Project Report No. 501 September 2012

Maximising the control achieved by soil-applied herbicides

September 2012

Project Report No. 501

Maximising the control achieved by soil-applied herbicides

by

P. C. H. Miller[1], R. Stobart[2], N. Morris[2] and A. G. Lane[1]

[1]Silsoe Spray Applications Unit, Building 42, Wrest Park, Silsoe, Bedford MK45 4HP

[2]NIAB TAG, Huntingdon Road, Cambridge

This is the final report of a 36 month project (RD-2006-3343) which started in October 2007. The work was funded by a contract for £54,060 from HGCA.

CONTENTS

1. ABSTRACT

A combination of wind tunnel experiments and field trials examined the use of different spray nozzles to apply pre- and early post-emergent herbicides based on the hypothesis that improving the uniformity of deposition at the soil surface would improve product efficacy. Results of the wind tunnel study showed no major differences in the shadowing effects of spray deposits around clods when sprayed with different nozzle designs and the surface coverage around clods was mainly influenced by the droplet size distribution in the spray. Angling the spray delivery did tend to increase the deposition shadow probably because more of the spray was then deposited in the clods. Results from the field trials gave no significant differences in black-grass control when treatments were applied with a wide range of droplet size distributions in the spray and therefore there is likely to be no benefit from applying pre-emergence sprays as fine or medium quality sprays. The use of sprays with a larger droplet size such as those generated by air-induction nozzles would be expected to give comparable product efficacy when compared with possible alternatives and has the advantage of a reduced drift risk. Results from work conducted in parallel with that reported here indicated that the use of application volumes of 100 L/ha would give no adverse effects on efficacy and again deliver important advantages relating to work rate and timeliness.

Taking the results from this project together with those from associated work enabled the following key messages to be defined:

- Efficacy is likely to be higher when using 100 L/ha rather than 200 L/ha and this also gives timeliness advantages;
- There is flexibility in nozzle selection for pre-emergence applications such that using an air-induction nozzle will represent a good option for delivering high efficacy and drift control – and the potential to improve timeliness;
- There are no differences in the application requirements for chemicals having primarily root or shoot uptake modes of action;
- In coarser seedbeds, there may be some advantages from using application systems that generate mixing of the spray during delivery;
- It is important that factors influencing the spray volume distribution pattern below the boom including nozzle pressure, boom stability and forward speed are managed to keep the larger scale deposit distribution as uniform as practicable.

2. SUMMARY

This project aimed at exploring the relationship between the spray deposit distribution at the soil surface and product efficacy when using products with uptake routes primarily through the shoot or the roots. The hypothesis to be tested was that product efficacy would be improved by improving the uniformity of spray deposit distribution at the soil surface as achieved by the appropriate choice of nozzle and mounting so as to give the required droplet size distribution and spray delivery trajectory.

The work involved two main activities, namely:

a) Wind tunnel studies in the first year of the project with a wide range of spraying configurations in which the uniformity of spray deposit distribution around sample clods was both visualised and measured using a fluorescent tracer dye and image analysis;
b) Field trials in the second and third year of the project in which two pre-emergence formulations with different primary modes of action (root or shoot uptake) were applied to a randomised plot trial design established on two sites potentially having different seedbed qualities using equipment capable of operating at a forward speed of 10 km/h: results of these trials were assessed by counting black-grass populations in treated plots and comparing the results with those in untreated controls and those treated with a conventional nozzle to give measures of weed control with different application systems.

Techniques were developed that enabled the spray deposits around typical clods taken from an example seedbed to be quantified. Six class sizes of clod were identified and sample clods were stabilised using a varnish treatment. Sample clods were then mounted 500 mm below a three nozzle boom on matt black cardboard bases and then sprayed with a fluorescent tracer dye at a speed of 10.0 km/h. The clods were removed and the spray coverage in the area immediately around the clod was determined by image analysis. Measurements of the surface coverage around clods sprayed with the different systems showed that higher percentages of the area was covered by chemical deposits when finer sprays were used as expected. There was little evidence of substantial differences in the “shadowing” effects of deposits around clods with the different systems including those with an angled spray delivery. The main experiment was conducted in still air conditions. Experiments conducted with both a head and tail wind of 0.5 m/s at ground level gave similar levels of coverage and no major changes to the spray deposit distribution in “shadowed” areas around the clods.

Nozzles selected for use in the field trials gave very large differences in the mean droplet sizes (as defined by volume median diameters), with values ranging from 158 µm for the conventional flat fan nozzle to 517 µm for the air-induction “Turbo TeeJet Induction” nozzle. All nozzles were used to apply 100 L/ha of the two formulation types at a speed of 10.0 km/h. Although formulation type

made a difference to the droplet size distribution in the generated spray, these effects were relatively small when compared with differences between the nozzle types selected.

Results from the field studies gave no statistically significant differences between treatments based on the nozzles used and therefore showed no advantage in using fine to medium spray qualities to make applications of pre-emergence herbicides. There was a small trend in the results from the field trials towards higher levels of control with the coarser sprays. Seedbed conditions in the second year of the trials had a finer tilth than in the first year.

Taking the results from this project together with those from associated work undertaken at the National Agronomy Centres, enables the following key messages to be defined:

- Efficacy is likely to be higher when using 100 L/ha rather than 200 L/ha and this also gives timeliness advantages;
- There is flexibility in nozzle selection when applying the 100 L/ha such that using an air-induction nozzle will represent a good option for delivering high efficacy and acceptable drift control and also has the potential to deliver improved timeliness;
- There are no differences in the application requirements for chemicals having primarily root or shoot uptake modes of action;
- In coarser seedbeds, there may be some advantages from using application systems that generate mixing of the spray during delivery (such as the “Hawk” nozzle operated forwards and backwards) to improve the uniformity of coverage at the soil surface;
- It is important that factors influencing the spray volume distribution pattern below the boom including nozzle pressure, boom stability and forward speed are managed to keep the larger scale deposit distribution as uniform as practicable.

3. TECHNICAL DETAIL

3.1. Introduction

Much of the guidance relating to the use of pre-emergence herbicides has indicated that sprays can be applied in relatively large droplet sizes so as to minimise the risk of drift. The basis for such recommendations was supported by work conducted at the Weed Research Organisation in the 1980's that showed that high levels of grass weed control could be achieved with a wide range of deposit distributions on the soil surface. However, results from commercial studies conducted in the period 2006/7 showed substantial differences in grass weed control when pre-emergence sprays were applied with different nozzle types. One possible explanation for these results relates to a potential requirement to ensure that germinating grass weeds are able to take up soil applied herbicides at very early stages of plant development because larger plants are likely to be less susceptible to the herbicide. This then led to the hypothesis that there is a relationship between the distribution of herbicide at the soil level at a scale that is likely to relate to nozzle performance and the level of weed control that can be achieved. It was recognised that this relationship is likely to depend on the mode of action of the herbicide and particularly whether herbicide uptake is mainly via the root or shoot of the weed.

This study had the objective of developing spray application approaches that would maximise the control achieved with autumn applied pre- or early post-emergent residual herbicides based on the hypothesis that spray distribution on the soil surface influenced product efficacy possibly due to weed susceptibility and dispersion within the soil.

3.2. Materials and methods

The work comprised two main components, namely:

a) An assessment of the interactions between characteristics of the spray delivery system and seedbed quality (roughness) on the distribution of deposited spray – work conducted in a wind tunnel; and
b) A field evaluation of selected spray techniques identified from the results of the wind tunnel study involving two field sites over two cropping seasons.

It was recognised that the presence of cloddy aggregate structures in a seedbed will influence the uniformity of spray deposits on the soil surface. Large clods will give a "shadow" with an area of soil close to the clod where deposits are likely to be low. The size of this shadowed area is likely to be a function of the roughness of the seedbed (clod size distribution), spray characteristics including droplet trajectories with a horizontal speed component, application volume, and wind conditions close to the soil surface. The effect of seedbed conditions, nozzle characteristics and wind speed were therefore examined in a series of wind tunnel measurements with the aim of identifying treatments to be used in the field trials.

3.2.1. Wind tunnel studies to study the spray distribution at the soil surface

The initial work plan for this project indicated that the initial laboratory and wind tunnel phase of the work would use three seedbed conditions representative of coarse, medium and fine seedbed tilth conditions. Each condition as identified from field observations was to be recreated in trays using gravel as representative of the aggregate size distribution associated with a fine seedbed and clods collected from field conditions added to give the medium and coarse seedbed conditions. Spray applications of a fluorescent tracer dye would then be made and the size of spray "shadows" around the clods determined by photography and image analysis. However, preliminary experimental work to validate this technique showed that there were problems with reliably tracking spray retention on the gravel surface and that it was not possible to have a repeatable reference condition for which assessments could be made. An alternative approach was identified related to positioning a wider range of clod sizes singly on a flat matt black background against which the spray deposition could be mapped with greater repeatability.

Prior to undertaking the wind tunnel experiments, samples of clods were taken from a field in which a relatively coarse heavy land seed bed had been established in the autumn of 2007. These were then manually sorted in the laboratory and six examples of six clod sizes (36 clods in total) were selected for use in the experiments. Each selected clod was then dipped in a light varnish to stabilise its surface and allowed to dry. Each clod was then measured and weighed and its footprint on a 150 mm by 150 mm matt black card determined – this size of card being used for mounting the clods in the wind tunnel experiment. Mean sizes of the six size classes of clods are given in Table 1 and all the data for each of the reference clods used is given in Appendix 1.

Table 1. Mean sizes and weights of the clods in the six size classes used in the laboratory experiments

Clod size class	Mean weight, g	Mean height, mm	Plan area, % of a sample card
1	19.17	24.33	3.86
2	44.00	31.00	6.81
3	95.50	42.00	11.49
4	135.17	46.83	14.83
5	220.83	53.83	20.25
6	385.50	66.83	30.51

A diagram of the arrangement used in the wind tunnel study is shown in Figure 1 and the arrangement of clods under the boom is shown in Figure 2. A small boom supporting three nozzles spaced at 0.5 m was mounted on a transporter mechanism able to move the boom along the tunnel at a calibrated speed of 10.0 km/h. Individual clods of three size classes were mounted on the 150 mm by 150 mm cards supported on a base table (Figure 2) 500 mm below the nozzles with clods immediately below and between nozzles.

