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Basic research into different parameters influencing the quality of vertical distribution by crop sprayers

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In practice, optimum adjustment of sprayers requires knowledge of the interaction between a whole series of different parameters influencing application success. In the basic research reported here, the technical parameters pressure, distance to target surface, nozzle-to-nozzle distance, nozzle design and blower-boosted application versus application without air blower are tested for their influence on vertical distribution. Used for this purpose was a multifactorial measurement program with a vertical distribution test stand. This set-up allowed all five parameters to be varied. The distributions thus achieved were subsequently assessed through coefficients of variation. In conclusion, the extent to which variations of a single parameter influenced the distribution was analysed. The results show that all observed parameters influence vertical distribution, although the extent of influence differs. The high standard deviation at times observed in the results suggests that the applied parameters also influenced one another. However, these influences are not quantified in this study. The result of the qualitative analysis is that type of spray nozzle has the greatest influence while other important influences on spray distribution are distance to target surface and nozzle-to-nozzle spacing. Lesser influence comes from spray application pressure and blower-boosted application: the latter probably due to the type of blower fan (tangential blower) used in the investigation.

Keywords
Crop sprayer, vertical distribution, espalier crop, distribution quality, nozzles, distance from target surface, spray pressure, coefficient of variation

For application of crop protection sprays on espalier crops the technical challenges in achieving a uniform distribution of spray liquid on the target surface are much higher than with field crops. There are numerous reasons for this. As a rule, applications on field crops involve a uniform distance from spray nozzles to target surface, while distance between nozzles and target surface in espalier crops can fluctuate substantially during application. In espalier crops, transport of the spray droplets is usually helped with a blower system. This technique tends to be the exception with field crops. Additionally, gravity tends to help spray droplet application with field crops. In addition, espalier crop sprayer adjustments that have to be taken account of for successful application are much more complex than with field sprayers because espalier crops have many more characteristics to adjust for.

All these identified differences were the reason for conducting an experimental investigation on a vertical distribution test stand aimed at clarifying whether different parameters affected vertical distribution of crop sprayers and, if so, the extent of the various influences. The aim of the research is to generate more basic knowledge on specific influences of various technical parameters on sprayer

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performance, so that this knowledge can then be considered in the medium term during further development of crop sprayer technology and in the future preparation of recommendations for optimum adjustment of such implements. The following study presents first results of trial evaluations, from which some trends can already be recognized.

An investigation to analyse the vertical distribution of crop sprayers in relationship to target surface distance has already been conducted by Dekeyser et al. (2012) in order to develop a simulation model for spraying. The results of this investigation showed that the distribution of liquid depends on the air distribution at the sprayer. Additionally, the type of air distribution strongly depends on the design of the blower fan applied. This statement is supported by investigations by Vereecke et al. (2000) that studied the influence of different blower types on the quality of vertical distribution. The volumetric distribution in relation to target surface distance for different nozzle types was measured for field crop sprayers in a lateral distribution test stand in an investigation by Bauer and Raetano (2004). The results show that the lateral distribution with variation of target surface distance is less influenced if the distance between the nozzles on the boom is reduced. In the work by Womac et al. (2004), the influence of different types of nozzles with various spray fan angles on droplet distribution onto target surfaces during band spraying was investigated. Trial results showed that the applied flat fan nozzles gave a better deposit formation compared with hollow cone nozzles. The distribution characteristics of a single nozzle with blower supported spray application was investigated by Koch et al. (1998). The aim of this work was creation of a tool to support development engineers in the simulation of the effects on distribution characteristics when altering distance between nozzles on the nozzle holder. The result of this investigation is that the observed vertical distributions are characteristic for each of the tested nozzle types. Thus, from the distribution function of the single nozzle, the distribution function of the nozzle group under variation of the distance between the nozzles can be simulated. A further investigation by Debaer und Jaeken (2006) concerned the question of how a mix of different nozzle types influences the vertical distribution of sprayers. The authors felt, however, that the recorded results offered no clear answer.

