The aim of this study was to test the application accuracy of commercially available hydraulic nozzles for the purpose of applying herbicides to decimetre sized cells. Based on various technical performance tests, 3 nozzles were selected for further biological efficacy tests. From the technical tests, nozzle output and nozzle height to achieve a 100-mm-wide spray swath were determined. In biological tests, efficacy and application accuracy controlling Matricaria perforata at the cotyledon stage with glyphosate in 100 mm/C2100 mm/C2 cells were tested. Efficacy was measured inside the square, in the border zone and just outside the square. The study showed that with commercially available nozzles, it is possible to apply a herbicide to a 100 mm/C2100 mm/C2 cell at an application speed of 1/C21 e/C21 ms/C21 with a high precision and with only a limited proportion of the spray being lost outside the intended target area. The biological efficacy obtained in the central part of the cell was slightly reduced compared to a broadcast application. A tracer study revealed that this could be explained by a reduced nozzle output compared to the measured output in the technical test. The reduction was probably caused by a much shorter nozzle operating time during application to the cell. The valves used in this study therefore should be replaced with faster acting valves.

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In order to achieve an effective control of weeds, herbicide application is carried out at very early stages of weed growth (Rydahl, 2004) when weed coverage is typically below 5%. As crop coverage is also limited at this growth stage, by far the largest proportion of the applied herbicide is deposited on the soil surface (Jensen & Spliid, 2003a, 2003b) where the deposits constitute a potential risk for leaching to the groundwater (Carter, 1999) and surface run-off (Paetzold, Klein, & Bruemmer, 2007). The combination of a limited coverage and an uneven distribution and species composition makes the use of broadcast applications a very inefficient and wasteful method, especially in the case of foliar-acting herbicides. For environmental as well as for economic reasons more efficient herbicide application methods are desirable. However, many challenges are involved in developing a system for spatial variable weed control. Different approaches towards applying herbicides in variable doses based on the actual weed species composition and density have been developed and have recently been reviewed by Christensen et al. (2009). These range from patch spraying with standard broadcast techniques (Gerhards & Oebel, 2006; Paice, Miller, & Bodle, 1995), patch spraying of decimetre sized cells with specially adapted application techniques (Lee, Slaughter, & Giles, 1999; Lund, Jensen, & Olsen, 2008) to the ultimate concept of individual plant treatment (Søgaard & Lund, 2007). Such systems depend on a combination of a weed sensing system, a weed management model and a precision spray application method. Generally, research has focussed on weed sensing and management whereas application technique has received limited attention. In the few studies investigating the precision application of herbicides at a high resolution, validation has been carried out by measuring the distance of the applied spray droplets to the target (Lee et al., 1999; Nieuwenhuizen, Hofstee, & van Henten, 2010; Søgaard & Lund, 2007). Only Nieuwenhuizen (2009) appears to have used biological efficacy testing as a method to validate the application accuracy of a precision spray application system. The aim of the study described in this paper was to test the application accuracy of commercially available hydraulic nozzles for the purpose of applying herbicides to decimetre sized cells. During the study nozzles and valves were selected from technical tests, and subsequently tests were carried out measuring biological efficacy with the system compared with conventional broadcast application. The study was part of a larger project aiming at reducing the herbicide consumption by 50% while maintaining the biological efficacy. The approach was to subdivide the field into small cells, use a vision system to evaluate the weed density in these cells and apply a herbicide in the cells where the density was above a certain level (Lund et al., 2008).

2. Materials and methods

In the period 2006–2008, commercially available valves and nozzles were tested for their potential to applying herbicides to cells with a size of 100 mm × 100 mm. The spray characteristics and the spray distribution of these nozzles were measured and their biological efficacy was evaluated under semi-field conditions.

2.1. Valves

In order to apply pesticides to small cells at a driving speed of approximately 2 m s⁻¹, it is necessary to use valves with a rapid response time. Different types of small solenoid Teflon® valves (Omnifit) from BioChem Valve Inc. (Boonton, NJ, USA) were chosen. The technical specifications of the valves are given in Table 1. The valves used are 2-way, normally closed, fully isolated solenoid valves operating at maximum pressures from 138 to 207 kPa depending on the type of valve.