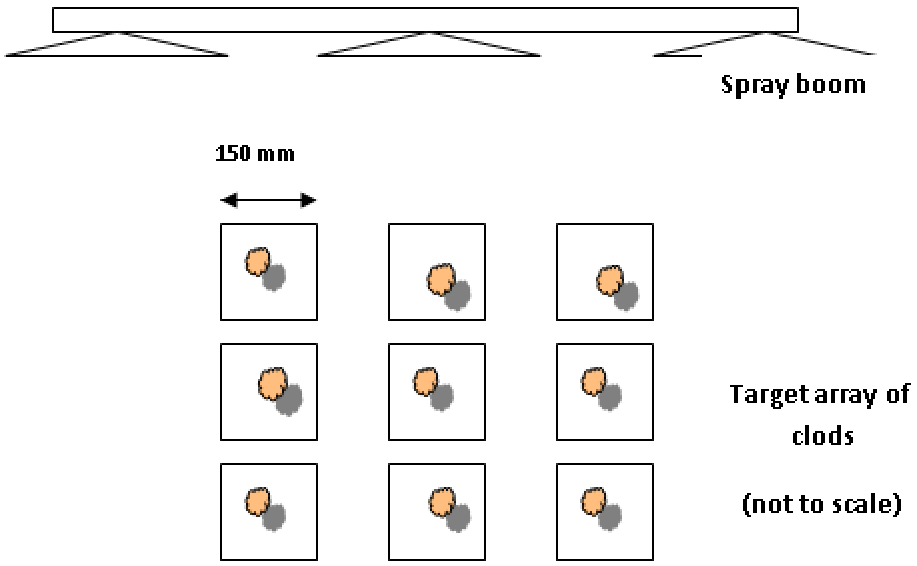


Figure 1. Diagram of wind tunnel layout.

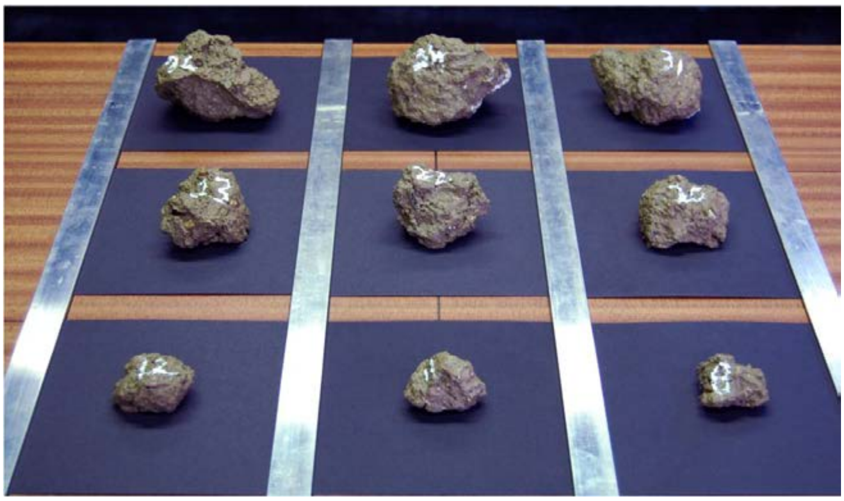


Figure 2. Arrangement of clods on the sample cards prior to treatment

A spray containing a surfactant and a fluorescent tracer dye was sprayed over the clods and the area of supporting card around the clods (i.e. not including the area directly under the clods) covered by the spray deposit was determined by image analysis using the WinDIAS system (Delta T Devices Ltd). Cards were illuminated by fluorescent light so as to enhance the contrast between areas of the card covered by the spray and photographs were also taken of the cards to give a visual record of the coverage achieved. Because the clods had been stabilised with varnish, it was possible to use the same clods with different nozzle/spraying systems to give a direct comparison of the coverage achieved.

In the first series of experiments, the coverage achieved with a range of nozzle systems was compared when spraying in nominally still air. The nozzles used are summarised in Table 2. So that direct comparisons between treatments could be made, all applications were made as near as possible at the same application volume. This was achieved by using multiple passes and adjusting the number of passes to keep the application volume approximately constant.

Table 2. Nozzle conditions used in the first series of wind tunnel experiments

Nozzle	**Spray description**	**Pressure, bar**	**Flow rate, L/min**	**No. of passes**
FF110/1.2/3.0	Flat fan “03” vertical. Reference condition. Medium spray quality.	3.0	1.20	2
FF110/0.82/2.0	Flat fan “025” XR/VP. Fine spray. Vertical.	2.0	0.82	3
AI110/1.2/3.0 (Spraying Systems Ltd)	Air-induction. Coarse spray (Large droplet AI). Vertical.	3.0	1.20	2
Hawk nozzle (Sygenta Crop Prot. Ltd)	Flat fan “03”. Fine spray. Angled forwards.	1.5	0.85	3
Guardian Air (Hypro EU Ltd)	Small droplet AI. Backward angle to compensate for speed effect.	3.0	1.20	2
Hawk nozzle Forward/backwards	Nozzle angles alternating – central nozzle forward.	1.5	0.85	3
Hawk nozzle Forward/backwards	Nozzle angles alternating – central nozzle backwards.	1.5	0.85	3
Twin-cap with two FF110/0.6/3.0	Fine spray angled backwards and forwards.	3.0	1.20 (total)	2
Twin-cap with two AI110/0.6/3.0	Coarse spray angled backwards and forwards.	3.0	1.20 (total)	2
Twin-cap with: Front nozzle - blank. Rear nozzle AI110/1.2/3.0	Coarse flat fan spray angled backwards.	3.0	1.20	2
Twin-cap with: Front nozzle AI110/1.2/3.0. Rear nozzle – blank.	Coarse flat fan spray angled forwards.	3.0	1.20	2

All measurements were based on deposits around three clod sizes with three clods sampled on each occasion. Some observations were also made of the spray distribution around clods in close proximity to each other but detailed measurements of coverage were not made for these conditions.

A second series of experiments was conducted with a smaller number of nozzles examining the effects of air movements on the spray distribution around the clods. The nozzles used for this part of the study were:

- A conventional flat fan "03" at a pressure of 3.0 bar;
- A Spraying Systems "TTI" (Turbo TeeJet Induction) "03" at a pressure of 3.0 bar as being representative of a large droplet air-induction nozzle;
- A Lechler "IDK" "03" at a pressure of 3.0 bar as representative of a small droplet air-induction nozzle;
- The "Hawk" nozzle from Syngenta Crop Protection Ltd as an example of an angled spray nozzle.

Measurements were made in still air and with a uniform air flow down the tunnel of 0.5 m/s with the nozzles travelling with and into the wind. This wind speed was chosen based on the likely wind speed at very close to ground level for conditions representative of those that are good for crop spraying.

3.2.2. Measurement of droplet size distributions

Droplet size distributions in the sprays generated by the nozzles used in the study were measured using a laser-based analyser ("Spraytec", Malvern Instruments Ltd) in the nozzle laboratory on the Silsoe site (Tuck *et al*., 1997). Nozzles were mounted 500 mm above the sampling laser on a computer-controlled transporter that was programmed to move the nozzle at a speed of 20 mm/s such that the whole of the spray cloud was sampled. Droplet size statistics were calculated directly from the output of the analyser and the effective spray angle of the nozzle calculated from the positions at which the analyser detected droplets at the edge of the spray cloud.

It was recognised that droplet size distributions are also influenced by the nozzle size and design and also by the physical properties of the spray liquid (Miller and Butler Ellis, 2000). Measurements were therefore also made with nozzles spraying the tank mixes used in the field experiments conducted as part of the project.

3.2.3. Field trials

Field trials were conducted on two sites over two seasons, harvest years 2009 and 2010. Nozzle conditions were selected to give a range of physical spray characteristics based on the laboratory measurements of nozzle performance and observations in the wind tunnel. Two chemical formulations were used and were selected to give two different primary modes of action based on either root (“Liberator”, Bayer CropScience) or shoot (“Stomp 400”, BASF) uptake.

All field trials used a randomised plot design with plots that were 3.0 m wide and 15 m long. Initial assessments of black-grass populations were made at the time of treatment to ensure that no plants had emerged at this stage. Assessments of black-grass populations were made at monthly intervals following treatment up until the end of December with a further count of black-grass plants made in early spring (February/March). Black-grass counts were made using 6 – 8 of 0.25 m^2 quadrats in each plot. In addition to black-grass counts, visual assessments of crop ground cover were made in November/ December and again in February/March. At each site, samples of the seed bed were taken and the soil aggregates dried prior to a sieve analysis to determine the particle size distribution of clods forming the seed bed. Plots were not taken to yield but the option of counting black-grass heads in June was retained at all sites.

Field trials in the 2009 harvest year

The treatments applied at the two trial sites are detailed in Tables 3 and 4. A reference treatment based on a conventional flat fan “02” nozzle operating at a pressure of 3.0 bar to give a fine spray quality was used at both sites. At both sites all treatments were applied at a forward speed of 10.0 km/h to give an application volume of 100 L/ha using a nozzle pressure of 3.0 bar in all cases. The small droplet air-induction nozzle (see HGCA Nozzle Guide, 2010) was the “Billericay Bubblejet” (Billericay Farm Services Ltd) and the large droplet air-induction nozzle was the “Turbo TeeJet Induction” nozzle (Spraying Systems Ltd) at both sites. At site A, the adjuvant “Grounded” was added to the spray mix for treatments 3 and 7 using the small droplet air-induction nozzle. This adjuvant was likely to change the droplet size distribution produced by the nozzle and also could potentially modify chemical distribution within the soil. At site B, an air-induction nozzle generating a medium droplet size distribution for this nozzle design (“Injet”, Hardi Ltd) was also used.

Table 3. Treatment used at Field site A in the 2009 harvest year

Treatment number	Formulation and dose	Nozzle type	Nozzle code
1	Liberator (0.6 L/ha)	Flat fan	FF/110/0.8/3.0
2	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
3	Liberator (0.6 L/ha) + Grounded (0.2 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
4	Liberator (0.6 L/ha)	Air-induction – large droplet	AI/110/0.8/3.0
5	Stomp 400 (3.3 L/ha)	Flat fan	FF/110/0.8/3.0
6	Stomp 400 (3.3 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
7	Stomp 400 (3.3 L/ha) + Grounded (0.2 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
8	Stomp 400 (3.3 L/ha)	Air-induction – large droplet	AI/110/0.8/3.0
9	Untreated	-	-

Table 4. Treatment used at Field site B in the 2009 harvest year

Treatment number	Formulation and dose	Nozzle type	Nozzle code
1	Liberator (0.6 L/ha)	Flat fan	FF/110/0.8/3.0
2	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
3	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
4	Liberator (0.6 L/ha)	Air-induction – medium droplet	AI/110/0.8/3.0
5	Stomp 400 (3.3 L/ha)	Flat fan	FF/110/0.8/3.0
6	Stomp 400 (3.3 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
7	Stomp 400 (3.3 L/ha)	Air-induction - medium droplet	AI/110/0.8/3.0
8	Stomp 400 (3.3 L/ha)	Air-induction – large droplet	AI/110/0.8/3.0
9	Untreated	-	-

Field trials in the 2010 harvest season.