Materials and methods

Based on the above-mentioned preparation work as well as on own reflections, the following parameters were selected for investigating the influences on vertical distribution quality:

- Distance from target surfaces: 20 cm, 30 cm, 40 cm und 50 cm
- Nozzle-to-nozzle distance on the nozzle holder: 15 cm, 25 cm and 30 cm
- Spraying pressure: 500,000 Pa and 800,000 Pa
- Application: with and without blower support
- Nozzle type: flat fan nozzle (IDK 90-015 C) and hollow cone nozzle (TXA 80 015)

An experimental construction was realised for this investigation whereby all mentioned parameters could be varied (Figure 1). The structure comprised a vertical distribution test stand (type Herbst VV 3000, resolution: 10 cm), a nozzle holder with steplessly adjustable distances between individual nozzles onto which a tangential blower fan for air assisted application is attached (type Weber QU 14, total height: 1.5 m, air throughput: 9,257 m³/h) (Figure 2), as well as a sprayer with hydraulic pump for water supply and for spray pressure adjustment. To vary the target surface distance, the platform upon which the nozzle holder and tangential blower are mounted, can be moved into different positions in front of the vertical distribution test stand. The coefficient of variation for vertical distribution was used for assessing the quality of the vertical distribution achieved with different parameter combinations. Spraying was with water without any additives. The measurement of vertical distribution for each parameter combination was repeated three times, thus a total of 288 measurements were made. In order to exclude any side effects with blower-assisted application, only the section of the measurement stretch where spraying took place with full blower support was considered. This measurement stretch was 1.4 m (14 measurement sections of 10 cm). To ensure comparability, application

Figure 1: Test set-up comprising vertical distribution test stand, adjustable platform with nozzle holder and tangential blower as well as assessment unit (Photo: H.J. Osteroth)

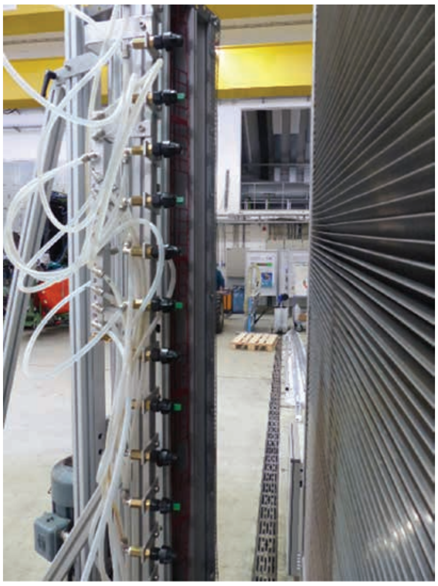

Figure 2: Detail view of the Weber QU14 tangential blower with nozzle holder (Photo: H.J. Osteroth)

without blower support was also tested on the same measurement section. Finally, the coefficient of variation (CV) was applied as measurement of distribution quality. The CVs of the repeats were then determined for every parameter combination. Subsequently, for all tests, the arithmetic mean of the CV in relation to just one of the following parameters was prepared and presented:

- Target surface distance
- Distance nozzle-to-nozzle
- Spray pressure
- Application with and without blower support
- Nozzle design

Results and discussion

Figure 3 shows the CV arithmetic mean for vertical distribution in relation to target surface distance. For geometric reasons we can expect that the CV increases tendencially with reduced target surface distance. This is because the overlapping of the spray fans is increasingly less, and no longer exists at a certain point. On the other hand, should the distance to the target surface and therefore also the overlapping area become tendencially greater, the CV improves. As can be expected for geometric reasons, the CV then tendencially improves to a given value (see CV at 40 cm) and alters after that point only minimally. The reasons for these minimal changes to the CV are then possibly to be found, above all in the parameters that influence the transport of individual droplets (e. g. droplet size, distance to be travelled, influence of gravity, air resistance and, where attributable, blower assistance during application). Furthermore, it is noticeable that the standard deviation for all the calculated CVs are relatively large where the target surface distances are small at 20 or 30 cm. From this, two points can, in principle, be concluded. One: with smaller target surface distances it appears that the influences of the other observed parameters are more strongly apparent. Two: it can be observed that, despite the small target surface distances, all possible parameter combinations managed, on average, to still achieve qualitatively good vertical distributions.

