Advantages from Canopy Related Spray Application in Organic Top Fruit Production

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Summary:

To reduce the negative environmental impact of copper as an important fungicidal substance, especially for the control of apple scab, new molecules and formulations with lower dose rates of copper have been developed in the past years. Canopy related dosing may contribute to this desired reduction by adapting the dose rate to canopy characteristics. Since spray application produces losses to non target areas and the atmosphere and may influence quantitative and qualitative distribution of pesticides on the target, it was interesting if there are possibilities for improvements of the application process that may be utilized to once more reduce dose rates in relation to canopy characteristics or increase efficacy at dose rates that may no more be increased.

Based on the MABO-dosing model, relating water volume, dose rate, forward speed and fan power to the canopy, the effects on spray deposits have been compared with common dosing and application rules using fixed water volume, preset forward speeds and nominal fan power. Spray cover from three canopy systems has been analysed on deposit on the entire leaf and on coverage and droplet deposit density on both upper and lower leaf surface.

The canopy related application could for the very most parameters compensate a reduction of water volume per ha as canopy width decreased, leading on the upper leaf surface to very similar coverage and droplet deposit density and improved spray cover in the centre of broad canopies. On the lower leaf surface both methods resulted in a strong overdeposition increasing as canopy width increased. The results clearly showed that canopy adapted spray application improves efficacy of deposition, and thus may be utilized to further reduce dose rates in combination with canopy related dosing models.

Key words: copper, fan power, spray deposit, coverage, droplet deposit density

Introduction:

A better understanding of apple scab (*Venturia inaequalis, Cke., Wint.*) and its host in the past two decades has yielded several tools like sophisticated simulations to predict the behaviour of the fungus, sanitation means to reduce the primary inoculum to levels the fungicides can handle with acceptable success, and specific spray strategies increasing the efficacy of control of individual infections. Altogether these tools allow this important disease of apple to be controlled in organic farms at least as effectively as in integrated production in the primary season. To obtain this result in organic apple production, copper is probably the strongest fungicidal substance available and is required to control the most severe primary infections. Since copper is a heavy metal accumulating in the soil and exhibiting some negative impacts, e.g. on earth worms and aquatics, its further use in Germany has been endangered. With the development of new formulations and new copper containing molecules the amount of copper required per unit area of a crop has been reduced enormously and resulted in the registration of new copper products in

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Germany recently. However it has not yet been assessed if spray application may offer some potential to either directly reduce the farm specific total consumption of copper by canopy related dosing and more efficient spray application or indirectly by an increase of an insufficient efficacy from dose rates that may no more be increased.

Results from a project to develop a method to reduce spray drift with small droplet nozzles (Triloff, 2011) may provide another means for a further reduction of total copper consumption used for e.g. apple scab control in organic fruit production. Besides an almost horizontal air stream the main key for the reduction of spray drift from small droplets is the adaptation of fan power to the canopy by forward speed and fan speed, transporting the spray mist just into the canopy but not out again into the next alley way. Since this adaptation is contrary to the widespread opinion that only a strong air stream produces a good cover it was also interesting to assess the effect of the adaptation of fan power to the canopy on spray deposition. Therefore both methods - dosing and application after a model that adapts water volume, dose rate, forward speed and fan power to the canopy and the classical method with fixed dose rates per ha, low forward speed and full fan power - have been compared in three canopy systems; a broad three row bed, a regular slender spindle and a super spindle.

