# Optimizing sprayer boom design for bed-grown crops

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## Summary

For bed-grown crops, ideally the spray is applied evenly to the bed only, while no spray should be applied onto the paths between the beds. Usually these criteria cannot be fulfilled easily. The current study describes the development and use of a model to design adequate set-ups of nozzles on a sprayer boom optimized for bed-grown crops. Spray patterns of various single nozzles at different boom heights have been measured on a patternator. The model combines these spray patterns while varying nozzle types, nozzle spacing and the position and angling of end nozzles. Examples are given for designs using Lechler Varioselect fourfold nozzle bodies to find optimal solutions for beds with widths between 1.1 and 1.5 m and boom heights of 0.2 to 0.6 m above the crop, while being able to apply different dose rates depending on crop canopy height. A large number of potential set-ups are simulated, but only relatively few meet the requirements that can be defined by the user.

**Key words**: Bed sprayer, optimizing distribution, simulation, model, patternator

## Introduction

For arable crops there is sufficient knowledge available to obtain evenly distributed sprays. The evenness of spray distributions can be managed by selecting proper nozzle types, nozzle spacing and sprayer boom height. For bed-grown crops, ideally the spray is applied evenly to the bed only, while no spray should be applied onto the paths between the beds to avoid losses. This is a complicating factor that usually is hard to meet using conventional boom designs. Additionally, at different growth stages the crop may require different spray doses (Zande *et al*., 2008). Spray dose can be changed by adjusting forward speed and/or changing nozzles at the boom.

In this study, a model is developed to help design adequate set-ups of nozzles on a sprayer boom that is optimized for bed-grown crops. For this purpose, the spray patterns of various individual nozzles at different boom heights have been measured on a patternator. The model combines these spray patterns while varying nozzle types, nozzle spacing and the position and angling of end nozzles. The model searches for set-ups that fulfil the requirements for high-quality patterns as defined by the user.

Currently, the model is focussed on the use of Lechler Varioselect fourfold nozzle bodies to find optimal solutions for beds with widths between 1.1 and 1.5 m and boom heights of 0.2 to 0.6 m above the crop (

Fig. **1**), while being able to apply different dose rates depending on crop canopy height. Large numbers of potential set-ups can be tried and assessed quickly. The model can be modified easily to use different nozzle types and boom set-ups, provided that the necessary spray patterns are available. Different user requirements can be implemented as well, e.g. for band spraying or other user-definable spray distributions.

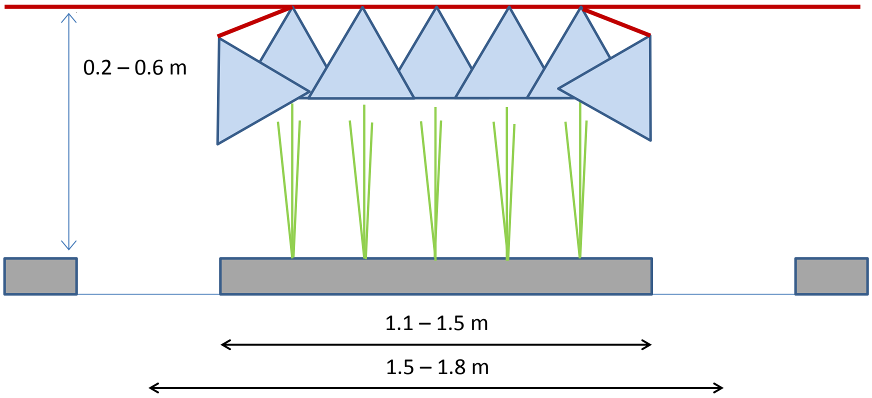


Fig. 1. Schematic set-up of an arrangement of nozzles on a boom sprayer for bed-grown crops showing typical dimensions.

## Materials & Methods

*Nozzles and blocks*

The Lechler varioselect fourfold blocks can be arranged in longitudinal (L) or squared (S) set-up, see
Fig. **2**. Table 1 indicates the nozzles (Spraying Systems) and pressures used, together with the corresponding flow rates and spray cone angles. The relative location of the four positions of each nozzle to the centre of the block was measured.