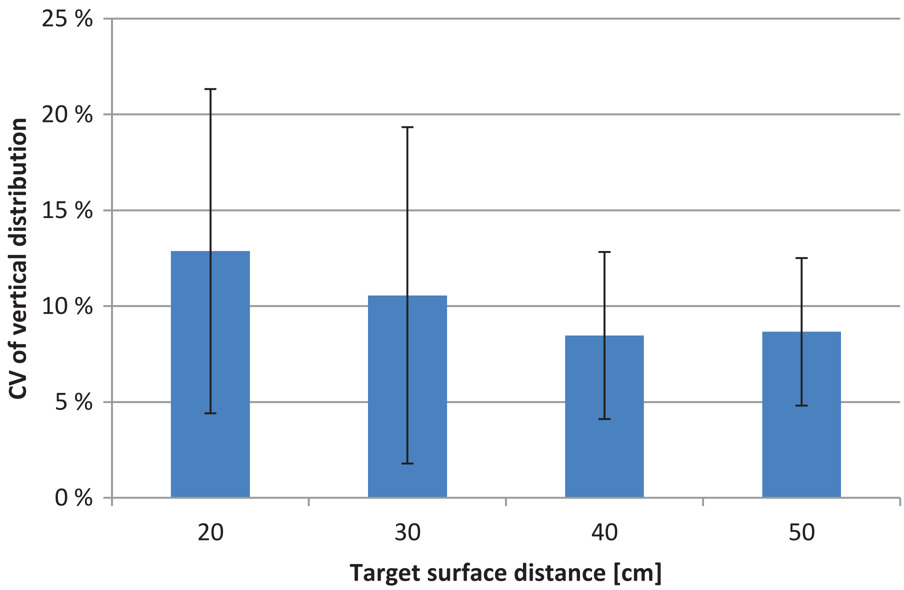

Figure 3: Arithmetic mean values and standard deviation of the coefficient of variation (CV) for the vertical distribution from all parameter combinations in relationship to target surface distance n_{total} = 288)

The changes in the CV of the vertical distribution in relationship to the distance between the individual nozzles is presented in Figure 4. Here too, a clear tendency is shown with the CV arithmetic mean becoming clearly smaller with reductions in the nozzle-to-nozzle distances. This result is also not surprising because if the distance between nozzles becomes smaller spray fan overlapping areas are, from a geometric point of view, larger which in principle positively influence the CV or the quality of the vertical distribution. However, the larger standard deviation with 25 and 30 cm nozzle-to-nozzle distances appear to indicate that, with reducing overlapping of spray fans, the variation of the other parameters could influence the CV increasingly strongly.

