf surface, average values of relative coverage and droplet deposit density have been approximately 2.5-fold higher compared to the upper leaf surface for the “grower” settings, while values obtained from “model” settings have been 2-fold higher. From these results may be concluded that also spray deposit is significantly higher on the lower leaf surface compared to the upper one, although a tower sprayer has been used.

The adaptation of the air stream to the canopy structure by fan speed and forward speed in most cases also reduced the gradients between the surface and the center of the canopy, thus leading to a more uniform spray deposition over canopy width. Coefficients of variation calculated from the 120

samples per treatment also did not disclose any remarkable difference compared to the "grower" settings. Another positive effect obtained from canopy adapted forward speed and fan speed was a better spray deposition on the upper leaf surface in the upper part of the canopy in the center of broad canopy systems which may reduce pest and disease infestation, frequently occurring under classical application with high fan speed and relatively high forward speed. Finally a canopy adapted fan speed leads to an enormous reduction of fuel consumption and noise emissions, reducing the CO_2-footprint of fruit production as well as preventing complaints from settlements in the vicinity of orchards.
With these results, providing a method of spray drift reduction for small droplets easily applied in practice without quantitative and qualitative compromises in terms of spray deposition, a method to preserve low volume spray application for growers as a highly efficient spray application technique has been found. As positive side effects it adds reduced pesticide consumption from canopy adapted dosing and significant reduction of fuel consumption and noise emission to the list of benefits of small droplets.

Vertical air distribution - the unexpected obstacle

As prerequisites for registering tower sprayers in the official German list of spray drift reducing devices for this method of spray drift reduction in the 75% spray drift reduction class, the Julius-Kühn-Institute (JKI) at Braunschweig, Germany, demands that the sprayer has to be a cross flow fan sprayer or a tower sprayer with cross flow characteristics equipped with a full set of air induction nozzles, already registered in the 90% drift reducing class. Equipped with the mixed nozzle set the sprayer has to be operated according the results of the MABO-dosing model concerning water volume, pesticide dose rate and forward speed at canopy adapted fan speed. As references, the PTO speed has to be determined that is required to just penetrate the canopy of orchards in full leaf, where the MABO-dosing model computed forward speeds of 6, 9, and 12 km h^1.
Testing one of the first tower sprayers with cross flow characteristics suitable for this method of spray drift reduction in an orchard, even without reducing fan speed disclosed a serious malfunction of the fan: since no redirecting system was installed behind the fan the tower was supplied only with the air from an approximately 940 cm^2 outlet area, corresponding to ca. 30% of the fan outlet, which after redirection by deflector plates then had to be distributed by the tower with a total outlet area of ca. 2840 cm^2, respectively an approximately 3-fold larger outlet area compared to the section of the fan supplying it with air. As a result the radial air distribution of the axial fan on both sides was cut off at an angle of approximately 45° symbolized by the red line in **fig.** 2. Therefore on one hand the air stream directly from the fan was creating a barrier for the weak air stream of the tower reaching the canopy while on the other hand the vertical angle of the direct air stream of the fan was too low to reach the top of the trees, leaving them partly untreated. At the tower the air stream was decreasing with increasing sampling position and at the top of the tower the air support was so low that the spray mist from the top most nozzle did not even move away from the tower but partly deposited at the rear side of the tower and also formed a vertical cloud of droplets drifting vertically into the atmosphere (area framed by the blue line). This observation has been confirmed by growers reporting serious apple scab infestation at the top of the trees after having purchased this sprayer type. Alarmed by this situation, a whole range of orchard sprayers with cross flow characteristics has been tested with the air test bench borrowed from the fruit growing school at Gleisdorf, Austria. The results disclosed that with a few exceptions the fans with cross flow characteristics showed a defective air distribution, ranging from a generally too low working height to big differences between the two fan sides. In some cases a satisfying function in top fruit production even at full fan speed has been questionable. But also vertical air distribution very often was strongly uneven, making it impossible to adapt fan speed to the canopy for efficient spray application because then the air stream that was already weak at one or more sections of the fan at full fan speed would have been too low to generate sufficient spray cover at the canopy sections being treated by this section of the fan. A selection of vertical air distributions is presented in **fig.** 3, where the horizontal lines picture the maximal air speed and the small arrows in the center of each graph indicate the direction of the air stream at each measuring position.