Trials in the 2010 harvest season followed a similar pattern to those conducted in the 2009 season but with two additional treatments added. The treatments used at the two sites (C and D) are detailed in Tables 5 and 6.

Comparing Tables 3 and 5, it can be seen that the two treatments added at site C in the 2010 harvest season used the small droplet air-induction nozzle at a pressure of 2.0 bar with all other treatments as for site A in the 2009 harvest season. This was because some of the results from the laboratory analysis suggested that the spray volume distribution pattern from some nozzle designs may change with pressure particularly as the fan angle reduces with reducing pressure.

Comparing Tables 4 and 6, it can be seen that the two treatments added at site D in the 2010 season used a pre-orifice nozzle in addition to the same treatments as at site B in the 2009 season. This was to explore further the initial indication that a small droplet air-induction nozzle (or similar nozzle design) may be the best option for applying pre-emergent herbicides.

Table 5. Treatment used at Field site C in the 2010 harvest year

Treatment number	Formulation and dose	Nozzle type	Nozzle code	Pressure, bar
1	Liberator (0.6 L/ha)	Flat fan	FF/110/0.8/3.0	3.0
2	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0	3.0
3	Liberator (0.6 L/ha) + Grounded (0.2 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0	3.0
4	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0	2.0
5	Liberator (0.6 L/ha) + Grounded (0.2 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0	2.0
6	Liberator (0.6 L/ha)	Air-induction – large droplet	AI/110/0.8/3.0	3.0
7	Stomp 400 (3.3 L/ha)	Flat fan	FF/110/0.8/3.0	3.0
8	Stomp 400 (3.3 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0	3.0
9	Stomp 400 (3.3 L/ha) + Grounded (0.2 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0	3.0
10	Stomp 400 (3.3 L/ha)	Air-induction – large droplet	AI/110/0.8/3.0	3.0
11	Untreated	-	-	

Table 6. Treatment used at Field site D in the 2010 harvest year

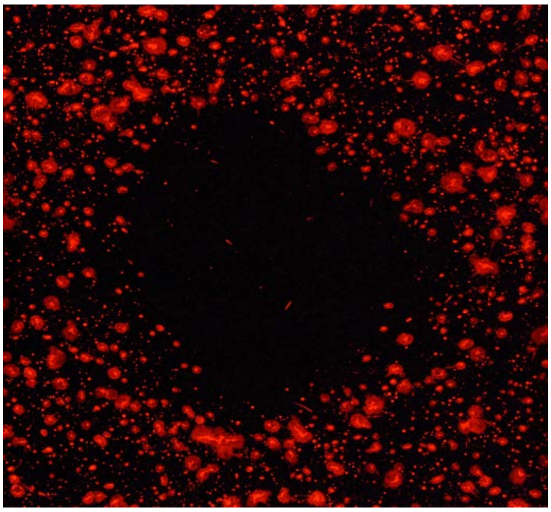
Treatment number	Formulation and dose	Nozzle type	Nozzle code
1	Liberator (0.6 L/ha)	Flat fan	FF/110/0.8/3.0
2	Liberator (0.6 L/ha)	Pre-orifice	LD/110/0.8/3.0
3	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
4	Liberator (0.6 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
5	Liberator (0.6 L/ha)	Air-induction – medium droplet	AI/110/0.8/3.0
6	Stomp 400 (3.3 L/ha)	Flat fan	FF/110/0.8/3.0
7	Stomp 400 (3.3 L/ha)	Pre-orifice	LD/110/0.8/3.0
8	Stomp 400 (3.3 L/ha)	Air-induction - small droplet	AI/110/0.8/3.0
9	Stomp 400 (3.3 L/ha)	Air-induction - medium droplet	AI/110/0.8/3.0
10	Stomp 400 (3.3 L/ha)	Air-induction – large droplet	AI/110/0.8/3.0
11	Untreated	-	-

3.3. Results

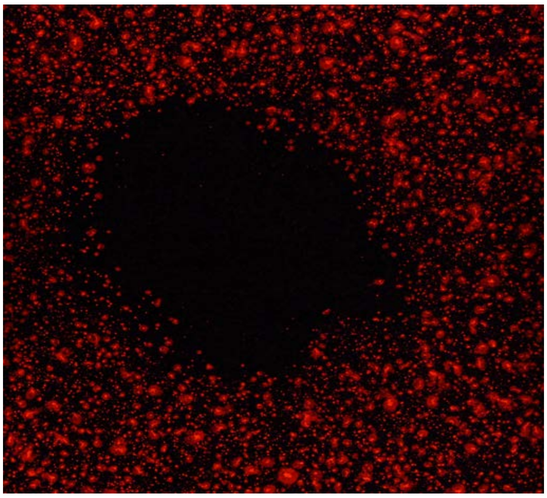
3.3.1. Wind tunnel studies to study the spray distribution at the soil surface

Typical examples of the spray deposit coverage on the sample cards supporting an individual clod when sprayed in still air are shown in Figure 3. It can be seen that:

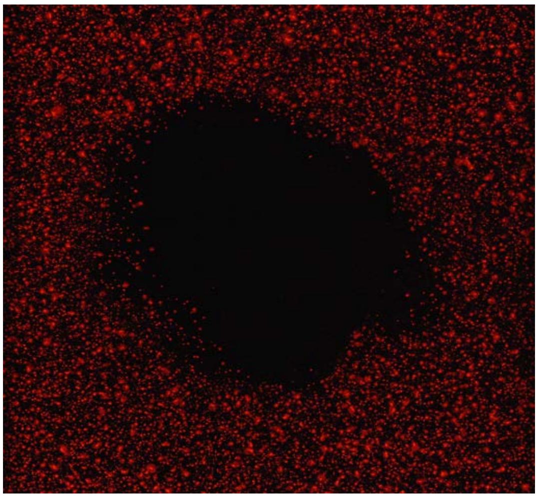
- The deposits on the cards corresponded to expectations based on the likely droplet size/spray quality produced by the nozzles with larger deposits from the air-induction nozzles as expected (Butler Ellis *et al*., 2002);
- A relatively consistent outline of the clod with little evidence of a shadow on the lee of the direction of travel with any of the spray treatments shown;
- Relatively small changes to the deposition pattern when sprays were delivered from angled nozzles but with some evidence of a larger shadow with the angled spray.



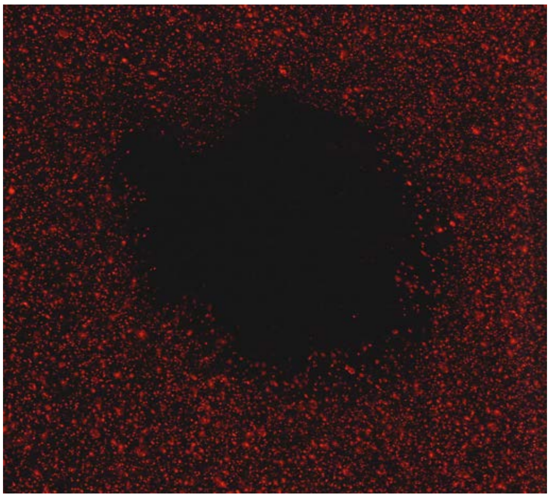
Large droplet air-induction nozzle



Small droplet air-induction nozzle



Standard flat fan nozzle



“Hawk” (angled) nozzle

Figure 3. Spray deposit distributions around a given clod sprayed with different nozzle designs in still air

It should be noted that the study did not seek to quantify the magnitude of the deposits on the clods although the use of the tracer dye did enable such deposits to be visualised particularly after multiple applications (Figure 4). Deposits around multiple clods showed that spray did land on the portion of supporting card between clods (Figure 5) when sprayed with the nozzles used in the study that directed spray vertically downwards.

Figure 4. Views of a treated (large) clod after multiple applications of the tracer fluorescent dye.

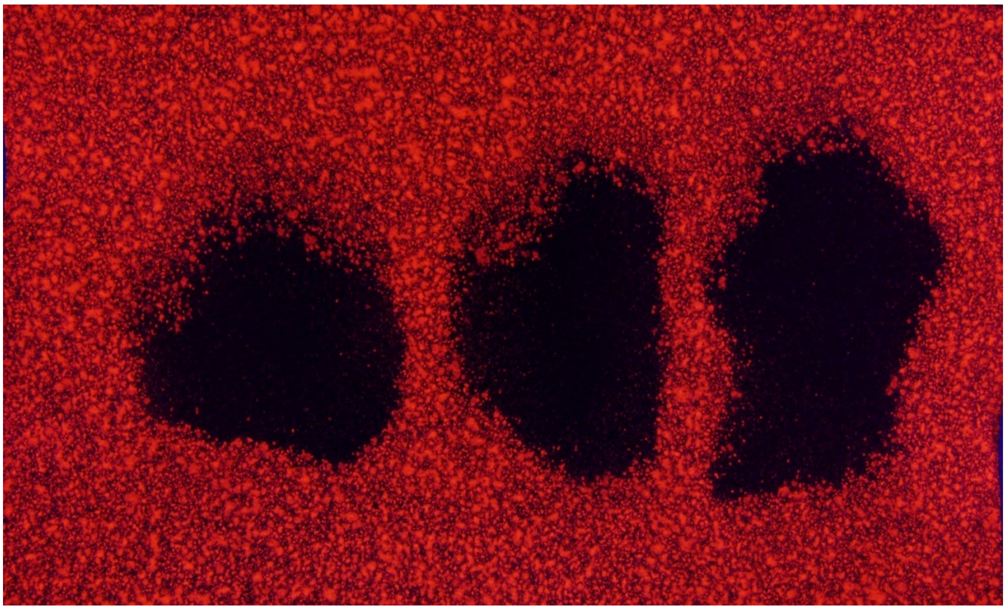


Figure 5. Spray deposits around clods placed in close proximity on the base card.