From only little research on the effect of reduced fan power on spray deposit, it is known that in trials with big canopies, already Randall (1971) reports most uniform spray deposits from highest air volumes and lowest air speed inside the canopy. In citrus Whitney & Salyani (1991) find lower spray deposits at the canopy surface than 0,6 m inside the canopy and attribute this effect to a high air volume at high speed. In fruit trees with a large canopy also Derksen & Gray (1995) did not find an increase of spray deposit after raising fan speed. An improvement of spray deposit has been achieved by Landers & Farooq (2004), who did not reduce fan speed of axial fans in top fruit but reduced air intake by wooden “donuts” with various size and so reduced air volume. An indirect prove of a positive effect of a reduced fan power on spray deposit in apple is reported from Richardson *et al.* (2000), who at crosswind found higher deposits on the upwind tree row than on the downwind *row. But also headwind not only leads to an improvement of spray deposit as* Cross et al. (2003) state, but also decrease spray drift, indicating the positive effect of a reduced reach of the air stream. Also in grape vine a reduction of fan power improved spray cover even at early developmental stages with little leaf area as Pergher & Gubiani (1995) report. Later in the season with a high leaf area the authors even found a reduced spray deposit from increased fan power and increased water volumes, indicating a poor penetration of the spray mist into the canopy at high air speed because of a shielding effect of the large leaves and a loss of spray liquid through run off at higher water volumes. The influence of fan power on spray deposit is rather high as Pergher (2005) notes which before bloom decreased spray deposit by 23% and after bloom by 21% when increasing fan power from 6,3 $m^3 \cdot s^{-1}$ to 10,6 $m^3 \cdot s^{-1}$. This improvement of the spray cover in grape vine by reduced fan power was also confirmed by Pezzi & Rondelli (2000) and Pergher & Lacovic (2005).

To evaluate combinations of a canopy adapted air stream and varying forward speed on the spray deposit, a trial series was carried out which combined a three dimensional dosing model adapting spray volume per ha, forward speed and fan power to the canopy (Triloff, 2005). While spray volume per ha and forward speed are calculated by the model and decrease resp. increase as canopy width decreases, fan power has to be adjusted visually for each canopy to a value where at the forward speed calculated by the model only very little spray mist is transported through the canopy into the next alley way.

Material and methods:

Orchards: Three apple orchards with differing dimensions have been selected from commercial farms to cover the range of planting systems at Lake Constance area:

1) „3-row bed“, variety Jonagold M9, planted in 1982, canopy width 3,20 m
2) „Slender spindle“, variety Jonagold M9, planted in 1986, canopy width 1,35 m
3) „Super spindle“, variety Jonagold M9, planted in 2004, canopy width 1,00 m

Orchard Sprayer: For all three orchards a tower sprayer „Wanner SZA32/1500“ with a nominal fan power of 34.000 $m^3 \cdot h^{-1}$ at the small fan gear was used, fitted with 2 x 8 hydraulic hollow cone nozzles „Albuz ATR purple“ which were used in all treatments.

Adaptation of fan power: To adjust fan power at each forward speed the model calculated to a value where only little spray mist was transported through the canopy into the next alley way, a few metres where sprayed in each planting system, with a second person visually monitoring the reach of the air stream in the alley way next to the sprayed tree row.

Dosing and application treatments: In each of the three orchards three plots were sprayed according to the owners setting of forward speed at a constant water volume of 200 $l \cdot ha^{-1}$ and nominal fan power. According to the dosing model three other plots were sprayed at differing settings of water volume$\cdot ha^{-1}$, forward speed and fan power (table 2).

Table 1: Trial treatments to evaluate spray cover

Treatment	Training system	Application method	Forward speed $km \cdot h^{-1}$	Fan power PTO* min^{-1}	Spray liquid pressure bar	Water volume $l \cdot ha^{-1}$
I	3 row **Be**d	„**g**rower“	**6,7**	**540**	**16,5**	**200**
II	3 row **Be**d	„**m**odel“	**3,8**	**460**	**7,5**	**237**
III	slender **Sp**indle	„**g**rower“	**8,0**	**540**	**9,0**	**200**
IV	slender **Sp**indle	„**m**odel“	**9,0**	**330**	**7,5**	**153**
V	**Su**per spindle	„**g**rower“	**9,0**	**540**	**11,0**	**200**
VI	**Su**per spindle	„**m**odel“	**12,1**	**290**	**7,5**	**114**

* = The fan of the sprayer was operated only in the low gear

Bold letters and numbers indicate treatments in the graphs: e.g. treatment I: Be g 6,7 540 16,5 200

Leaf sampling: From each trial plot in the 3rd of five beds/rows sprayed, 10 leaves where picked in each of 4 canopy sectors from the top to the bottom of the canopy in each of three trees according to the protocol for spray cover trials (Schmidt & Koch, 1995; Ganzelmeier & Schmidt, 2003) shown in figure 2. Leaf samples were picked immediately after the spray cover had dried off.