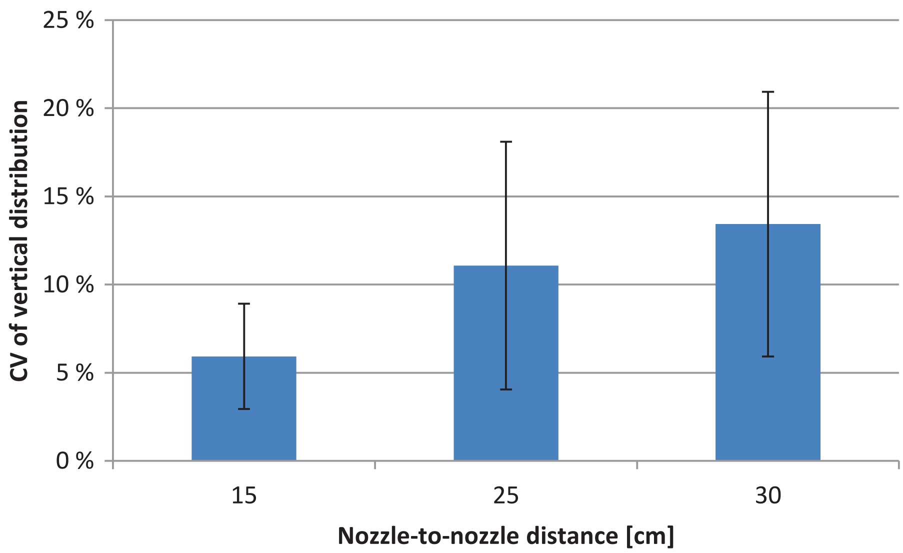

Figure 4: Arithmetic mean and standard deviation of coefficient of variation (CV) for vertical distribution in all trials in relation to distance between nozzles (n_{total} = 288)

The spray pressure also has an influence on the CV arithmetic mean as shown in Figure 5. Tendencially, this reduces with increasing spray pressure. The causes of this reaction are not so easy to interpret in as much as the standard deviation, caused by the various combinations of the other observed parameters, is relatively large in both cases. In principal, the droplet spectrum changes with increasing pressure in the direction of smaller droplets that are more susceptible to drift and more strongly influenced by air streams where application is with blower support. The large standard deviation and the relatively small difference regarding the CV arithmetic mean show, however, that this general tendency tends to be weakly characterised, i. e. does not apply for a whole series of individual cases. This allows the conclusion that the influence of the pressure on the CV is less marked compared to the other investigated parameters.

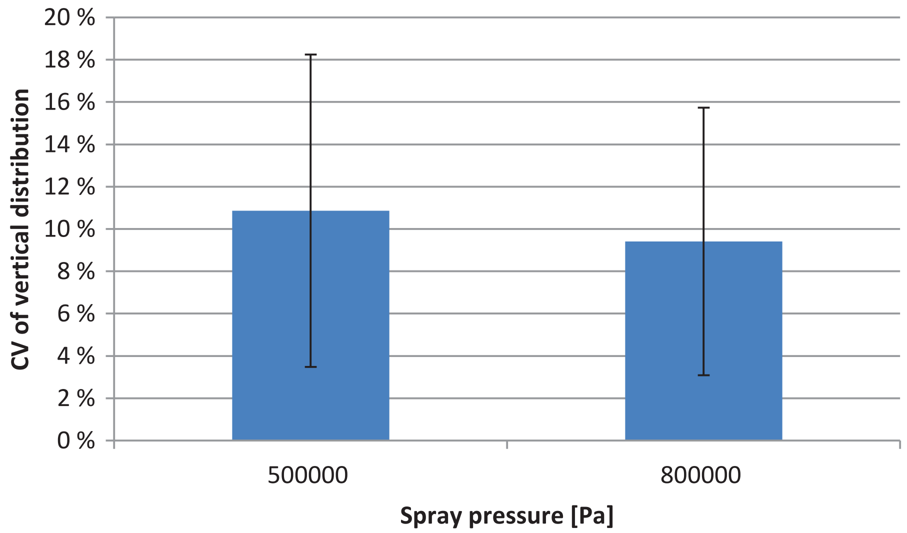

Figure 5: Arithmetic mean and standard deviation of the coefficient of variation (CV) for vertical distribution in all trials with relation to spray pressure (n_{total} = 288)

Figure 6 shows the CV arithmetic mean broken down according to measurements from blower supported application, as well as for application without air support. The difference in the mean value compared with all other observed parameters is smallest here. One reason for this could lie in the fact that the type of blower used (tangential blower) basically produces a comparatively homogenous air stream with regard to air volume as well as flow direction, so that the influence of the blower support with regard to vertical distribution occurs to a relatively limited extent. The large standard deviation is, on the other hand, an indication that other parameters have a more marked influence on the quality of the vertical distribution.