The opening time of the solenoids ranged from 10 to 15 ms, which corresponds with a travel distance of 20–30 mm at a forward speed of 2 m s⁻¹. The closing time for all solenoids was 5 ms.

Table 1 – Technical specifications for Bio-Chem 12 v magnetic valves.

<table>
<thead>
<tr>
<th>Valve type</th>
<th>Valve orifice diameter (mm)</th>
<th>Internal volume (µl)</th>
<th>Max pressure (kPa)</th>
<th>Power (W)</th>
<th>Opening time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM07ST254</td>
<td>0.8</td>
<td>39</td>
<td>207</td>
<td>2.8</td>
<td>15</td>
</tr>
<tr>
<td>OM07STZNC</td>
<td>1.4</td>
<td>39</td>
<td>138</td>
<td>2.8</td>
<td>15</td>
</tr>
<tr>
<td>1254</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM03ST2NC</td>
<td>1.4</td>
<td>42</td>
<td>138</td>
<td>1.8</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2 – Characteristics of reference nozzle and nozzles tested for cell application.

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Spray angle (°)</th>
<th>Nominal flow rate (l min⁻¹ at 309 kPa)</th>
<th>BCPC classification</th>
<th>VMD (µm)</th>
<th>Mean droplet velocity (m s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardi® LD 110015</td>
<td>110</td>
<td>0.61</td>
<td>Fine</td>
<td>181</td>
<td>2.1</td>
</tr>
<tr>
<td>Teejet® TP4001E®</td>
<td>40</td>
<td>0.39</td>
<td>Fine</td>
<td>173</td>
<td>4.0</td>
</tr>
<tr>
<td>Teejet® TP6501E®</td>
<td>65</td>
<td>0.39</td>
<td>Fine</td>
<td>156</td>
<td>3.1</td>
</tr>
<tr>
<td>Teejet® 650067®</td>
<td>65</td>
<td>0.28</td>
<td>Fine</td>
<td>146</td>
<td>2.7</td>
</tr>
</tbody>
</table>

a Hardi International A/S, Taastrup, Denmark.

b Teejet Technologies, Wheaton, U.S.

c VMD, volume median diameter, is the droplet diameter below which smaller droplets constitute 50% of the total volume.

d Reference broadcast spray application.

e Cell spray application.
2.2. Nozzles

Various commercially available nozzles with small spray angles were tested initially. However for the final testing three nozzles with a narrow angle were selected for the cell applications, two even flat-fan nozzles (TeeJet TP4001E and TeeJet TP6501E) and a standard flat-fan nozzle (TeeJet 650067). The nozzles were manufactured by Spraying Systems Inc., Wheaton, IL, USA. The Hardi LD 110015 pre-orifice nozzle (Hardi International A/S, Taastrup, Denmark) was included as reference nozzle in the experiments and this nozzle type was typically used for broadcast spray application. Some important characteristics of the chosen nozzles are given in Table 2. The nozzles were tested at 300 kPa for comparison reasons.

Droplet size and one-dimensional vertical droplet velocity characteristics of the different nozzle pressure combinations (Table 2) were measured using an Aerometrics Phase Doppler Particle Analyzer (TSI, Minneapolis, MN, USA) at a distance of 0.30 m below the nozzle using a rectangular scan trajectory with a distance of 0.01 m between the scan lines. The measurement set-up and protocol were described in detail by Nuyttens, Baetens, De Schampheleire, and Sonck (2007) and Nuyttens, De Schampheleire, Verboven, Brusselman, and Dekeyser (2009). The volume median diameter (VMD), the mean droplet velocity and the British Crop Protection Council (BCPC) classification are presented in Table 2. This classification is based on the comparison of the droplet size spectrum produced by the nozzle pressure combinations with the BCPC reference nozzle pressure combinations as defined by Southcombe et al. (1997) and measured by Nuyttens et al. (2007). Similar droplet size characteristics were produced by the different nozzle pressure combinations, which were all classified as ‘fine’.

2.3. Static spray distribution

The spray distribution from the single nozzles was measured using a spray patternator with a number of 10-mm-wide channels placed perpendicularly below the spray plume of the nozzles. The test rig was constructed according to the guidelines in ISO 5682-1 (1996). The spray distribution was tested at pressures 140 kPa and 180 kPa and at a height of 340 mm for the TeeJet TP4001E, TeeJet TP6501E and the TeeJet 650067.