Fluorescent tracer: As fluorescent tracer Tinopal® NFW, a 20% water soluble formulation of disodium-2,2'-([1,1'-biphenyle]-4,4'-diyldivinylene)bis(benzolsulfonate) was used. The dose rate of the tracer was set to 1,0 $l \cdot 100\ l^{-1}$ to achieve sufficient fluorescence for the image analysis. For thoroughly mixing the tracer in the spray tank a 15 minute agitating period was required.

Leaf sample analysis: Leaf samples were analysed on coverage and droplet deposit density on each upper and lower leaf surface by image analysis (Media Cybernetics "Image-Pro 5.0") followed by an analysis on spray deposit of the total leaf area by fluorometry (auto-sampler "Perkin Elmer AS 91", luminescence-spectrometer "Perkin Elmer LS 30").

Results:

Spray deposit: With both methods of dosing and application a decrease in spray cover is observed as canopy width decreases, even at the constant water volumes·ha^{-1} in the "grower" scheme, but with a higher gradient in the "model" scheme. Adapting water volume, forward speed and fan power to the canopy, "model" improved average spray deposit in the bed system by 36% compared to "grower" although water volume was increased by only 18,5%. In the slender spindle "model" gave the same average spray deposit as "grower" despite water volume·ha^{-1} was reduced by 24%. In the super spindle "model" resulted in a 23% reduction of spray deposit despite a 43% reduction in water volume per ha, compared to "grower". Comparing "model" to "grower" in terms of overall efficiency of spray deposition, "model" resulted in a 28% more efficient use of pesticides, comprising a 16% reduction in pesticide consumption and an average increase of spray deposit by 7,7%.

Plotting spray deposit over canopy height, increasing canopy width resulted in a strong increase of spray deposit as the sampling position increased. The highest increase was observed in the bed system at the "grower" scheme with a factor of 2,4 between the