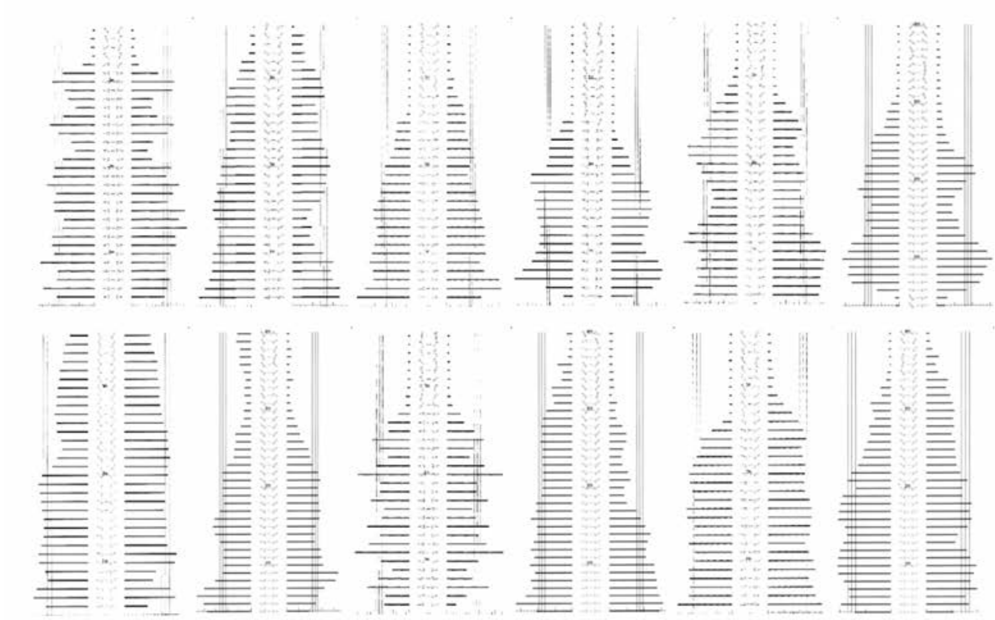


Fig. 3. Examples of the vertical air distribution of various types of fans of orchard sprayers with cross flow characteristics.

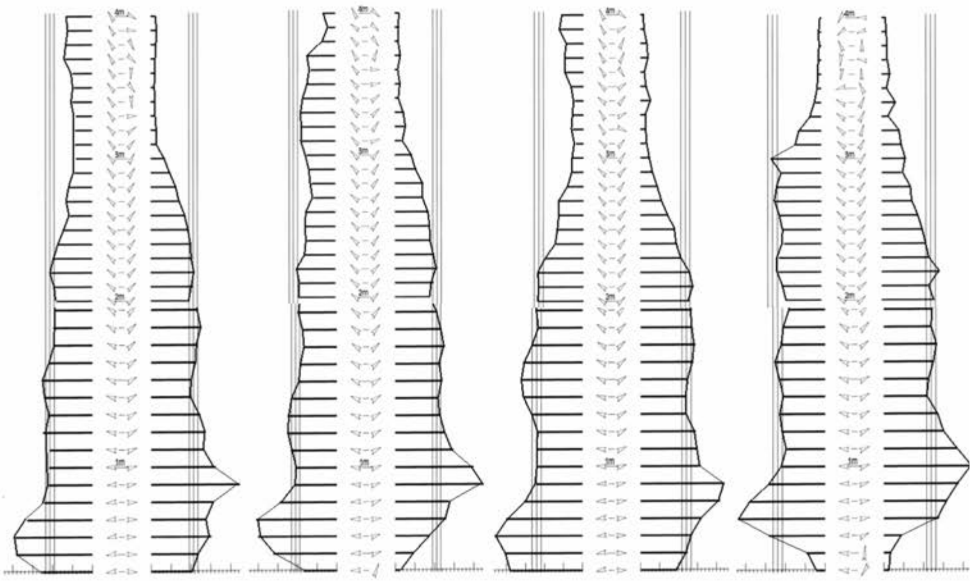


Fig. 4. One example of the varying vertical air distribution of individual fans from a series (axial fan with cross flow characteristics) for the treatment of tall trees (e.g. stone fruit).