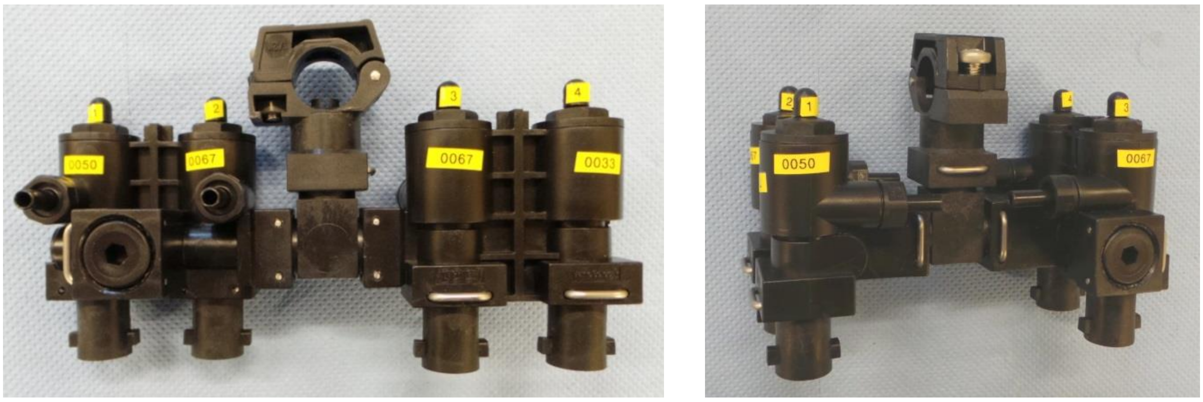

Fig. 2. Lechler varioselect fourfold block. *Left*: longitudinal configuration (L); *right*: square configuration (S). Nozzle positions are numbered (1..4), nozzle sizes are indicated for each position.

Table 1. *Nozzle types and pressures used in this study*

| Nozzle type | Pressure [kPa] | Flow rate [L min$^{-1}$] | Top angle [°] |
|---|---|---|---|
| Teejet 650033 | 300 | 0.13 | 65 |
| Teejet 650050 | 300 | 0.20 | 65 |
| Teejet 650067 | 300 | 0.26 | 65 |

*Patternator measurements*

Spray patterns were measured on a patternator with 25 mm gutters. Nozzle blocks were placed at heights 30, 40 or 50 cm, measured from nozzle outlet to top of the patternator. The side shifts of the four nozzle positions were accounted for. Tilted blocks were placed at heights 25, 35 and 45 cm, measured from the centre of the block to the top of the patternator. In this case not only side shifts had to be accounted for, but also height shifts. Tilt angles of 45º and 32.5º were used; the latter representing half the top angle, in which case one of the spray cone boundaries was directed vertically downward.

With a levelled fourfold nozzle block, 15 combinations of open/closed nozzles can be made. Each nozzle position contributes to eight of such combinations. Thus, in principle, each nozzle contributes to eight spray patterns produced by one to four open nozzles. By appropriate subtraction of different spray patterns, the contribution of nozzles at each single position can be estimated in eight ways. After appropriate side-shifting these eight single-nozzle patterns, the patterns could be averaged and symmetrized. Nozzle patterns may be affected by the presence of neighbouring nozzles; however, the observed differences were small and not accounted for.

The same method can be used for a tilted block, but some difficulties arise. Spray patterns not only need side-shifting, but also require corrections for height differences. Symmetrizing the patterns is not possible since tilted nozzles cannot produce symmetrical patterns. For relatively small differences in nozzle height, the angular spray distributions can be assumed to be the same. This feature can be used to compute the spray pattern at different nozzle heights. Spray patterns of levelled individual nozzles were computed for heights 25 through 55 cm, at 1 cm interval. For tilted nozzles patterns at heights 20 through 50 cm were computed at 1 cm interval.

*Model description*

As the number of possible arrangements of nozzles and blocks is almost infinite, some limitations have been defined to keep some practical control. For convenience, blocks are designated as edge blocks (at both ends of the boom) and central blocks (not being edge blocks). The following limitations are applied:

- Each block at the boom has the same set-up of nozzle types
- Each block has the same nozzles opened or closed
- All blocks are either longitudinal or squared
- Edge blocks at both ends are tilted by the same angle
- Edge blocks are mirrored, thus giving similar patterns in each case
- Edge blocks are turned by 90º in order to have each nozzle position at approximately the same height
- Distance between central blocks is variable but equal for each pair of neighbouring blocks
- Edge blocks are always 5 cm below central blocks
- Edge blocks can be placed further outward, but symmetry is remained

The above criteria may seem too restrictive, yet many thousands of possible arrangements remain. Fig. **3** gives an example of a possible set-up of nozzle blocks.