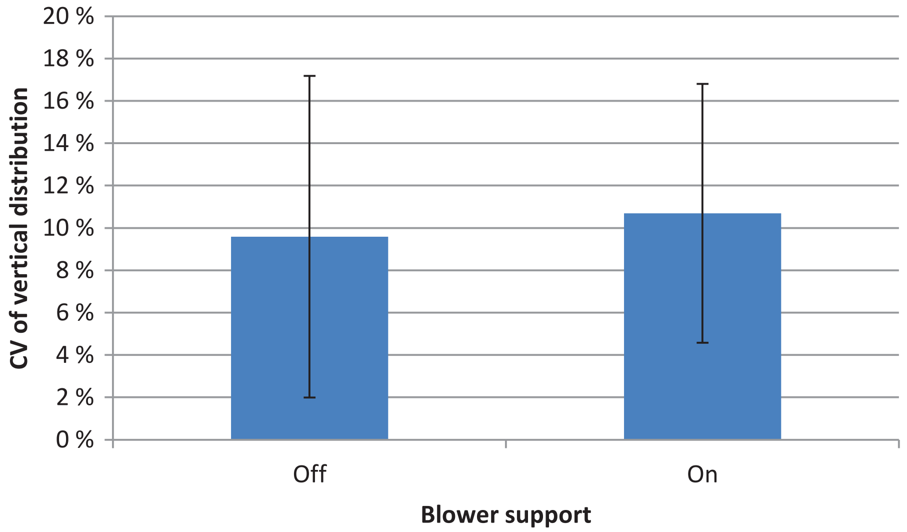

Figure 6: Arithmetic mean and standard deviation of the coefficient of variation (CV) for vertical distribution in all trials with and without blower support (n_{total} = 288)

The clearest difference can be seen when comparing the CV arithmetic mean related to tests with different nozzle types (Figure 7). Clearly seen from the graph is that the CV of the flat fan nozzle IDK 90-015 C with an average 6.2 % is definitely smaller compared with that of the hollow cone nozzle TXA 80-015 with 14.1 %. This result is not really surprising in that, generally, the triangular form distribution characteristic of a single flat fan nozzle is substantially better optimised for performance in the nozzle group compared with the hollow cone pattern. It can also be seen that the standard deviation with the flat fan nozzle is markedly smaller than that of the hollow cone nozzle. It can therefore be concluded that the flat fan nozzle appears to be less susceptible to variation of other observed parameters compared to the hollow cone nozzle.

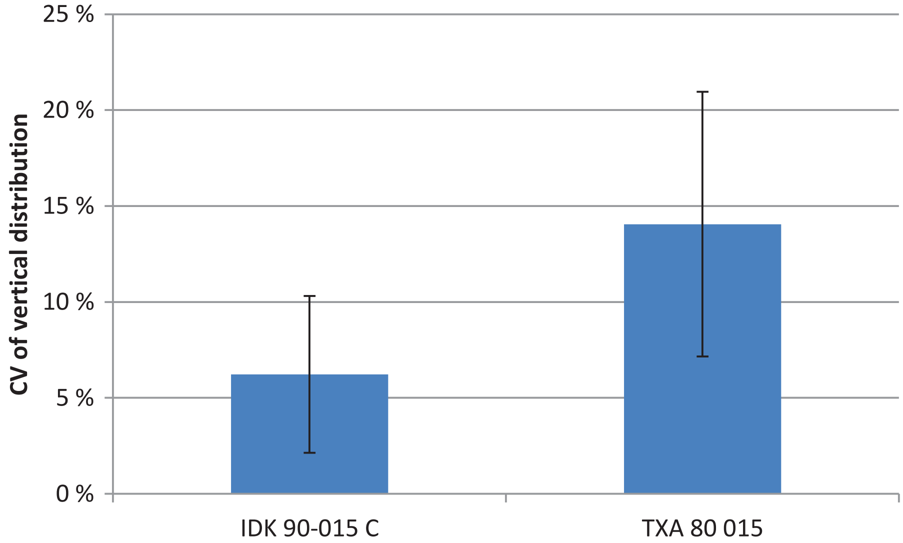

Figure 7: Arithmetic mean and standard deviation of the coefficient of variation (CV) for all trials regarding nozzle type (n_{total} = 288)