Results of measurements of the coverage of the area around clods using the image analysis system for applications made with a range of nozzle systems operating in still air are summarised in Figure 6. It can be seen that the highest levels of coverage are associated with sprays having the smaller droplet size distributions and this is consistent with the visual observation that any shadowing of deposits due to the forward motion of the sprayer was small. Angling of the spray, either from a single nozzle as with the “Hawk” design or from a “twin-cap” did not give high levels of coverage and this probably relates to higher deposits being delivered to the clods with such systems and a small increase in the shadowing effect when there is more horizontal movement in the spray droplets.

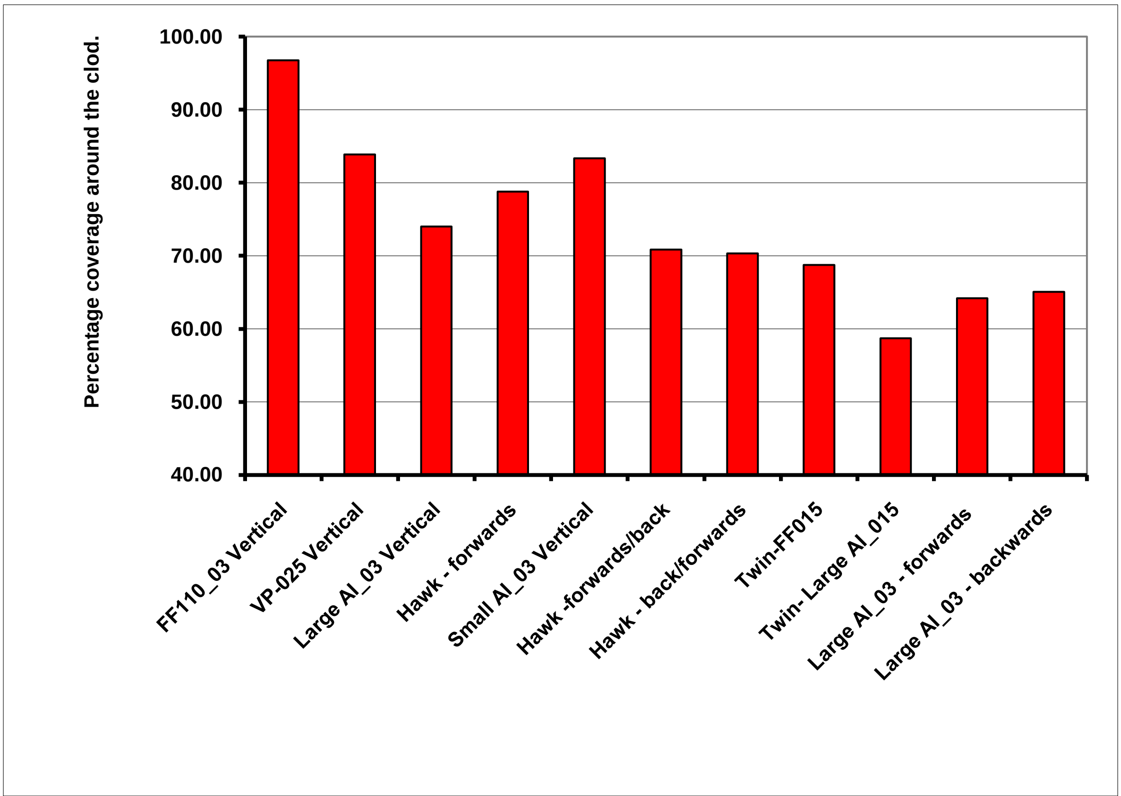


Figure 6. Coverage around clods sprayed with different nozzles in still air.

It should be noted that the levels of coverage indicated in Figure 6 and shown visually in Figures 3, 4 and 5 are not representative of those that would be achieved under typical field conditions because the laboratory experiment used multiple passes of the sprayer in order that volume rate effects were accounted for. The figures shown in Figure 6 are therefore comparative rather than realistic measures of coverage at application volumes typically used in the field.

There was some variability in the values plotted in Figure 6 due to:

- Variations in the tracer dye concentration in the spray liquid that influenced the images of droplets when illuminated with ultra-violet light: the dye was a suspension and required constant agitation to ensure a uniform concentration in the spray;

- Small differences in the definition of the clod boundary projected on to the supporting base card: this was done by taking photographs of the base cards from vertically above them and then removing this area from that analysed to determine coverage.

Results from the second series of wind tunnel studies with nozzles travelling into and with a wind are summarised in Figure 7 and photographs of the deposit coverage in these conditions are shown in Figure 8. For these experiments a single pass of the sprayer over the clod array was used so that deposit coverage levels are lower than in Figure 6 but are representative of typical field conditions.

The results shown in Figures 7 and 8 indicate that the wind had no effect on the spray distribution around the clods. There were no differences in deposition pattern when the nozzles were travelling into the wind or with the wind. Levels of deposition were again higher for the nozzles giving the smaller droplet size distribution and the coverage with the angled “Hawk” nozzle was lower probably due to an increased deposit shadow and more of the spray being deposited on the clods.

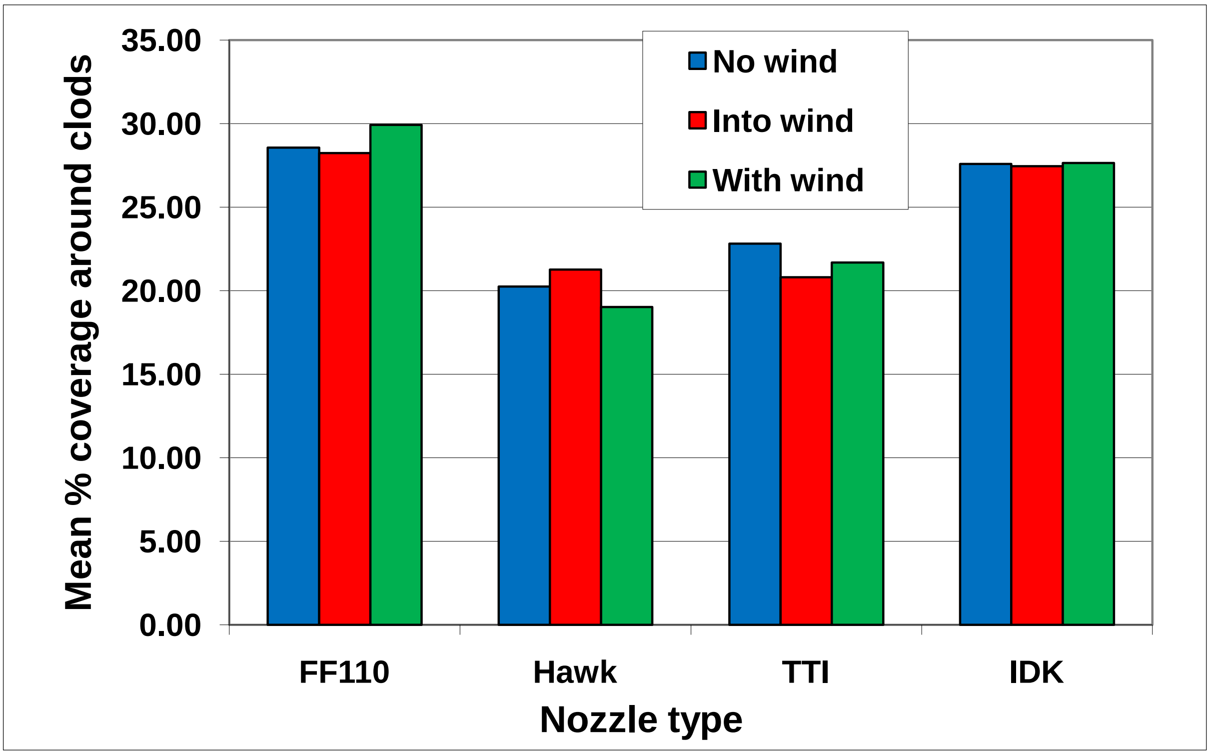


Figure 7. Coverage around clods sprayed with different nozzles in still air and in two wind conditions