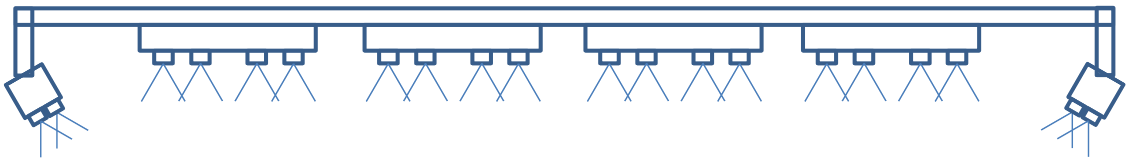

Fig. 3. Example of design of four central L-blocks and two tilted edge blocks (L-type). Edge blocks are turned and have their longitudinal shape in the direction of travel.

Simulations involve varying the following parameters:

- Number of central blocks (5..10)
- Distance between central blocks (20, 22.5, 25 cm)
- Additional distance between edge block and nearest central block (0, 5, 10, 15, 20 cm)
- Block type (L or S), involves all blocks at the boom
- Height of central blocks (25, 30, .., 55 cm); edge blocks are always 5 cm lower than central blocks

- All possible nozzle configurations per block are considered (i.e. all combinations of 3 nozzle types at four positions, open or closed)

With these parameters and the restrictions given above, a total of 321300 different designs can be made.

To assess spray patterns for the bed sprayer, a symmetrical trapezoidal function is fitted to the simulated pattern, using the least squares method (
Fig. **4**). The quality of the pattern is assessed by comparing it to the shape of the fitted trapezium: width of the central plateau ($W_0$), the variance of deposits at the central plateau (i.e. at the top of the bed), width of the sides ($D_0$). For a high-quality pattern $W_0$ is close to the actual bed width, the variance at the plateau is low and $D_0$ is as small as possible. Variance at the plateau is computed for 10 cm gutters ($CV_{10}$) and should be less than 10% in accordance with regulations for field sprayers (ISO16122; SKL, 2017). For an acceptable pattern, it was assumed that deviation of $W_0$ and actual bed width is < 5% and $D_0$ < 20 cm. Additionally, a promising boom design should be flexible in the sense that different dose rates could be used (by merely changing nozzle types or simply just opening or closing nozzles) without losing quality of the pattern.

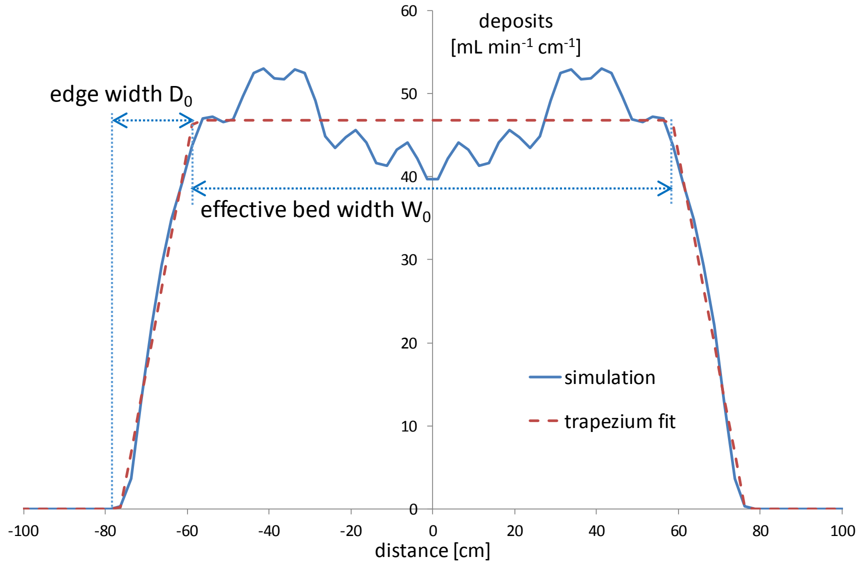


Fig. 4. Example of simulated pattern of spray deposits (solid curve) and a symmetrical trapezium (dashed line) fitted to it.