The parameters looked at here: pressure, target surface distance, nozzle-to-nozzle distance, nozzle design and blower assisted vs. application without air assistance, appear, based on the results presented here, to all generally have an influence on the quality of the vertical distribution, although the influences appear to vary in strength. Because of the, in part, very large observed standard deviations it can be concluded that the effect of individual parameters overlap, or influence one another, so that different parameter combinations lead to a large band breadth with regard to observed CVs. One example of this is illustrated in Figures 8 and 9. Here, the results are not only differentiated according to target surface distance (see Figure 3) but also according to nozzle type. For instance, if one compares the height of the CV arithmetic mean as well as standard deviation at a target surface distance of 30 cm, there are marked nozzle-specific differences to be seen. In the general observation (Figure 3) the CV with a target surface distance of 30 cm lies at 10.6 % and the standard deviation is comparatively large. If one compares, on the other hand, the nozzle-specific results with a standard target distance of 30 cm, the CV arithmetic mean with IDK 90-015C is, with 4.7 %, markedly smaller than that of TXA 80 015 with 16.5 % CV. The standard deviation of the flat fan nozzle is at 30 cm target surface distance also markedly smaller.

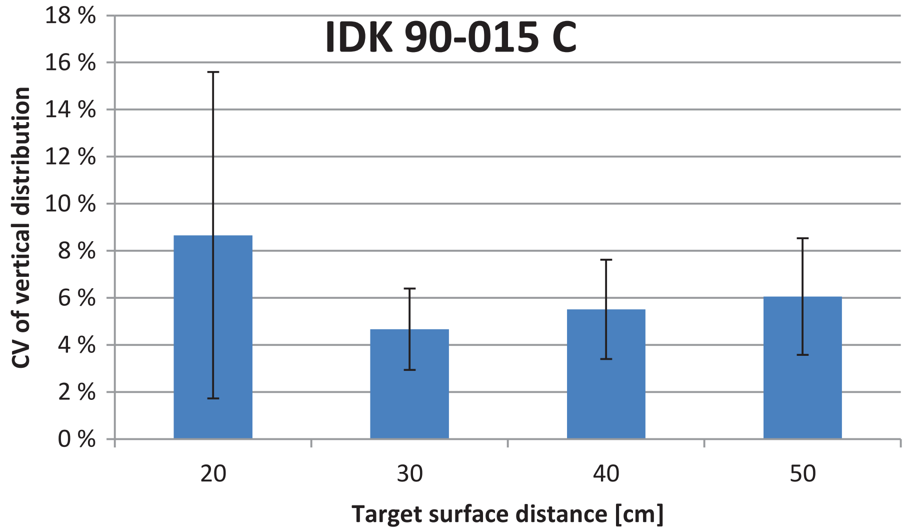

Figure 8: Arithmetic mean and standard deviation of the coefficient of variation (CV) for vertical distribution in all trials with the flat fan nozzle IDK 90-015 C in relation to target surface distance (n_{total} = 144)