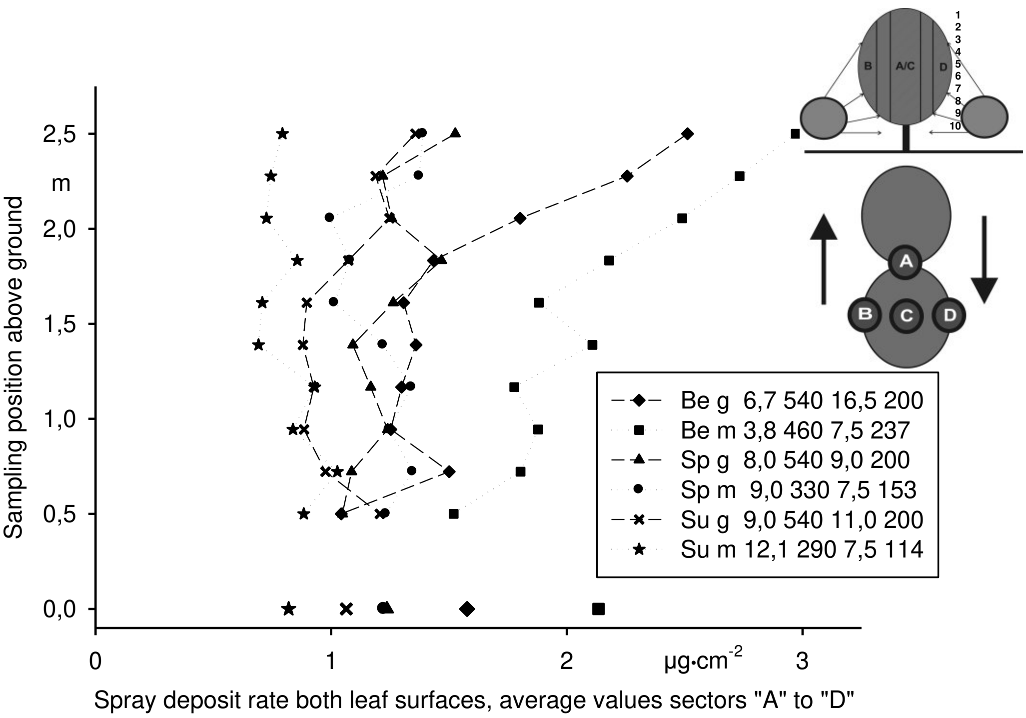

Figure 1: Spray deposits over canopy height calculated as average values of the 4 sampling sectors and average values of all individual data (n = 120) plotted at sampling position 0,0 m. Includes the scheme for leaf sampling at 4 canopy sectors (according to Schmidt & Koch, (1995), Ganzelmeier & Schmidt; (2003), modified)

highest and lowest sampling position. This increase is generally slightly stronger within the “grower” plots and is still visible in the super spindle, while “model” gave an almost uniform spray deposit over canopy height in this system (figure 1).

Relative Coverage: On the upper leaf surface, coverage ranged between 10% and 17% over all planting systems and spray schemes and decreased as canopy width became less. Maximum average values reached 17% and 14% in the bed system, 14,3% and 13,8% in the slender spindle and 10,5% and 10% in the super spindle for “grower” and “model” schemes. Plotting coverage data over canopy height showed a slight decrease as sampling position increased for all treatments (figure 2). Comparing “model” to “grower”, the efficiency of application decreased by 29% in the bed system but with still the same absolute values as in the slender spindle trees. In the slender spindle and the super spindle, “model” appeared to be 27% and 67% more efficient as the “grower” scheme.

Droplet deposit density: As observed with the spray cover on the upper leaf surface, also this parameter for both methods showed a decrease as canopy width decreased. Average values for “grower” and “model” in the bed system were $62 \cdot cm^{-2}$ and $70 \cdot cm^{-2}$, in the slender spindle $61 \cdot cm^{-2}$ and $59 \cdot cm^{-2}$, and $51 \cdot cm^{-2}$ and $45 \cdot cm^{-2}$ in the super spindle. When plotted over canopy height, the average values of the four sampling sectors in the bed system showed an almost vertical alignment, while in the slender spindle trees a slight decrease with increasing canopy height was observed which appeared to be more pronounced for “model” than for “grower”. In the super spindle, the values of “model” decreased with increasing canopy height while for “grower” an increase was recorded (figure 3). Separating the average values over canopy height into the 4 canopy sectors, very clearly a higher droplet deposit density has been measured in the upper part of the centre of the bed system for “model” which was not detected in the “grower” scheme. The droplet deposit densities measured on the upper leaf surface also indicate an increase of the efficiency of deposition of “model” compared to “grower” of 27% in the slender spindle and 55% in super spindle orchard, while in the bed system “model” appeared to be 5% less efficient than the application according to the “grower” scheme.

On the lower leaf surface image analysis for both relative coverage and droplet deposit density revealed a strong oversupply of spray liquid of about 2,5 x for „grower“ and 2,0 x for „model“, compared to the upper leaf surface, even without taking into account overlaying deposition on the lower leaf surface (figure 4). From this reason detailed data of the lower leaf surface are not presented.

Discussion:

The spray trials clearly showed that even with a fixed water volume per ha in the „grower“ plots the average spray deposit is decreasing as canopy width decreases. This decrease may be caused by the slight increase of forward speed in the “grower” plots because the relative reduction of the spray deposit complied with the relative increase of forward speed from the bed system to the super spindle. Since this reduction of the average spray cover per cm^2 is stronger in the “model” plots compared to “grower”, canopy related dosing models may not produce a constant average spray deposit per cm^2.