## Results

*Single nozzle patterns*

Fig. 5a shows examples of spray patterns for a single 650050 nozzle at three heights. Clearly, when nozzle height increases, the pattern becomes wider and the central peak decreases, as expected. Another example, Fig. 5b shows patterns of tilted nozzles (32.5º to the right) at height 25 cm. Note that x=0 represents the horizontal position of the nozzle. The left boundary of the spray cone is vertically downward (
Fig. 6), and indeed almost no spray is depositing for x<0. The point where the cone centre touches the ground is located at $x = h \tan \theta$. For h=25 cm and θ=32.5º, x=15.9 cm. The peaks in Fig. 5b are located close to this value. Note in this figure that the nozzle with the finest spray quality (650033) has the narrowest pattern (or highest peak). This is also observed for levelled nozzles (not shown) and is a common feature of hydraulic energy nozzles.

*Patterns for different boom designs*

Although the number of possible designs is very large, only relatively few designs meet the criteria.

Fig. **7** show the number of designs that meet the above-mentioned quality criteria ($CV_{10}$<10%, $D_0$<20 cm), for different bed widths and number of blocks (both L and S type) at the sprayer boom. Designs with 10 blocks fail to qualify for beds up to 150 cm, but will pass the test for wider beds. The figure shows that seven blocks at the boom is suitable for all bed widths. Considering only the subset with seven blocks (N7),

Fig. **8** shows the separation according to boom height. For 110 cm bed width, boom heights 30 and 35 cm are most suitable. For other bed widths, boom heights between 25 and 35 cm are suitable. Boom heights of 50 and 55 cm fail to qualify, mainly because of the pattern edges becoming too wide.

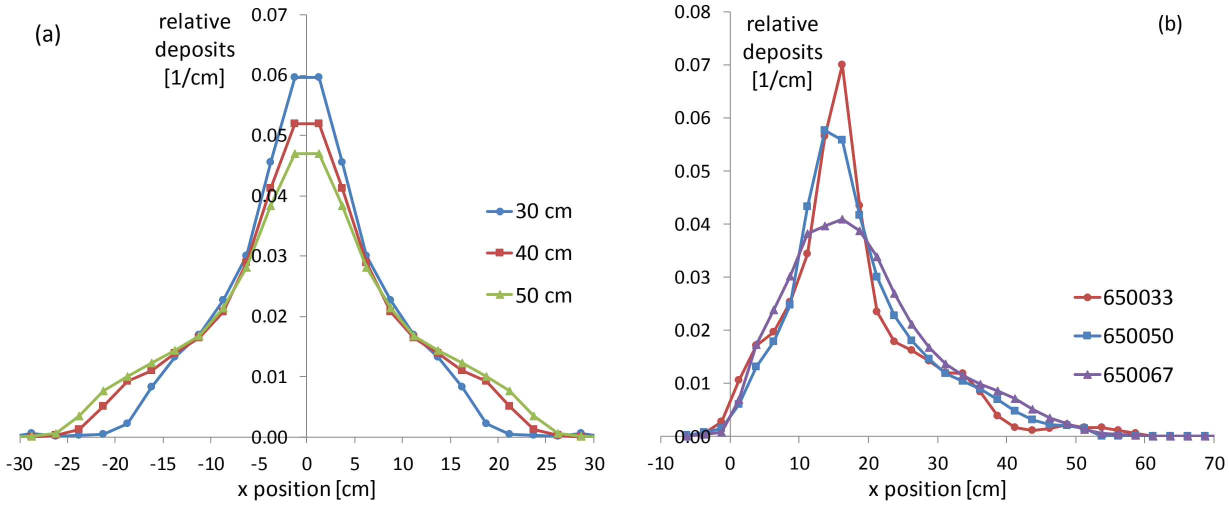


Fig. 5. Spray patterns below a single flat fan nozzle (300 kPa); (a): levelled 650050 nozzle at three heights; (b): tilted nozzle (32.5º) at height 25 cm, three nozzle types.

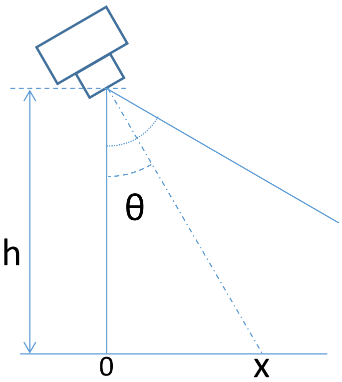


Fig. 6. Spray cone for a nozzle that is tilted half its top angle.