2.4. Dynamic spray distribution

The nozzles were mounted in the test rig and the test was conducted at a speed of 0.5 m s\(^{-1}\) corresponding to a low driving speed. The spray pressures tested were 140 and 180 kPa. The spray was collected on white plastic plates to visualize the actually obtained cell sizes. By varying the nozzle output, speed, and height, different spray distributions were obtained.

Table 3 – Details of nozzle choice, height, speed, valve and application method in biological efficacy tests.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Nozzle</th>
<th>Nozzle output (l min(^{-1}))</th>
<th>Speed (m s(^{-1}))</th>
<th>Nozzle height (cm)</th>
<th>Method</th>
<th>Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TeeJet TP4001E</td>
<td>0.20</td>
<td>1</td>
<td>41.5</td>
<td>Cell application</td>
<td>OM075T2S44</td>
</tr>
<tr>
<td>1</td>
<td>TeeJet TP6501E</td>
<td>0.20</td>
<td>1 and 2</td>
<td>16</td>
<td>Cell application</td>
<td>OM075T2S44</td>
</tr>
<tr>
<td>1</td>
<td>TeeJet 650067</td>
<td>0.17</td>
<td>1</td>
<td>12.5</td>
<td>Cell application</td>
<td>OM075T2S44</td>
</tr>
<tr>
<td>2</td>
<td>Hardi LD-110015</td>
<td>0.60</td>
<td>2</td>
<td>50</td>
<td>Broadcast application</td>
<td>OM075T2S44</td>
</tr>
<tr>
<td>2</td>
<td>TeeJet TP4001E</td>
<td>0.18</td>
<td>1 and 2</td>
<td>34</td>
<td>Cell application</td>
<td>OM075T2NC1254</td>
</tr>
<tr>
<td>2</td>
<td>TeeJet TP6501E</td>
<td>0.18</td>
<td>1</td>
<td>15</td>
<td>Cell application</td>
<td>OM075T2NC1254</td>
</tr>
<tr>
<td>3</td>
<td>Hardi LD-110015</td>
<td>0.60</td>
<td>2</td>
<td>25</td>
<td>Cell application</td>
<td>OM038T2NC1254</td>
</tr>
<tr>
<td>3</td>
<td>TeeJet TP4001E</td>
<td>0.22</td>
<td>1 and 2</td>
<td>25</td>
<td>Cell application with 2 nozzles at 10 cm spacing</td>
<td>OM038T2NC1254</td>
</tr>
<tr>
<td>3</td>
<td>TeeJet TP6501E</td>
<td>0.22</td>
<td>1</td>
<td>12</td>
<td>Cell application with 2 nozzles at 10 cm spacing</td>
<td>OM038T2NC1254</td>
</tr>
<tr>
<td>3</td>
<td>TeeJet 650067</td>
<td>0.17</td>
<td>1</td>
<td>12</td>
<td>Cell application with 2 nozzles at 10 cm spacing</td>
<td>OM038T2NC1254</td>
</tr>
<tr>
<td>4</td>
<td>TeeJet TP6501E</td>
<td>0.22</td>
<td>1</td>
<td>25</td>
<td>Cell application with 2 nozzles at 10 cm spacing</td>
<td>OM038T2NC1254</td>
</tr>
<tr>
<td>5</td>
<td>Hardi LD-110015</td>
<td>0.55</td>
<td>2</td>
<td>50</td>
<td>Broadcast application</td>
<td>OM038T2S44</td>
</tr>
<tr>
<td>5</td>
<td>TeeJet TP4001E</td>
<td>0.22</td>
<td>1</td>
<td>25</td>
<td>Cell application with 2 nozzles at 10 cm spacing</td>
<td>OM038T2NC1254</td>
</tr>
</tbody>
</table>

Fig. 1 – Illustration of the zones from which plants were harvested in experiments 1 – 3, after cell treatment with one nozzle, after broadcast application and from untreated boxes. Each cell represents 1 plant in a square of 20 mm \(\times\) 20 mm. The yellow area (1) indicates the central part of the cell, the green area (2) the border zone of the cell and the blue area (3) is the area just outside the intended sprayed cell. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
height, the cell spray applications were optimized to spray an area with a width of 100 mm. For each nozzle, the dynamic spray distribution test resulted in a nozzle height corresponding with a 100-mm-wide spray swath. This nozzle height was used in the biological efficacy tests.