Measuring several fans from one fan series in addition showed that the vertical air distribution was not uniform as to be expected, but showed big individual differences (**fig.** 4), very likely originating from tower assembly.
As a general picture from many fans tested, vertical air distribution in many cases has been very poor in terms of uniformity of working height, uniform angles of the air stream at both sides of the fan and uniform reach of the air stream over the working height. In addition individual fans from a series showed no uniform pattern of air distribution, but may vary remarkably from machine to machine. From these findings may be concluded, that testing and possibly also adjusting the vertical air distribution of every new orchard sprayer before purchase is an essential need when aiming at a highly efficient spray application, especially with small droplets and low volumes, producing high quality spray cover on the target, reducing spray drift compared to air induction nozzles, reducing pesticide consumption technically as well as fuel consumption and noise emissions.

Conclusions

Tab. 3. Basic features of the new air distribution test bench "WP 5000"

Dimensions (folded)	3,85 m, 1,30 m, 1,50 m (l, w, h)		Before/after modifications; 3 pages:
Weight	485 kg		summary; wind speed and direction:
Measuring principle	Ultrasonic (0 - 60 m s^{-1})	Protocol	vX; IvI; vXZ; quadrants comparison;
Number of sensors	5		for each fan type: specific energy
Recorded data	Wind speed m s^{-1}, x-, y-, z-direction		consumption, CO_2-balance, noise
Effective range	2,0 m (h) x 5,0 m (v)		emissions (dBA)
Measuring grid	0,1 m (h) x 0,1 m (v)		Scan function, various protocols,
Records per position	Variable; default = 25		automatic evaluation of the air
Data transmission	WLAN	Special features	distribution according the „Low Loss
Time per measurement	< 25 min per fan side		Spraying" guidelines

Driven by these very unexpected findings, the "South Tyrolean Advisory Service for Fruit and W Growing" at Lana, South Tyrol, Italy, the "Styrean Fruit Growers Association" at Graz, Austria and the fruit cooperative "Marktgemeinschaft Bodenseeobst eG" at Friedrichshafen, Germany, representing a total fruit growing area of approximately 30.000 ha, in 2010 started a joint project for testing and adjusting the air distribution of new orchard sprayers as a first step to offer optimized orchard sprayers to the fruit growing industry in their regions. The reasons were to reduce negative environmental effects as there is spray drift from low volume spraying with small droplets, improve air distribution to allow operation with reduced fan speed for better and more efficient spray deposition, to bring down fuel consumption and noise emissions and to enable a reduction of pesticide consumption through canopy adapted dosing and spray application. Based on the experiences from the test bench that has been developed by the fruit growing school at Gleisdorf, Austria, in 1994, they assigned "Ernst Herbst Prüftechnik e. K." at Hirschbach, Germany, in 2010 with the development of a new test bench for measuring the vertical air distribution (fig. 5) of which some basic features are listed in tab. 3.

Completed by the mandatory sprayer testing extended by measuring the vertical spray liquid distribution with a patternator as the second step of testing and adjusting new orchard sprayers and the ones in use, the three organisations mentioned above develop and introduce a highly efficient but also environmentally safer spray application technique. The improvement and adjustment of air and spray liquid distribution of orchard sprayers is recognized as an important contribution to further implement their fruit industries business philosophies of an environmentally safer fruit production.

Fig. 5. The new air distribution test bench "WP 5000" (Photo: Triloff, 2012).

Literature

TRILOFF, P., 2011: Verlustreduzierter Pflanzenschutz im Baumobstbau - Abdriftminimierung und Effizienzsteigerung durch baumformabhängige Dosierung und Luftführung. Dissertation, Institut für Agrartechnik, Universität Hohenheim, Stuttgart, Germany, 351 p, Verlag Ulrich E. Grauer, Stuttgart, ISBN 978-3-86186-563-6.