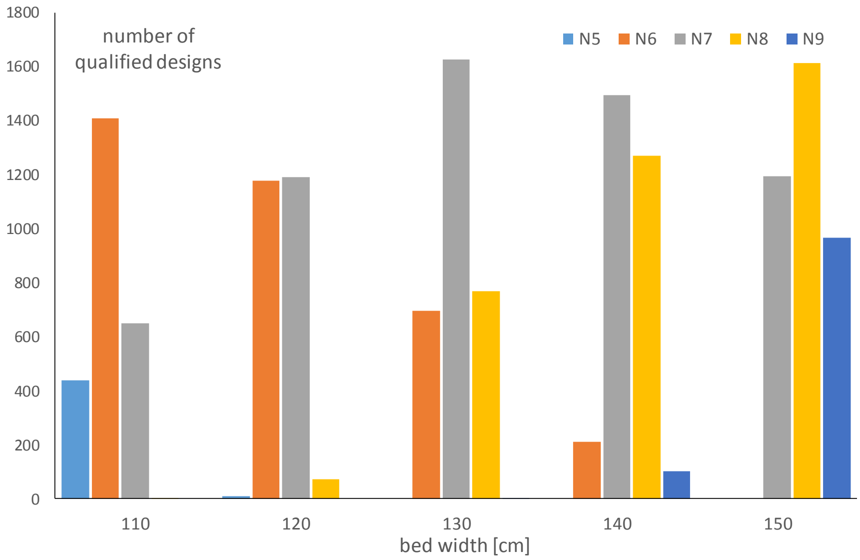


Fig. 7. Number of designs fitting the quality criteria; for bed widths 110 through 150 cm and booms with five through nine blocks (N5..N9).

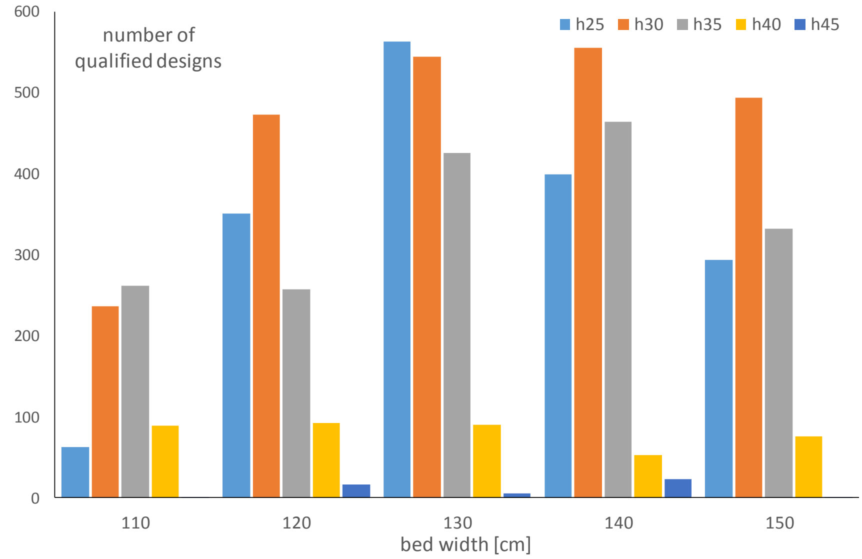


Fig. 8. Number of designs width seven blocks (N7) fitting the quality criteria; for bed widths 110 through 150 cm and boom heights 25 through 45 cm (h25..h45).

For designs with a fixed number of blocks, the optimal block spacing must increase with increasing bed width. Assuming the boom has seven blocks, a block spacing of 20 cm suits beds with widths 110 and 120 cm, a block spacing of 22.5 cm fits beds of 130 and 140 cm wide, and 25 cm spacing fits a 150 cm bed width.

As an example, designs for 120 cm beds will be looked at more closely. Assume a sprayer boom with seven blocks L3, spaced at 20 cm and edge blocks shifted 15 cm additionally.

Fig. **9**a shows effective bed widths from the trapezoidal fit for all possible boom heights and nozzle configurations.