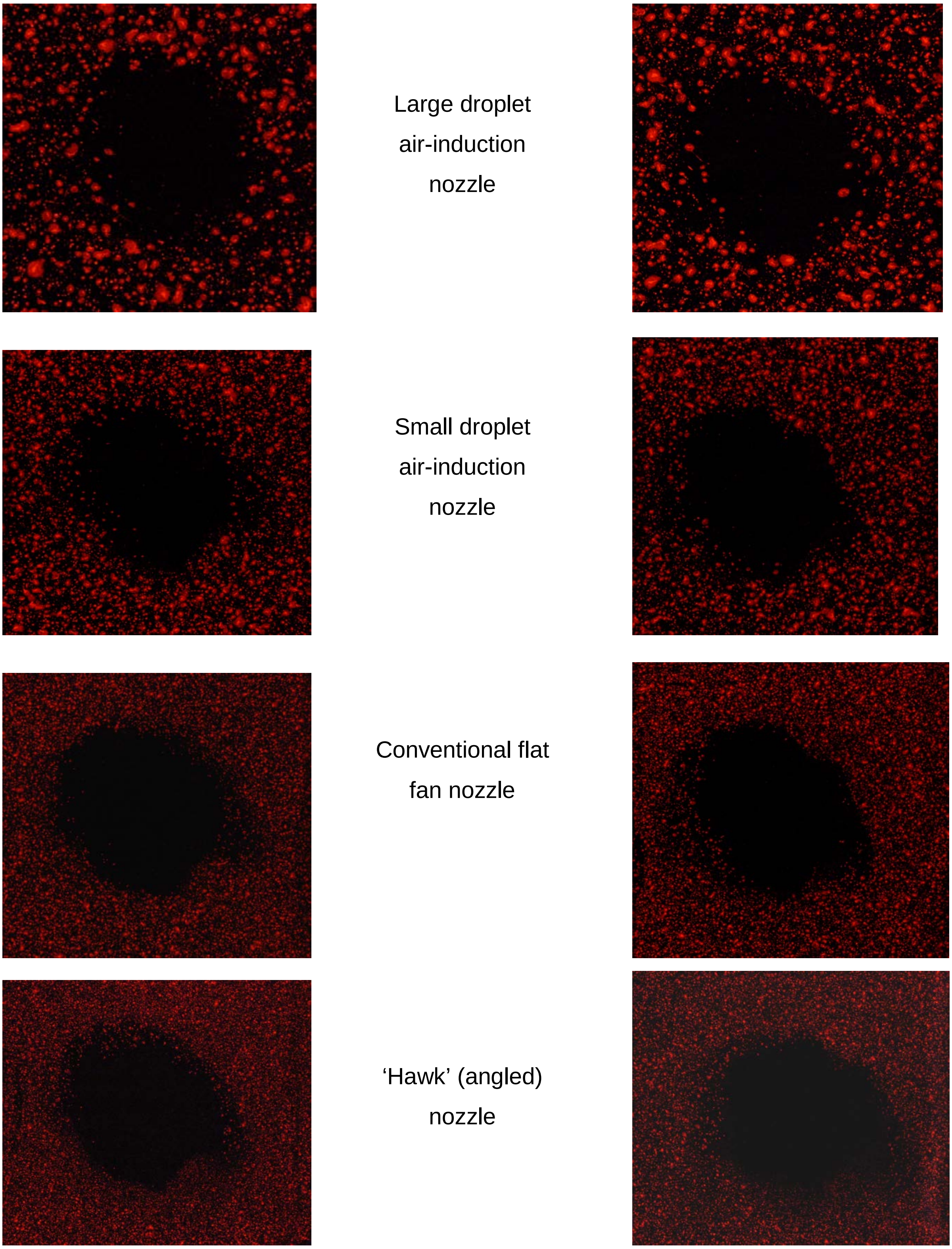


Figure 8. Spray deposits around clods sprayed with nozzles travelling into a wind of 0.5 m/s (left) and with a wind of 0.5 m/s (right)

3.3.2. Droplet size distributions in the sprays

The droplet size distributions in the spray were expected to be mainly a function of the nozzles used with these being selected to give as wide a range of mean sizes as practicable. However, since different formulations were also used and it is known that formulation properties influence nozzle performance, measurements of the droplet size distributions were also made with the nozzles used in the field trials spraying the range of tank mix liquids used.

Droplet size distributions from the nozzles used in the study

The results of droplet size distributions for the nozzles used in the wind tunnel study are summarised in Table 7. The results show the expected trends, namely:

- Much larger droplet sizes from the air-induction nozzles with the “small droplet” (Guardian Air and IDK), “medium droplet” (AI) and “large droplet” (TTI) designs showing the expected gradation in droplet sizes: it can be seen that the smaller size of the “AI” range gave the larger droplet size and this has been observed previously;
- The smallest sizes of conventional nozzle giving the smallest droplet sizes (finer sprays) and with droplet sizes increasing with increasing nozzle size and reducing pressure;
- The “Hawk” nozzle giving a droplet size in line with the other conventional nozzles used but slightly larger due to the relatively low pressure at which this nozzle was used.

Table 7. Droplet sizes measured with the nozzles used in the laboratory wind tunnel study

Nozzle	**Pressure, bar**	**VMD, μm**	**% spray vol. In droplets <100 μm**	**Spray angle, degrees**
Conventional flat fan FF/110/0.6/3.0 (“015”)	3.0	146.2 (0.2)	20.11 (0.06)	98 (1.2)
Conventional flat fan FF/110/1.0/3.0 (“025”)	2.0	188.1 (0.3)	10.88 (0.13)	99 (0.0)
Conventional flat fan FF/110/1.2/3.0 (“03”)	3.0	167.2 (0.6)	15.85 (0.26)	102 (0.6)
“HAWK” (Angled flat fan – “03”)	1.5	208.1 (0.1)	8.87 (0.03)	100 (0.6)
“Guardian Air” – Hypro EU AI/110/1.2/3.0 (“03”)	3.0	313.7 (0.8)	4.08 (0.05)	103 (0.0)
“AI” – Spraying Systems AI/110/0.6/3.0 (“015”)	3.0	485.4 (2.3)	2.08 (0.02)	90 (1.5)
“AI” – Spraying Systems AI/110/1.2/3.0 (“03”)	3.0	445.0 (1.7)	2.20 (0.03)	100 (0.6)
“IDK” – Lechler AI/110/1.2/3.0 (“03”)	3.0	310.6 (0.5)	4.71 (0.06)	104 (0.6)
“TTI” – Spraying Systems AI/110/1.2/3.0 (“03”)	3.0	529.3 (1.7)	1.19 (0.02)	122 (0.6)

Values are the means of three replicated measurements - Standard deviation values are shown in brackets.

Mean droplet sizes in Table 7 have been expressed as volume median diameter (VMD, µm) which is the droplet size at which half the spray volume is in larger or smaller droplets. The percentage of spray volume in droplets <100 µm in diameter gives an indication of the drift risk associated with a given spray although droplet velocities (speed and direction), spray fan angle and entrained air conditions will also influence the risk of drift. The results in Table 7 show a good correlation between VMD vales and the percentage of spray volume in small droplets for the nozzles used as expected. Estimated spray fan angles were calculated from the droplet size analyser results and are probably an under-estimate of the true value particularly for the air-induction nozzles where the droplet number density at the edge of the spray is relatively low.

Droplet size distributions used in the field trials including the effect of formulations.

The measured droplet sizes for the nozzles and different tank mixes used in the field trials are shown in Figures 9 to 12.

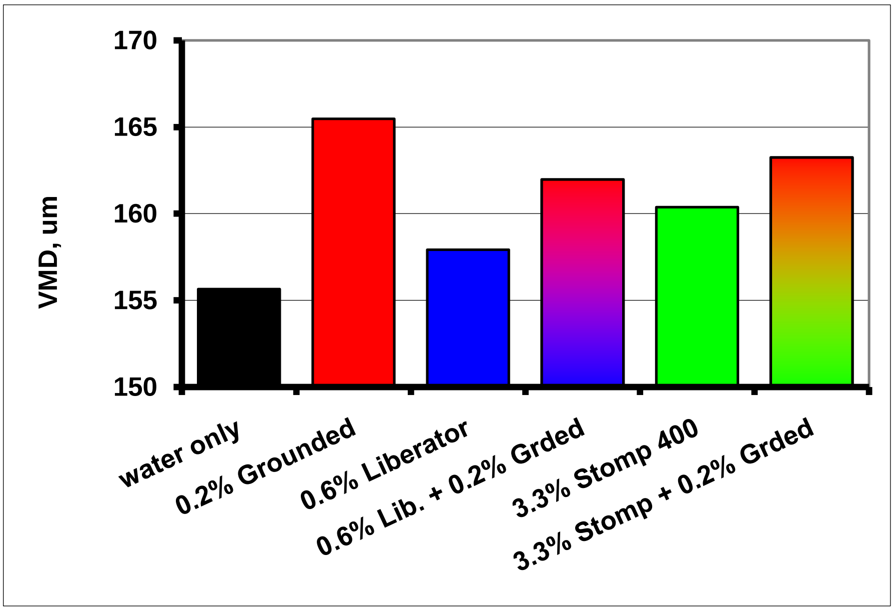


Figure 9. Mean droplet sizes (as VMD) for the tank mixes used in field trials sprayed through the conventional flat fan nozzle

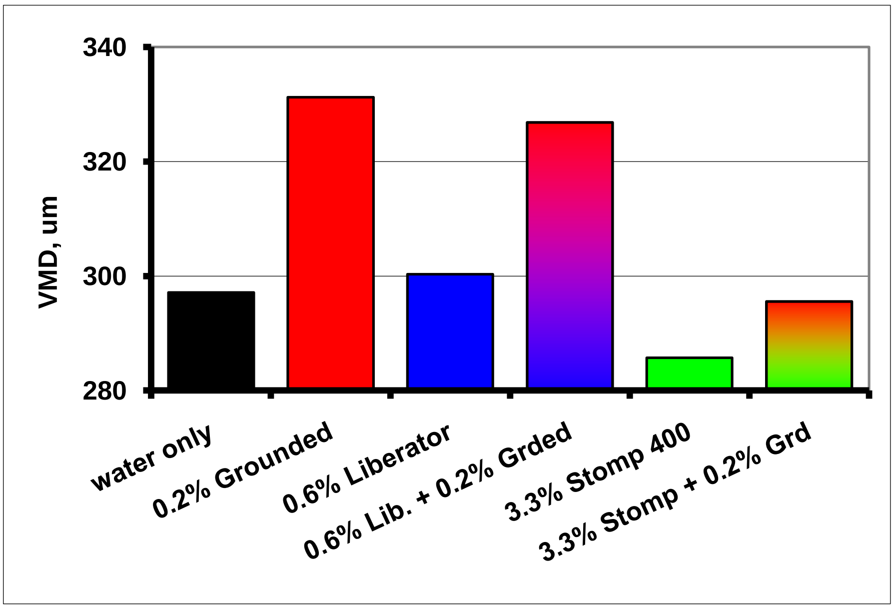


Figure 10. Mean droplet sizes (as VMD) for the tank mixes used in field trials sprayed through the small droplet air-induction nozzle (Billericay Bubblejet)

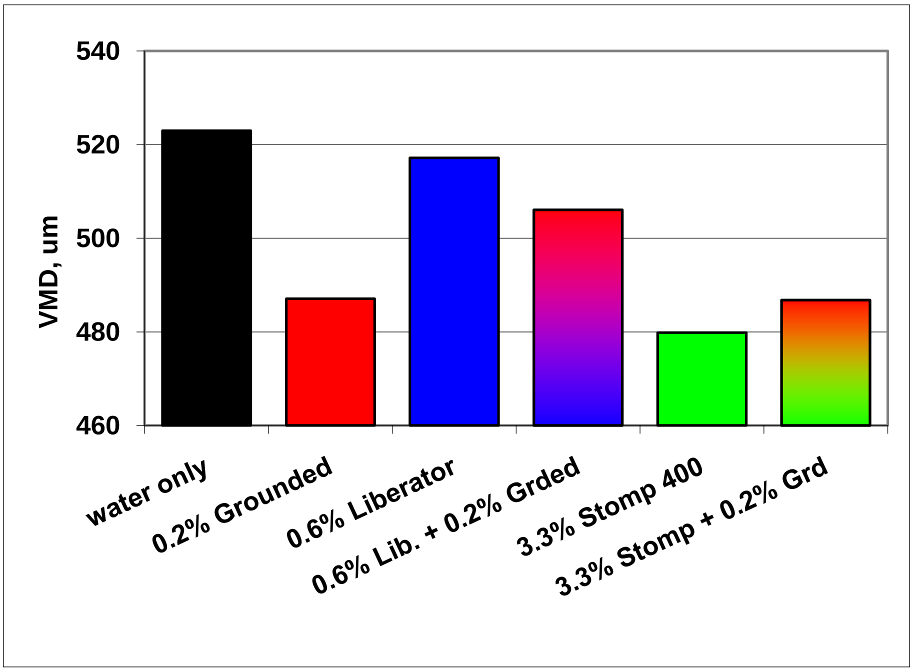


Figure 11. Mean droplet sizes (as VMD) for the tank mixes used in field trials sprayed through the large droplet air-induction nozzle (Spraying Systems TTI)