Plotting spray deposits over canopy height discloses a very uneven distribution of the spray deposits with a strong increase as sampling height and canopy width increase. As the results show, a great percentage of the spray mist has been deposited at the upper part of the canopy while values at the bottom of the canopy did not vary much between the

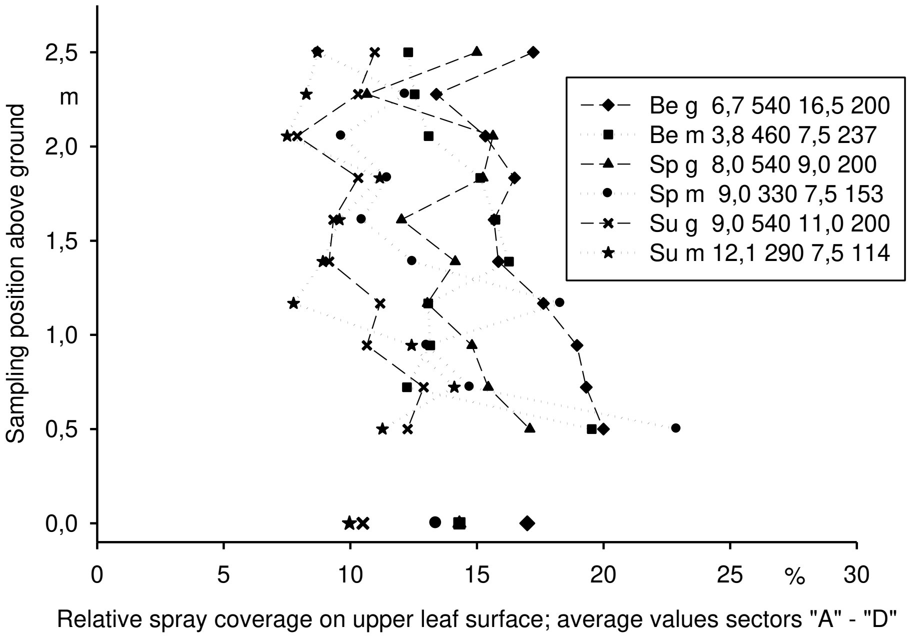

Figure 2: Relative coverage over canopy height calculated as average values of the 4 sampling sectors and average values of all individual data (n = 120) plotted at sampling position 0,0 m

three canopy structures and both dosing and application methods. Consequently a judgement of the spray cover by average spray deposits appears to be very questionable since it does not take into account an uneven distribution over canopy height and width.

However the analysis of the spray deposits of the canopy surface and the centre showed gradients from the surface to the centre which were lower for “model” than for “grower” in the spindle and super spindle trees, indicating a better deposition of spray mist inside the canopy with a canopy adapted fan power even at a high forward speed. In the bed system with a high canopy width, “model” resulted in a higher gradient but produced a higher absolute spray deposit in the canopy centre than did “grower”, indicating an improvement of spray deposition also in broad canopies. In this respect a slower forward speed at canopy adapted fan power seems to be more suitable than a high fan power at a higher forward speed.

But even a more detailed analysis of spray deposits appears to be inappropriate for judging the application of pesticides in fruit trees since it ignores an uneven distribution on the leaf surface over the canopy structure. This becomes very obvious when analysing spray coverage separately on the upper and lower leaf surface. These data clearly proved that even with the almost horizontal air stream of the tower sprayer the average coverage on the lower leaf surface over all canopy systems and methods was 2,3 x higher than on the upper surface. Since coverage mirrors mass distribution to a certain extent, it may be concluded, that also spray deposit is much higher on the lower leaf surface than on the upper one, but also much higher at the top of the canopy than at the bottom, decreasing as canopy width decreases.

Since coverage on the upper leaf surface in the three canopy structures did not vary remarkably between “grower” and “model”, an improved deposition from adapting forward speed and fan power to canopy width by the dosing model compensated a 24% reduction in spray volume·ha^{-1} in the slender spindle and a 43% reduction in the super spindle,