Fig. **9**b shows the corresponding widths of the pattern edges. Clearly, on average an increased boom height leads to smaller bed widths but wider edges, as expected. Considering the edge criterion ($D_0$<20 cm), for these boom designs heights of 25 through 35 cm are most appropriate (
Fig. **9**b). Correspondingly, bed widths of 110 through 130 cm can be met (
Fig. **9**a). Of all possible L3 designs with seven blocks and the given spacings, 241 designs appear to qualify for bed widths of 120 cm.

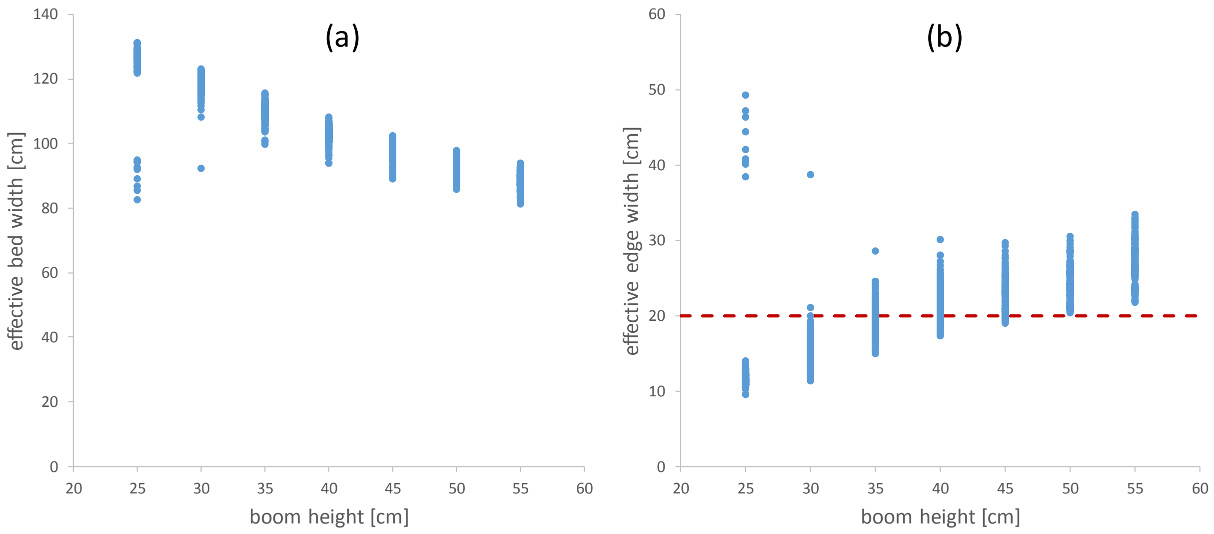


Fig. 9. Designs with seven blocks, type L3, spaced at 20 cm, edge shift 15 cm; all possible heights and nozzle configurations. (a) effective bed width as a function of boom height; (b) effective edge width as function of boom height.

In practice, nozzle configuration will usually be fixed as well, where nozzles can be opened or closed to adjust the dose. For a certain nozzle configuration, each of the four nozzles on a block can be either open or closed. This implies 15 possible combinations, but usually not all of them result in qualified set-ups. In this example with seven L3 blocks and given spacings, at most 11 designs appear to qualify for a few fixed nozzle configurations. One such configuration is '1313' (1: represents 650033 nozzle type, 3: 650067 nozzle type), summarized in Table 2. Relative deposits ranges from 13.8 to 41.2 which covers a range of about 1:3. Acceptable bed widths are within 5% of the intended width. Edge widths are all less than 20 cm; $CV_{10}$ <10%. A closer view at the relative deposits shows that five levels can be distinguished (indicated by letters a..e). These levels are in accordance with the sum of flow rates of the open nozzles. For instance, the second and third nozzle pattern both involve one 650033 and one 650067 nozzle, thus the overall dose must be the same. Note that for two patterns (1310 and 1303) two heights qualify (25 and 30 cm). The results show that by simply opening or closing different nozzles, 5 steps in dose rate can be achieved using the given design. The given range of relative deposits corresponds to average top-of-bed dosages between 115 and 343 L ha$^{-1}$ at 2 m s$^{-1}$ forward speed. It can be shown easily, that for the basic pattern '1313' at most 6 dose rates can be formed, if all open/close patterns would qualify. The patterns corresponding to the designs of Table 2 are shown in Fig. 10.