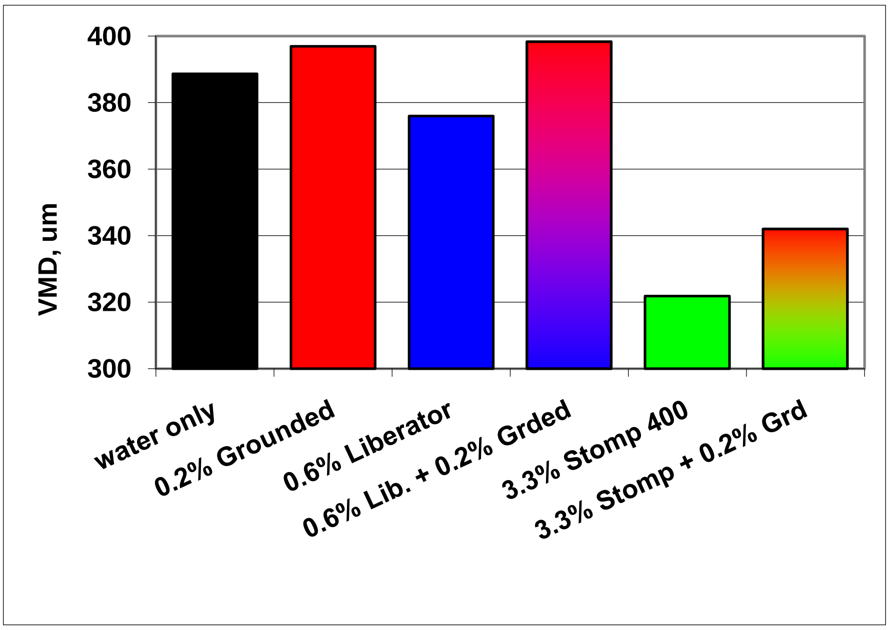


Figure 12. Mean droplet sizes (as VMD) for the tank mixes used in field trials sprayed through the medium droplet air-induction nozzle (Hardi Injet)

The results in Figures 9 to 12 again show many of the expected trends relating to both the nozzle selection and the effects of formulation on the droplet sizes used as follows:

- A wide range of droplet sizes was achieved as required with VMD values ranging from 158 μm (with Liberator sprayed through the conventional nozzle) to 517 μm (Liberator sprayed through the TTI nozzle): this size range represents spray qualities from the middle of the fine spray quality category to well beyond the defined limits for the extra coarse category and hence spans all conditions that could be relevant to practical applications;
- Some differences in the relative droplet sizes with the different tank mixes sprayed through the nozzles used with Liberator giving a larger size than Stomp with all the air-induction nozzles but not the conventional flat fan and the addition of the adjuvant "Grounded" increasing droplet sizes with tank mixes containing both Liberator and Stomp except when sprayed through the TTI nozzle: it can be seen that the effect of nozzle type on the droplet size in the spray is much greater than effects due to formulations;
- With the conventional flat fan nozzle all of the tank mixes gave droplet sizes that were greater than when spraying water but this was not the case with the air-induction nozzles such that with the large droplet design (the TTI nozzle), all droplet sizes when spraying the tank mixes were less than when spraying water.

The above trends are consistent with previously reported results for the types of nozzles used in the study and reflect the complex interactions between spray liquid properties and nozzle design parameters that influence performance.

3.3.3. Results from field trials

Results from field trials in the 2009 harvest season

Results of black-grass counts at two timings at site A in the 2009 harvest season are shown in Figure 13. For the autumn assessment, all treatments except the application of Stomp through the conventional flat fan nozzle gave a statistically significant reduction in black-grass populations compared with the untreated. With the exception of the conventional flat fan nozzle applying Stomp, no differences between treatments using the different nozzles and tank mixes were statistically significant at the 5.0% level (LSD = 40.0). For the spring assessment, all treatments gave statistically significant reductions in black-grass populations over the untreated. There were no statistically significant differences between treatments applied with the different nozzles and tank mixes although differences between the treatments using the two formulations were statistically different.

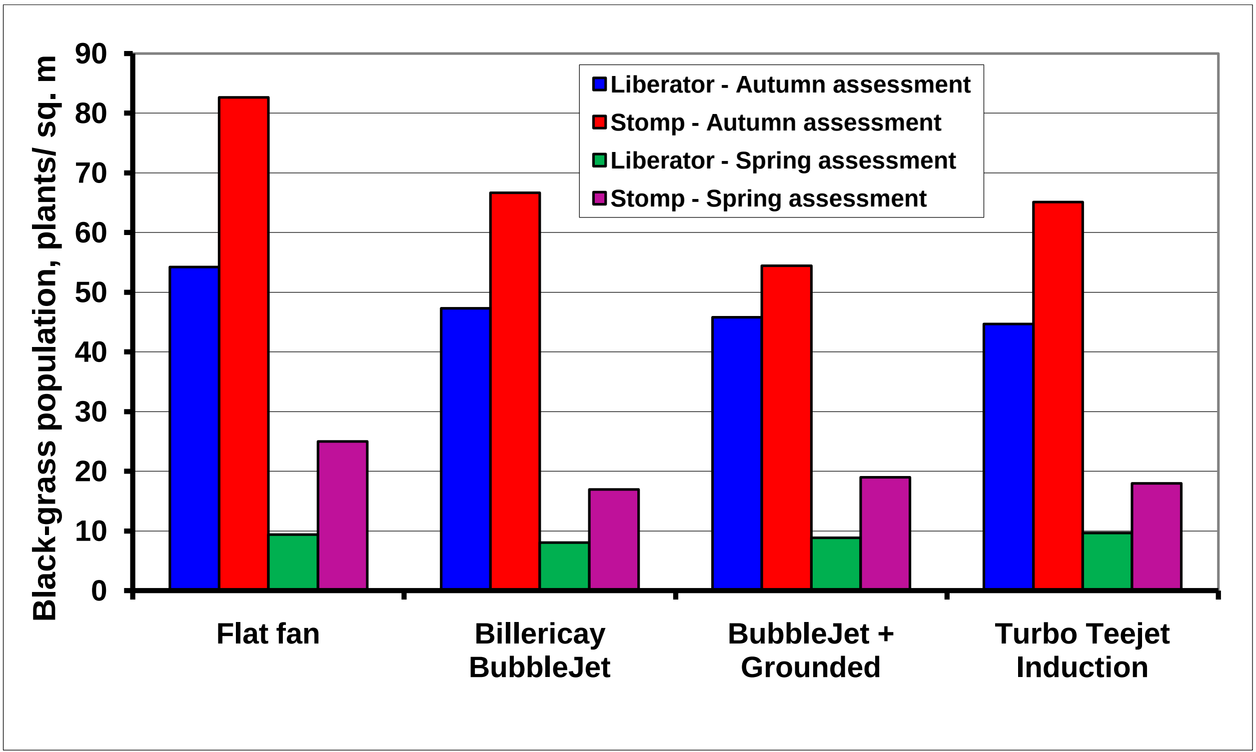


Figure 13. Black-grass populations in treated plots at site A in the 2009 harvest year

Results for site B in the 2009 harvest year gave much lower black-grass populations (Figure 14) but again with no statistically significant differences between treatments using different nozzles based on either the autumn or spring population counts. There were higher mean black-grass population in the plots treated with the conventional flat fan nozzle as assessed in the autumn but no discernable trend in the results from the spring assessments. There were significant differences between the performances of the two formulations used at this site.

The measured particle size distributions of clods forming the seedbed at the two sites showed little difference between sites (Figure 15) with a mean clod size by weight at both sites being retained on a 31.5 mm diameter sieve. This size corresponded well to the two smallest sizes of clods used in the wind tunnel study (Table 1).

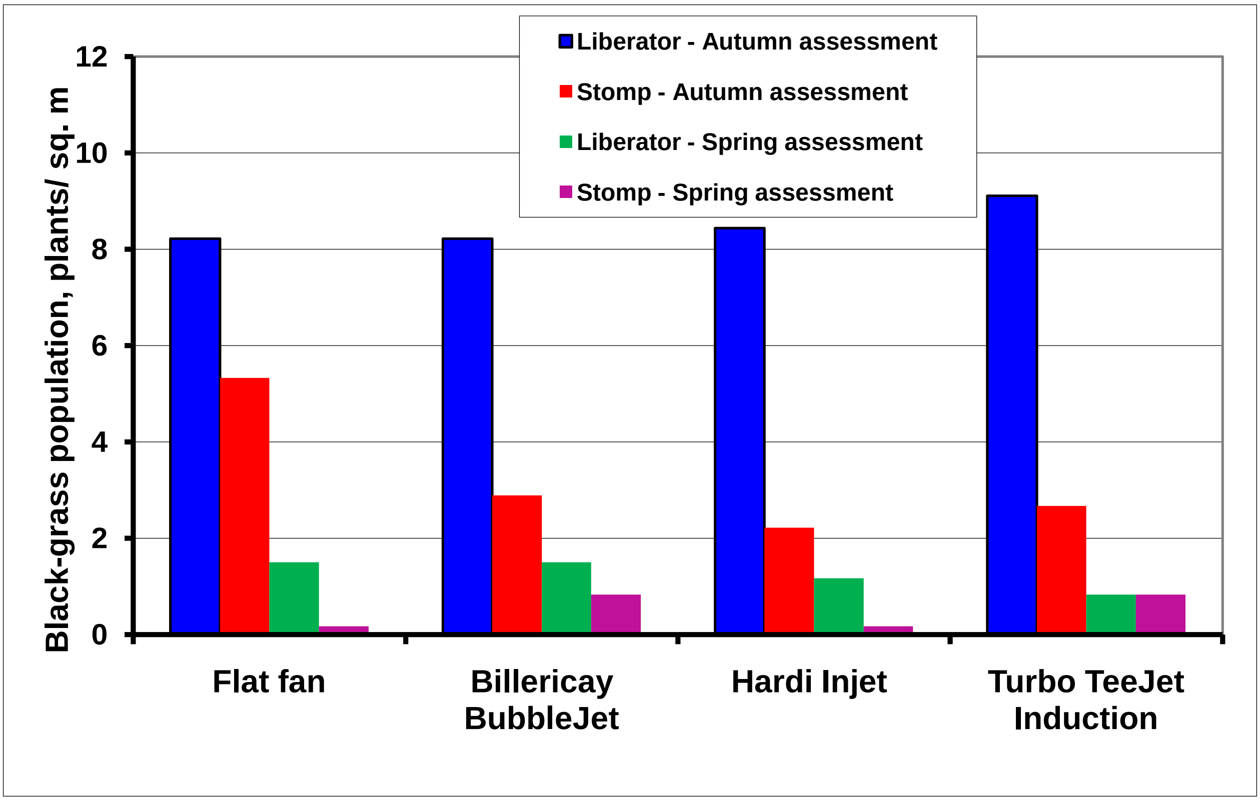


Figure 14. Black-grass populations in treated plots at site B in the 2009 harvest year