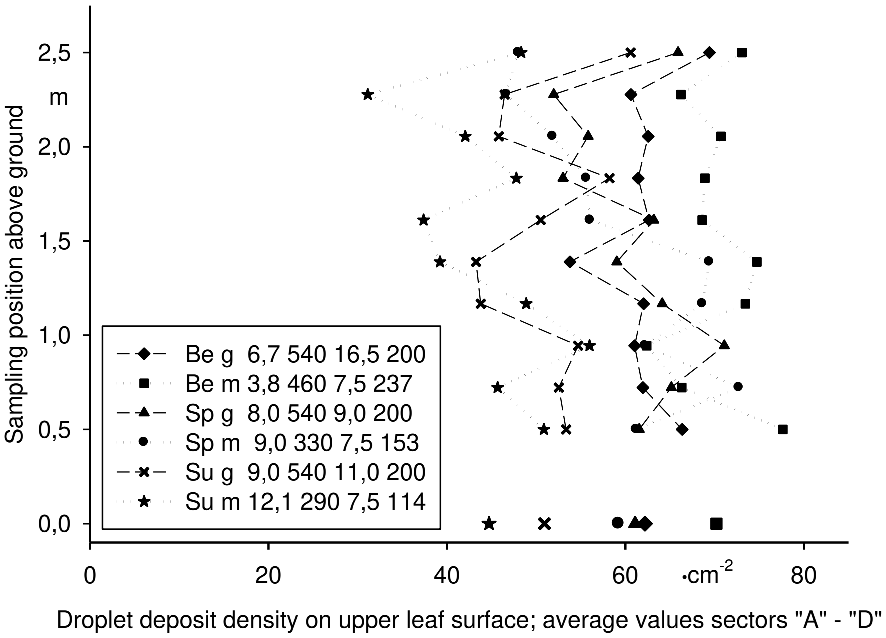

Figure 3: Droplet deposit density over canopy height calculated as average values of the 4 sampling sectors and average values of all individual data (n = 120) plotted at sampling position 0,0 m

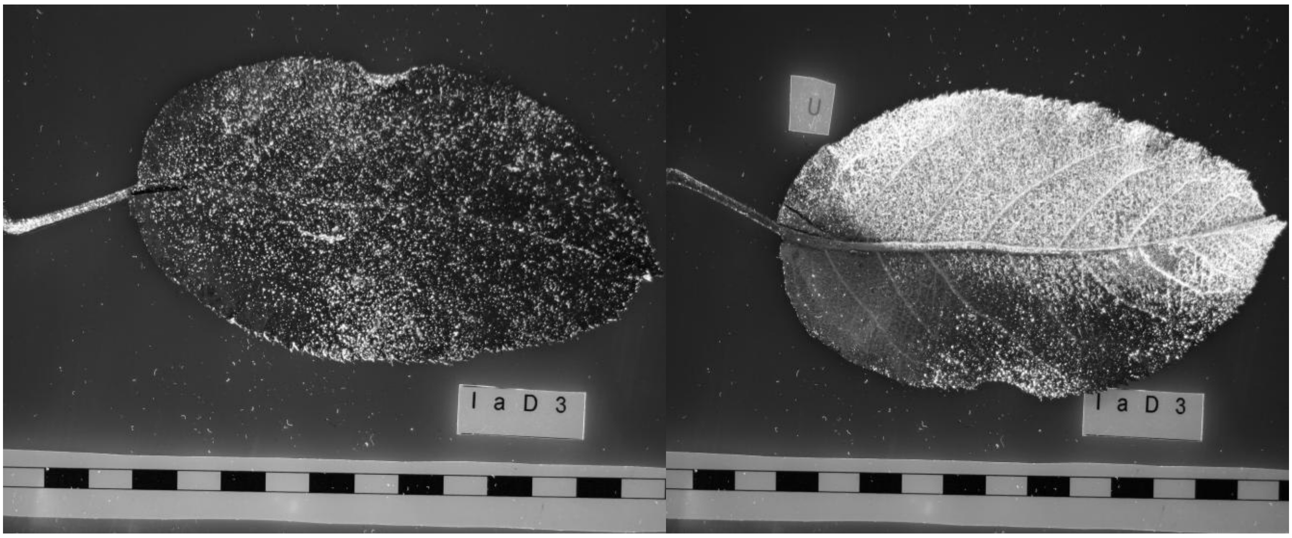

Figure 4: Differently covered leaf surfaces of the same leaf (left = upper surface; right = lower surface). On the lower leaf surface an uncovered spot (risk area) is visible (Photos: Triloff, 2007).

compared to “grower”. These results clearly show that the deposition efficiency increased as canopy width decreased and forward speed and fan power were adapted to the canopy. In the bed system “model” resulted in a 16% reduction of the coverage compared to “grower” on the upper leaf surface, but absolute values were still as high as recorded in the slender spindle from both methods.