2.5. Flow rate measurements

The selected nozzles were mounted in combination with the solenoid valves and the influence of the valve on nozzle flow rate was measured using a Danfoss MAGFLO (Danfoss Group, Nordborg, Denmark) electromagnetic flow meter (MAG3000/1100). The measurement accuracy is $\pm 0.25\%$ for the given flow rates (Table 1). The meter was read when the nozzle flow rate was stable.

2.6. Biological efficacy testing

Biological efficacy of the selected nozzles was tested using plant material grown under semi-field conditions. A series of 5 experiments testing different combinations of valve, nozzle,
spray pressure, application speed and number of nozzles were carried out (Table 3). Seeds of *Matricaria perforata* Mérat (Scentless mayweed) were sown in boxes in a quadratic pattern at a mutual distance of 20 mm (Figs. 1 and 2). At each spot two seeds were sown and after emergence thinned to 1 plant per spot before the application was carried out at the cotyledon stage. In the first three series of experiments, in which the efficacy using a single nozzle to control weeds in the central 100 mm $\times$ 100 mm of the box was tested (Table 3), plant boxes with a dimension of 200 mm $\times$ 200 mm were used (Fig. 1). In further experiments, testing the efficacy of two nozzles controlling weeds in two neighbouring cells each with a size of 100 mm $\times$ 100 mm, plant boxes with a size of 240 mm $\times$ 160 mm were used (Fig. 2). Based on applications on water sensitive paper the boxes were placed in such a way that the intended sprayed quadrant was in/at the centre of the boxes. In all experiments the herbicide used was glyphosate (Roundup BIO containing 360 g [a.i.] l$^{-1}$ glyphosate from Monsanto Crop Sciences, Denmark). Glyphosate was used at 3 dose rates in each trial and these were 58 (0.36n), 97 (0.6n) and 162 g a.i. ha$^{-1}$ (100% control) (Fig. 7). Error bars indicate standard deviation. Exp. 1.
162 g [a.i.] ha⁻¹ (1.0n) in experiment 1 and 40 (0.25n), 81 (0.5n) and 162 (1.0n) g [a.i.] ha⁻¹ in experiments 2–5. Spraying was carried out in a spray lane using a boom on which one or more nozzles can be activated using different driving speeds. Reference broadcast spraying was included in some of the experiments (Table 3) and was carried out with two Hardi LD 110015 pre-orifice nozzles at 2 m s⁻¹ mounted on the boom at 500 mm spacing to obtain double overlap in the sprayed area, and the total box was sprayed with the reference technique.

Approximately three weeks after the experimental treatments, plants were harvested and fresh weight was determined. The plants were harvested in 3 different areas in the boxes in experiments 1–3 in which one nozzle was tested for cell applications as illustrated in Fig. 1. For the experiments 4 and 5, where the use of two nozzles was evaluated for cell spray applications, plants were only harvested from two different zones (Fig. 2).

All experiments included 4 replicates. Percent efficacy was calculated by comparing plant weight in the sprayed treatment with the untreated controls from the same harvest zone. A statistical evaluation was made calculating standard deviation and further statistical significance between treatments at the $p = 0.05$ percent level was tested.

### 2.7 Tracer deposition experiment

Following the last biological efficacy experiment, an experiment was carried out comparing deposits of tracer following broadcast application versus cell treatment with two nozzles. The two application techniques were those used for experiment 5 (Table 3). Filter paper collectors, with an area of 18 mm × 50 mm were placed in the middle of areas 1 and 2 (Fig. 2) before application. The spray liquid consisted of water...
and the fluorescent tracer brilliant sulfoflavine applied at a dose rate of 200 g ha\(^{-1}\). Following the application the filter paper objects were collected and the amount of fluorescent tracer was determined. The amount of tracer is presented as a percentage of the applied dose rate in each zone. The experiment included 4 replicates and the statistical evaluation was made calculating least significant difference (LSD) (\(p = 0.05\)) values.