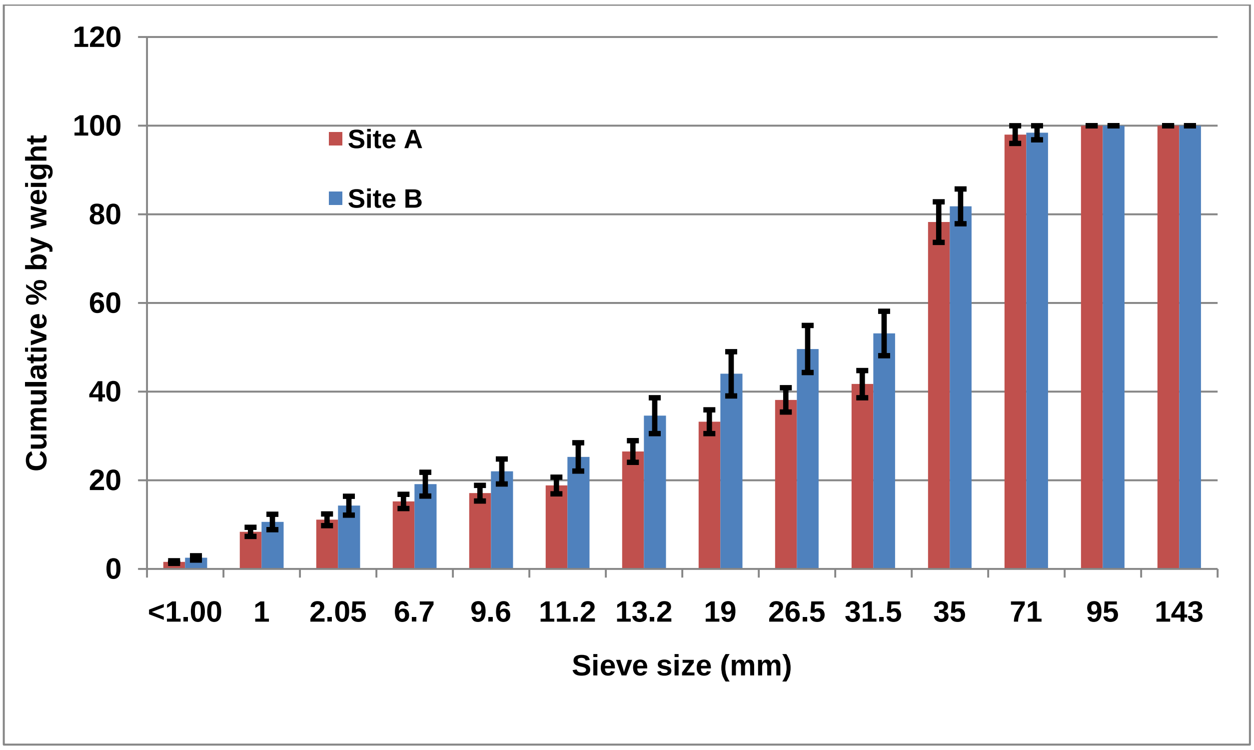


Figure 15. Clod size distributions at the two sites in the 2009 harvest year

Results from field trials in the 2010 harvest season

Black-grass population counts at site C in the 2010 harvest season were only made in the spring due to adverse weather conditions in November 2009 when the plots were snow covered. The results (Figure 16) again showed no statistically significant differences between nozzle treatments although all treatments gave significantly reduced black-grass populations when compared with the untreated.

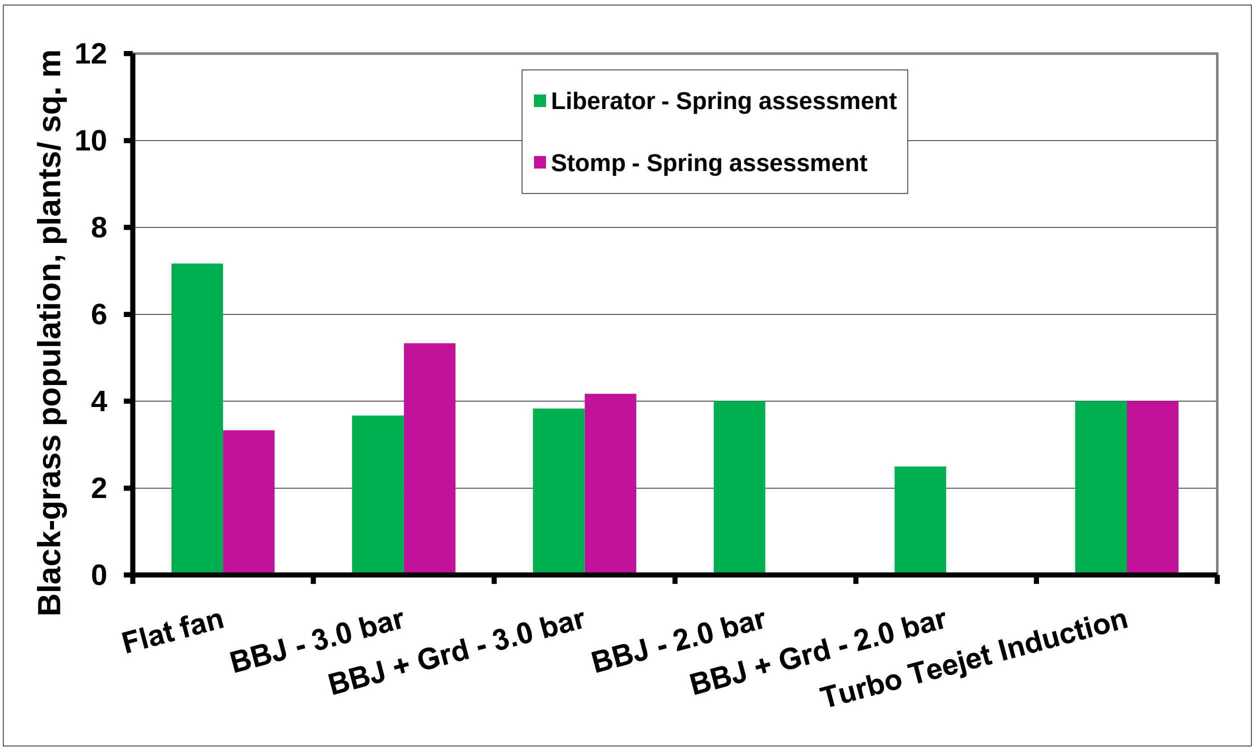


Figure 16. Black-grass populations in treated plots at site C in the 2010 harvest year

At site D in the 2010 harvest year black-grass populations on the trial site were low (Figure 17) and there was some rabbit damage on some of the plots early in the season. Although the analysis of variance did show some statistically significant differences in black-grass counts at the autumn assessment, these were not consistent across the treatments and probably related to the patchy nature of the black-grass and the low populations. Head counts at this site did produce some significant differences that correlated with the applied treatments with higher counts in plots treated with the conventional nozzle and the small droplet air-induction nozzle and lower counts in the plots treated with the large droplet air-induction nozzle. However it should be noted that head counts in plots treated with the pre-orifice nozzle were not statistically different from the mean and hence the trends with droplet size treatments were not entirely consistent. There were no significant differences between the levels of control achieved with the two formulations applied.

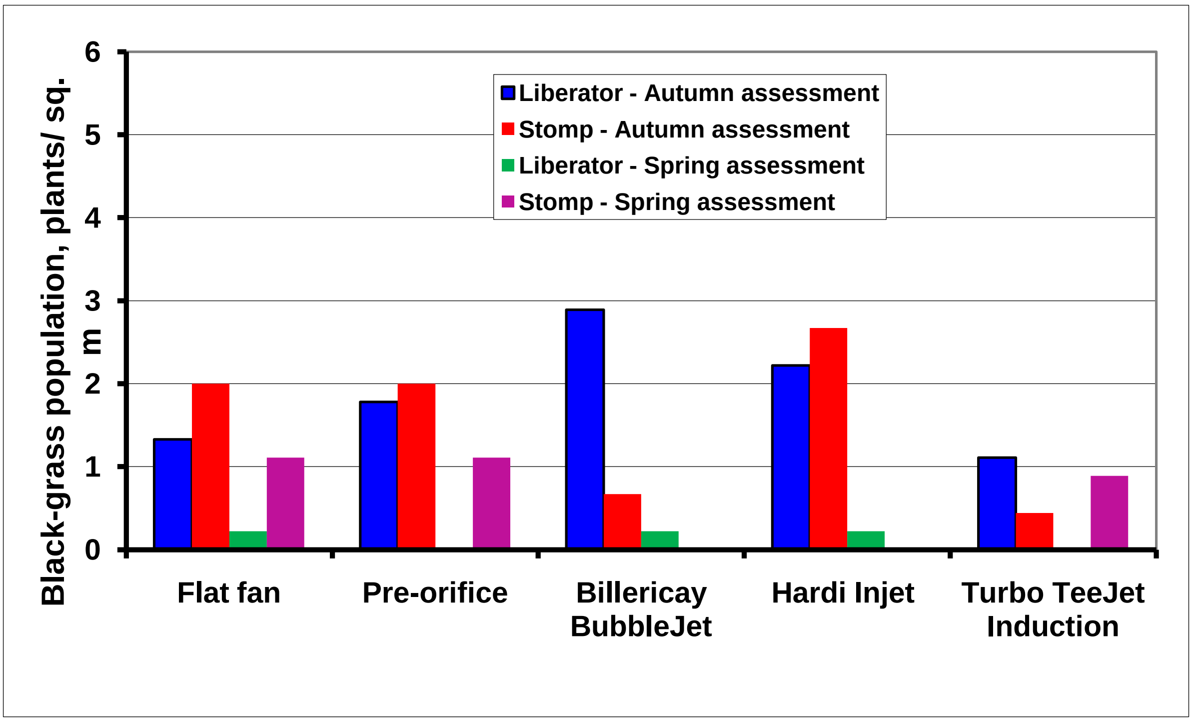


Figure 17. Black-grass populations in treated plots at site D in the 2010 harvest year

Results of measurements of clod size distributions for the seedbeds at the two sites in the 2010 harvest year (Figure 18) showed that there was a finer tilth at both sites than had been achieved at the sites used in the previous season and that the mean clod size was greater at site C than at site D. The mean clod size at site D was retained on an 11.2 mm sieve whereas at site C the mean clod size was retained on a 13.2 mm sieve.