Comparing coverage on the upper leaf surface of the canopy surface with the canopy centre, the average ratios over canopy height generally have been rather low with slightly lower values for “model” in the bed system and the slender spindle and a slightly higher value in the super spindle, indicating that canopy related dosing and spray application does not lead to a reduction of the coverage in the canopy centre.

But also coverage on its own does not allow a sufficient judgement of spray deposits since it does not supply any information about the distribution of the spray droplets over the individual leaf surface. This aspect is especially important, since the coverage measured is far below covering the entire leaf surface and therefore at least protective fungicides require a redistribution by natural rain to cover the primarily uncovered leaf area by this secondary fungicide liquid. This is required to kill e.g. spores of apple scab that accidentally may have landed in the gaps between spray deposits, germinate and infect if the distance between individual droplets is too large in order to redistribution cover these gaps. Therefore it is necessary to introduce droplet deposit density as a further means in order to judge the quality of a spray deposit.

Not only the constant water volumes per ha as applied by the “grower“ scheme, but also the canopy related dosing and application model led to a decrease of average droplet deposit density on both upper and lower leaf surfaces as canopy width decreased. However on the upper leaf surface this decrease was more pronounced for “model” being caused by a higher value in the bed system and a lower value in the super spindle compared to the “grower” scheme. Resolved over canopy height, also droplet deposit density showed a slight decrease with increasing sampling position and decreasing canopy width, which was observed in both methods of dosing and application. Focussing on the values in the centre of the bed system, “model” yielded a clearly higher droplet deposit density on the upper leaf surface in the upper part of this canopy - even despite a reduced fan power - than did “grower”. This indicates that a low forward speed leads to an improved air stream into the centre of broad canopies carrying more droplets to this canopy sector than higher forward speed can do, even at nominal fan power. These observations are confirmed by data presented by (Walklate *et al.,* 1996; van de Zande *et al.,* 2002). Such an improved spray deposition in the canopy centre through canopy adapted forward speed and fan power has also been observed in the slender spindle and the super spindle.

From these trials may be concluded, that, when using tower sprayers for spray application with an almost horizontal air stream, the adaptation of forward speed and fan power to the

Table 2: Average changes of efficiency of spray deposition of „model“ compared to „grower“ for three canopy structures

	3-row Bed	Spindle	Superspindle
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%

canopy width improves deposition efficiency (table 3) which compensates the reduction of water volume and pesticide dose rate from the canopy related dosing model completely at a forward speed of 9 $km \cdot h^{-1}$ and to a very high extent at 12 $km \cdot h^{-1}$.

Therefore a canopy related dosing and spray application may significantly reduce time consumption for pesticide application through less fillings and related travelling, and less time consumption for spraying through higher forward speeds in slim canopies. Both savings allow better usage of meteorological conditions favourable for spray application. Additionally the reduction of fan power significantly reduces noise, fuel consumption and spray drift thus also resulting in environmental benefits, but is applicable just with small droplets since they do not require much energy to keep them in the air and control direction and reach. Apart from these reductions the canopy related dosing model in practice leads to product savings ranging from 10 - 40% on a farm level.

The remarkable increase of deposition efficiency obtained by adapting the application process to the canopy may be specially utilized for a further reduction of the general consumption of copper based fungicides, reducing their negative impact additionally to the reductions obtained from the new formulations. Generally the method is applicable for any pesticide without reducing deposition on the upper leaf surface over a wide range of forward speeds and canopy structures. The reduction of deposition efficiency obtained on the lower leaf surface is welcome since it outlines a reduction of the overdeposition caused by excessive fan power. Since this disproportion between upper an lower leaf surface is even worse with plain axial fans because of the steep angle of their air stream, fan types with cross flow characteristics should be preferred whenever possible. To guarantee a uniform air distribution over canopy height at reduced fan speeds, it is strongly advised to test the fans on air distribution test benches before applying canopy adapted spray application to avoid problems caused by a potentially poor reach of the air stream at certain sections of the air outlets.