3. Results

3.1. Static spray distribution

The static spray distribution was tested at a low pressure due to the low maximum pressure tolerated by the valves with a maximum of 210 kPa. An example is shown in Fig. 3. With the TeeJet TP4001E the static spray distribution at 140 kPa resembles the distribution obtained with conventional flat-fan nozzles. However, at 180 kPa, a typical even flat-fan distribution is produced.

3.2. Dynamic spray distribution

Figure 4 shows the two-dimensional distribution from the even flat-fan nozzle, TeeJet TP4001E, at 140 kPa and at a height visually estimated to give a spray width of 100 mm. An even distribution was obtained in the square cell but with coarse droplets. By increasing the pressure to 180 kPa (Fig. 5) finer atomisation was obtained but still with an even distribution in the square cell. It also appears from the photo that droplets at the edge of the spray plume were coarser than in the central
part. Using the conventional flat-fan TeeJet 650067 nozzle (Fig. 6) a typical non-uniform distribution was seen and with coarser droplets in the central part of the spray.

3.3. Nozzle flow rate

The three solenoid valves influenced the flow rate of the selected nozzles (Table 4). Nozzle flow rate was strongly reduced when mounted in combination with the OM075T2S44 valve, whereas the OM038T2NC1254 did not influence nozzle flow rate. In order to achieve a visually acceptable spray the pressure used with the OM075T2S44 valve needed to be increased to above its maximum permitted. The OM075T2NC1254 had an intermediate influence on flow rate.

3.4. Biological efficacy

The first biological efficacy test was carried out with a single nozzle and included the TeeJet TP4001E, the TeeJet TP6501E and the TeeJet 650067 nozzles (Fig. 7). Generally high efficacy was obtained in the central part of the cell, with a reduction in fresh weight of above 95% in all the 4 treatments at the high dose rate. At the low dose rate (58 g a.i. ha\(^{-1}\)) efficacy with the TP4001E nozzle was significantly lower than with the other. In the border zone of the intended cell, efficacy was reduced and varied between 45% efficacy at the low dose rate and approximately 80% efficacy at the highest dose rate. The efficacy in the border zone, outside the target area, was reduced to values < 50% for all 4 treatments and with a more limited dose response effect. When the dose response curve of glyphosate is taken into account (Streibig & Kudsk, 1993, chap. 6) this actually means that a limited amount of spray was deposited outside the intended target zone. Surprisingly, the biological efficacy data for the TeeJet 650067 standard flat-fan nozzle showed a high precision for targeting with a limited spray loss outside the intended target area which corresponds with the results of the even flat-fan nozzles.

Two experiments were conducted comparing the efficacy of cell spray applications with the efficacy obtained using the reference broadcast spray application. Two different Omnifit valves and hence flow rates for the cell application treatments were used. The results are shown in Figs. 8 and 9. In the first experiment, shown in Fig. 8, some data are missing for the TP4001E nozzle at 1 m s\(^{-1}\). The general conclusion from both experiments is that there was a slight, but statistically significant reduction in biological efficacy in the central part of...
the cell using application with both the band nozzles tested and with both speeds tested when using the TP4001E nozzle. Very limited biological efficacy was seen for the three cell application treatments in the area outside the intended cell, demonstrating a rather precise targeting of the intended area.

Two of the tests examined cell application of two neighbouring cells using two nozzles. The results in Fig. 10 show a slightly reduced efficacy in the border zone compared to results from the central part of the cell for both tested nozzles indicating that the actual width of the spray swath was a little below 100 mm. In the second test with two nozzles for cell applications, the efficacy of a TP4001E nozzle for cell application in two neighbouring cells was compared with the efficacy of a continuous broadcast application with two LD 110015 flat-fan nozzles mounted with overlapping spray swath on the boom (Fig. 11). As expected, no significant difference in efficacy between zones was observed for the broadcast application. A statistical significant reduced efficacy of the cell application was found, compared to the broadcast application. Examining the efficacy of the cell application, a reduced efficacy was again seen in the border zone compared to the central part of the cells mainly at the reduced dose rate. This again indicates that the spray swath obtained was less than 100 mm.