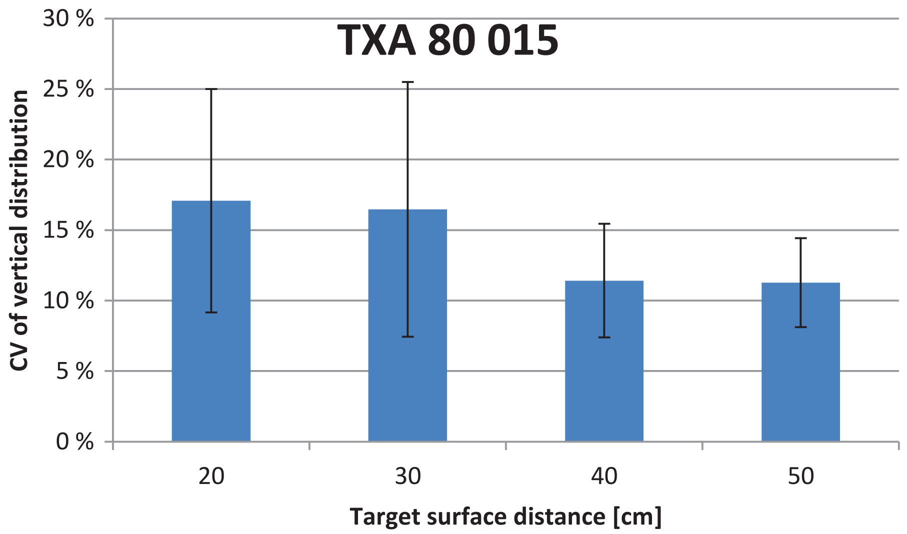

Figure 9: Arithmetic mean and standard deviation of the coefficient of variation (CV) for vertical distribution in all trials with the hollow cone nozzle TXA 80 015 in relation to target surface distance (n_{total} = 144)

The result that the CV arithmetic mean values with the observed hollow cone nozzle (TXA 80 015) are markedly higher than those of the flat fan nozzle (IDK 90-015 C) were, as already mentioned, to be expected because of the individual distribution characteristics of both different types of nozzle. The trial results from our own work also confirm, therefore, the results from Womac et al. (2004). On geometric grounds it is understandable that the target surface distance has a decisive influence on the distribution. Somewhat surprising, however, also with regard to the findings of Dekeyser et al. (2012) and Vereecke et al. (2000), is the result that blower supported application had the least influence on the CV. The same applies to spray pressure, the influence of which appeared to be only marginally greater. Compared to this, the nozzle-to-nozzle distance is among the parameters with a dominant influence on the CV, already shown by the work of Koch et al. (1998). The greater overlapping of the spray nozzle fans with smaller nozzle-to-nozzle distances mean that this is as expected. Figure 10 shows a qualitative presentation of the influence of the investigated parameters on the quality of the vertical distribution based on the CV arithmetic mean.

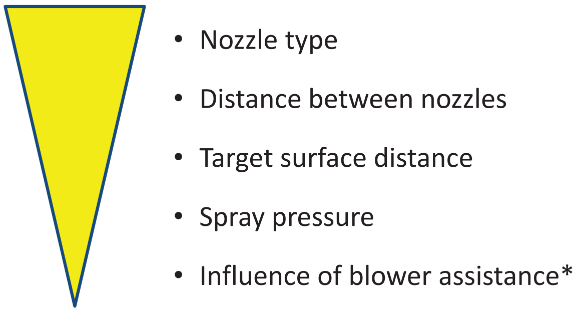

Figure 10: Qualitative presentation of the influence of different parameters on sprayer vertical distribution. * Apply a tangential blower.

Conclusions

From the results presented here, one can conclude that the optimum configuration in practice is given with flat fan nozzles with small nozzle-to-nozzle distances applied with greatest possible distance to target surface at high pressure and with blower assistance from a tangential blower. Naturally, the results presented here cannot be so simply interpreted. First of all, they concern first tendencies which have to be statistically further processed. Additionally, the vertical distribution CV applied here conveys nothing regarding the wetting of the target surface and the quality of the spray deposit cover on the target surface in practice. Here, external parameters also have an influence acting outwith simple observation of the sprayer in isolation, e. g. growth and management form of the crop. Even if the number of the tests presented here including the three repeats still do not offer decisive confirmation, through the results from this pre-trial it can still be assumed that the observed technical parameters all influence distribution. If the interaction of these parameters were better understood, then based on this, the adjustment of the crop sprayer could be further optimized with regard to external parameters. In further steps, suitable statistical analysis of the respective influences of individual parameters on the vertical distribution should help in decisions, and to analyse interactions between parameters. It would also be interesting in future investigations to study more variants of the parameters nozzle-to-nozzle distance and spraying pressure for improved analysis of relationships. Additionally, further possible influencing parameters such as nozzle design (e. g. double flat fan nozzles), nozzle calibre or spray fan angle could be investigated.

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