Table 2. *Qualified designs for bed width 120 cm, L3 blocks (N=7), block spacing 20 cm, edge shift 15 cm, nozzle configuration '1313'; sorted for increasing deposits*

| Nozzle pattern [1] | Boom height | Relative deposits [2] | Effective bed width | Edge width | $CV_{10}$ |
|---|---|---|---|---|---|
| | [cm] | [ml min$^{-1}$ cm$^{-1}$] | [cm] | [cm] | [%] |
| 1010 | 30 | 13.8 a | 117.7 | 16.2 | 6.6 |
| 1003 | 30 | 20.5 b | 117.9 | 17.0 | 8.3 |
| 0310 | 30 | 20.8 b | 117.1 | 15.9 | 7.0 |
| 1310 | 25 | 26.7 c | 125.9 | 12.0 | 9.4 |
| 1013 | 30 | 27.2 c | 119.1 | 16.2 | 8.7 |
| 0303 | 30 | 27.6 c | 116.0 | 17.6 | 5.7 |
| 1310 | 30 | 27.8 c | 116.8 | 15.9 | 7.6 |
| 1303 | 25 | 33.2 d | 125.6 | 12.9 | 5.2 |

| | | | | | |
|---|---|---|---|---|---|
| 0313 | 30 | 34.2 d | 117.9 | 16.4 | 7.5 |
| 1303 | 30 | 34.6 d | 116.0 | 17.2 | 5.8 |
| 1313 | 30 | 41.2 e | 117.5 | 16.4 | 4.0 |

[1] pattern of four nozzles on a block; 0: closed nozzle, 1: 650033 nozzle, 3: 650067 nozzle
[2] equal letters indicate same step in relative deposits.

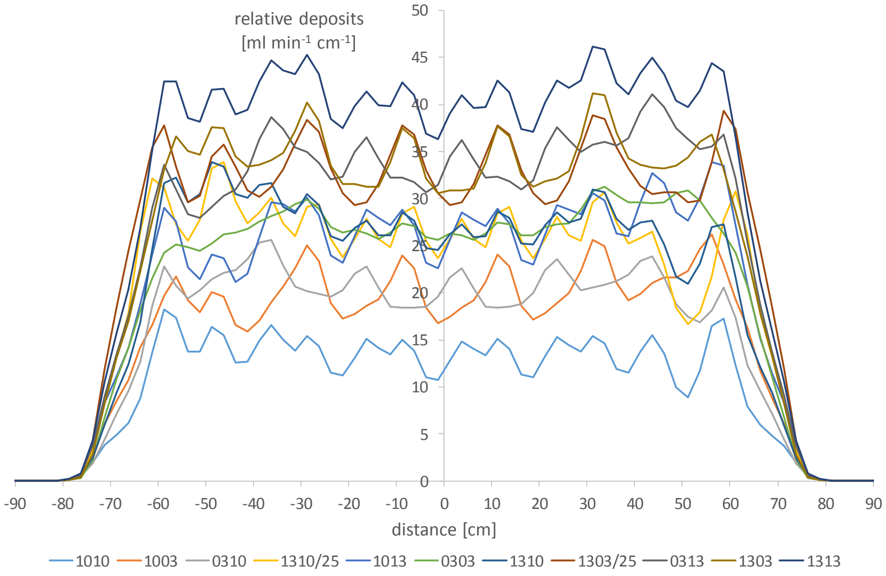


Fig. 10. Deposition patterns for the 11 qualified designs of Table 2.

## Discussion

A model has been developed that can quickly assess spray patterns for different boom designs for bed sprayers. Easy to do patternator measurements were used as input for the model and provided the best option settings in developing optimised variable rate sprayer designs for bed-grown crops. The examples were focussed on specific nozzle blocks, yet in principle boom designs using different block types or single nozzle holders can be studied in the same way.
Although the number of possible designs is extremely large, relatively few meet the user definable criteria concerning bed width, edge width and variance of deposits. Qualified solutions are considered particularly useful when these are flexible regarding the ability to change dose rates by merely changing nozzle types or (remotely) opening or closing them. Examples indicate that flexible solutions appear to be relatively rare, although for each bed width such solutions seem feasible.

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