3.5 Tracer spray deposition

The tracer study showed that the deposit of tracer recovered was close to 100% of the intended applied dose rate in the broadcast application (Table 5). Using cell application 82% was recovered in the central part of the cell and 70.3% in the border zone between the 2 nozzles.

4 Discussion

Studies on site specific weed control have primarily focused on spatial variability and stability of weeds (Clay et al., 2006; Heijting, van der Werf, Stein, & Kropff, 2007), weed sensing systems (Berge, Aastveit, & Fykse, 2008; Gebhardt & Kübbauch, 2007; Nieuwenhuizen et al., 2010; Singh, Agrawal, & Bora, 2011; Tyystjärvi et al., 2011) and potential in site specific weed control (Berge, Goldberg, Kaspersen, & Netland, 2012; Gutjahr et al., 2012) whereas studies on the application technology needed to apply pesticides precisely to small areas are scarce. Generally, the potential for saving herbicide increases as the field is resolved into smaller units where independent decisions on weed control are taken. Whereas treatment of large patches of weeds can be achieved with a traditional field sprayer, increasing demands on the application technology are posed when the spatial resolution increases. The approach from the study reported in this paper was to divide the field into small cells with a width of 100 mm. This means that nozzles should be mounted at 100 mm spacings on the boom. The other dimension in the longitudinal direction could be varied depending on the need to spray or not. However in this study, treatments of 100-mm-long cells were considered by choosing the correct valve opening time as a function of the application speed. Based on the visual observations of the dynamic distribution of spray and the biological efficacy testing, it is possible to obtain a rather precise spray application in such small cells using available commercial nozzles. Whether even flat-fan nozzles or conventional flat-fan nozzles should be selected for the task depends on the selected application method. Even flat-fan nozzles can deliver an almost even distribution across. The width of the treated area is, however, dependent on a correct and constant nozzle height. By using conventional flat-fan nozzles for this purpose, a more uneven distribution (and efficacy) will be obtained if only one nozzle is open, and it is necessary to accept a larger part of the spray outside the intended sprayed area. However, in areas of the field where neighbouring nozzles open an even distribution will be obtained, and conventional flat-fan nozzles are less dependent on nozzle height to maintain an even distribution.

The primary objective of the study was to investigate whether it was possible to apply herbicides precisely to small cells. However, the study also showed that the biological efficacy obtained in the central part of the cells was lower than the corresponding efficacy obtained using a broadcast application with nozzles with a similar spray quality. Deposition studies with a tracer revealed that the tracer content in the central part of the cell was lower for a cell application compared to the reference broadcast application. The difference in deposition was actually large enough to explain the difference in biological efficacy. A probable explanation for the reduced deposits measured using cell application could be that the nozzle flow rate was dependent on how long the valve was open as the flow rate used was determined from measurements when the valve was open for a longer time than the 100 ms opening time needed when spraying a 100-mm-long cell at 1 m s⁻¹. If a valve with such a characteristic was used for cell application, it would be necessary to open the valve some time ahead of the point at which a correct dose rate is needed. Using a slow acting valve is particularly a disadvantage in areas of the field where the valve needs to open and close frequently, which typically occurs in fields with a low weed pressure and a high potential for herbicide savings, and where it is particularly important that the weed control is carried out precisely. The valves selected for this study therefore seem to be not suitable for this situation and should, if possible, be replaced with faster acting valves.

5 Conclusions

Systems for precision weed control at a high resolution depend on a precise method for applying the herbicide to small cells. This study has shown that it is possible with commercially available nozzles to apply a herbicide to a
100 mm × 100 mm cell at an application speed of 1–2 m s⁻¹ with reasonably high precision, and with only a limited proportion of the spray being lost outside the intended target area. A constant boom height and a reduced nozzle distance are required. The study has also shown that although even flat-fan nozzles are well suited for applying herbicides in bands, the spray width is very dependent on the correct nozzle height. Conventional flat-fan nozzles will give a more uneven distribution if only one nozzle is open. However, when neighbouring cells are to be treated, traditional flat-fans are more robust when nozzle height varies during the application and might be an alternative for even flat-fan nozzles. Fast acting valves ensuring that the intended nozzle output is achieved within a few milliseconds are required in order to minimise the amount of herbicide applied.

REFERENCES