References:

Cross J. V., Walklate P. J., Murray R. A., Richardson G. M., (2003): Spray Deposits and Losses in Different Sized Apple Trees from an Axial Fan Orchard Sprayer: 3. Effects of Air Volumetric Flow Rates. Crop Protection, 22: 381 - 394

Derksen, R. C., Gray, R. L., (1995): Deposition and Air Speed Patterns of Air-Carrier Apple Orchard Sprayers. Transactions of the ASAE, 38(1): 5 - 11

Ganzelmeier H., Schmidt K., (2003): A German Approach on How to Measure Spray Distribution in Orchards/Vineyards. VIIth Workshop on Spray Application Techniques in Fruit Growing, Cuneo, Italy, 347 - 357

Landers A., Farooq M., (2004): Factors Influencing Air and Pesticide Penetration into Grapevine Canopies. Aspects of Applied Biology, International Advances in Pesticide Application, 71: 343 - 348

Pergher G., (2005): Improving Vineyard Sprayer Calibration - Air Flow Rate and Forward Speed: Annual Review of Agricultural Engineering: Proceedings of International Conference on Environmentally Friendly Spray Application Techniques, Warsaw, Poland, 4(1) 197 - 204

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: 205 - 216

Pergher G., Lacovig A. (2005): Further studies on the effects of air flow rate and forward speed on spray deposition in vineyards. Proceedings of the VIIIth Workshop on Spray Application Techniques in Fruit Growing,. Barcelona, Spain, 85 - 92

Pezzi F., Rondelli V., (2000): The Performance of an Air-Assisted Sprayer Operating in Vines. Journal of Agricultural Engineering Research, 76(4): 331 - 340

Randall J. M., (1971): The Relationship Between Air Volume and Pressure on Spray Distribution in Fruit Trees. Journal of agricultural Engineering Research, 16: 1 - 31

Richardson G. M., Walklate, P. J., Cross J. V., Murray R. A., (2000): Field Performance Measurements of Axial Fan Orchard Sprayers. In: Pesticide Application, Cross J. V., Glass C. R., Taylor W. A., Walklate P. J., Western N. M. (eds). Wellesbourne, Warwick, UK, Aspects of Applied Biology, 57: 321 - 327

Schmidt K., Koch H., (1995): Einstellung von Sprühgeräten und Verteilung von Pflanzenschutzmittelbelägen in Obstanlagen. Nachrichtenbl. Deut. Pflanzenschutzd., 47 (7); 161 - 167

Triloff P., (2005): An Extended Tree Row Volume Dosing Model: Adjusting Pesticide Dose Rate, Water Volume Rate and Air Volume Rate by Forward Speed. Annual Review of Agricultural Engineering: Proceedings of "International Conference on Environmentally Friendly Spray Application Techniques", Warsaw, Poland, 4(1) 69 - 80

Triloff P., (2011): Verlustreduzierter Pflanzenschutz im Baumobstbau – Abdriftminimierung und Effizienzsteigerung durch baumformabhängige Dosierung und optimierte Luftführung. Dissertation, Institut für Agrartechnik, Universität Hohenheim, Stuttgart, 2011, 351 p

Van de Zande J. C., Barendregt A., Michielsen J. M. G. P., Stalinga H., (2002): Effect of Sprayer settings on Spray Distribution and Drift Potential When Spraying Dwarf Apple Trees. ASAE Annual International Meeting / CIGR XVth World Congress, Paper No. 021036, 10 p

Walklate P. J., Weiner K.-L., Parkin C. S., (1996): Analysis of and Experimental Measurements Made on a Moving Air-Assisted Sprayer with Two-Dimensional Air-Jets Penetrating a Uniform Crop Canopy. Journal of Agricultural Engineering Research, 63, 365 - 378

Whitney J., Salyani M., (1991): Deposition Characteristics of Two Air-Carrier Sprayers in Citrus Trees. Transactions of the ASAE, 34(1): 15 - 17