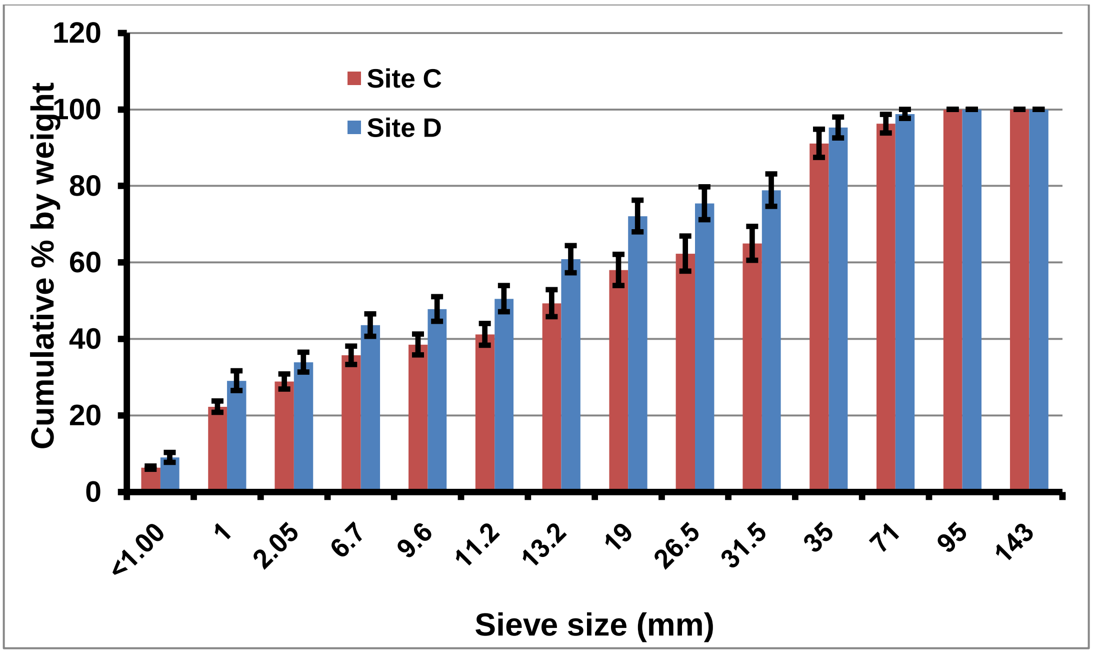


Figure 15. Clod size distributions at the two sites in the 2010 harvest year

3.4. Discussion

The laboratory studies showed that the more uniform spray deposit distributions at the soil surface were obtained when using the finer sprays with levels of this uniformity assessed at a millimetre scale. Using sprays with an increased horizontal trajectory did not improve the uniformity of distribution around clods but probably did increase the deposition on the clods. The relative importance of deposits around clods and on the clods is not clear but the results from the field trials suggest that this is not a major factor influencing the efficacy with the tank mixes used in the study. The field trials consistently gave no statistically significant differences between the different nozzle treatments used even though measurements of the droplet size distributions showed that the widest possible range of droplet sizes had been used in the trials. There was no consistent tendency in the results from the field trials for the applications made with the finer sprays to give improved levels of control. The hypothesis that the distribution of spray deposits at the soil surface would influence product efficacy could not therefore be supported by the results of the study.

The results obtained from the field trials were in broad agreement with those obtained from studies conducted at the National Agronomy Centres (run by TAG in conjunction with Agrovista) which included work at sites very close to sites A and C used in the work reported here but that used some different nozzle treatments. While most of the results from these studies gave results that were not statistically different, there were some relevant trends in the data, namely:

a) Applications at 100 L/ha tended to give higher levels of control than applications at 200 L/ha even when the same nozzle types were used to make the applications: all the work in this study was based on applications at 100 L/ha and the available evidence suggests that this would give the highest level of control;
b) Treatments using angled nozzles such as the “Hawk” and “Defy” nozzles tended to give higher levels of control suggesting that deposition on the clod rather than around the clod may be important in terms of efficacy;
c) There were no consistent trends between the level of efficacy obtained and the droplet size distribution in the applied spray.

A factor that is likely to be important in determining the efficacy of pre-emergence sprays is the patternation of the spray. This will relate to the variability in deposit at a larger scale than assessed in detail in this study and will have components relating to nozzle operating pressures, boom stability and the effect of air movements around the sprayer (Webb *et al*, 2002; Webb *et al*., 2004). The laboratory and wind tunnel studies in this work all used nozzles working within their defined operating pressure range and both pressure and boom movements were closely controlled. Results shown in Table 7 indicate that the spray fan angles for some nozzles even when operating well within their defined pressure range may be less than the nominal specification. In practical field conditions, boom movements and operation at low pressures (e.g. due to reducing speed when using a pressure control system) may also reduce the uniformity of deposits at the soil surface. Separate studies examined the effect of reducing operating pressure for two designs of air-induction nozzle with a specified minimum working pressure of 2.0 bar for the small droplet design and 1.0 bar for the large droplet design and the results are summarised in Figure19. While it is recognised that the spray fan angle as estimated from measurements with a spray analyser (as in Figure 19) does not necessarily relate directly to nozzle patternation, it does provide an indication of likely performance and the results in Figure 19 show the importance of maintaining operating pressures if patternation is also to be maintained.

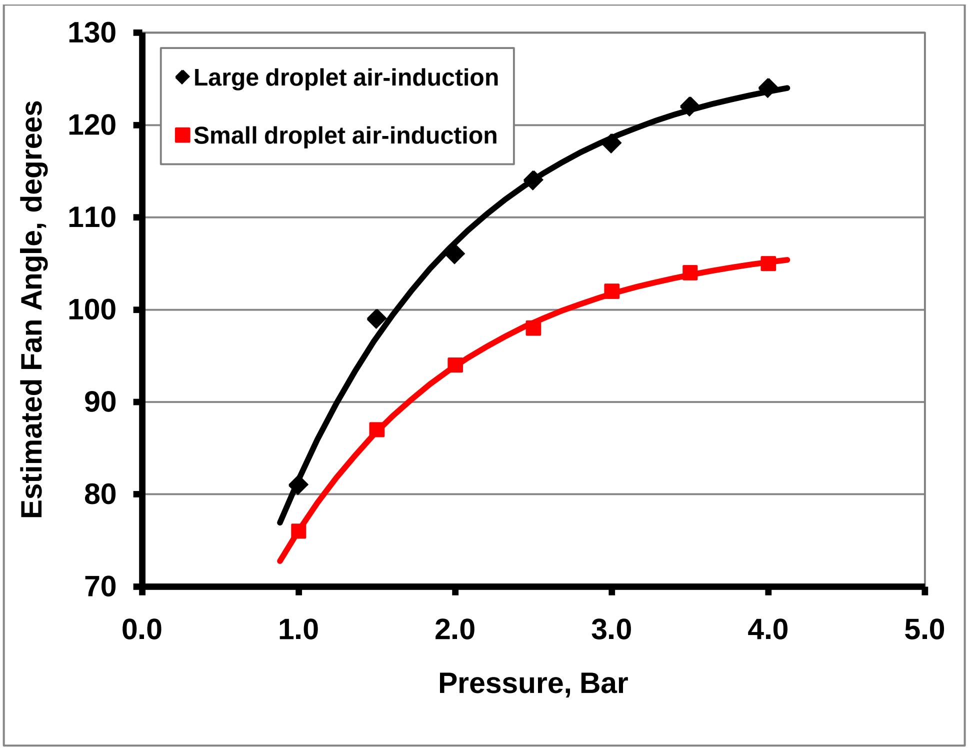


Figure 19. Spray fan angles estimated from droplet size analysis measurements with two air-induction nozzle designs.

Several authors have examined other factors that influence large scale variation in spray deposits such as boom movements and air flows around the spraying vehicle. Boom stability is a function of boom suspension design and recent advances in active attitude control systems matched to passive suspension design has enabled booms up to 36 m wide to be operated in a wide range of conditions. However, the need to keep boom heights to a minimum in order to control spray drift (Miller *et al*., 2008) will mean that boom movements will have a greater effect on deposit uniformity and further work is required to relate levels of deposit uniformity that are being achieved to the performance of boom suspension designs on modern sprayers. Studies reported by Webb *et al*., (2002 and 2004) examining deposit uniformity under booms showed that the deflection of sprays due to air movements behind both the spray vehicle and boom structure was much less when using air-induction nozzles than with conventional designs. This study used a very limited range of conditions and again there is a need to extend this study to more closely define the effects of sprayer design and forward speeds on the uniformity of deposits.

The ability to define the effects of seedbed tilth and wind speed on the smaller scale uniformity of deposits was limited in this study. The results from the wind tunnel work did not show effects due to clod size or wind speed although the range of wind speeds used may have been relatively limited in comparison with those encountered in practice. Rougher seedbeds with larger clods are likely to result in a greater percentage of the spray being retained on the clods particularly if angled sprays are used.

Given that the results of the study have shown that the use of a fine or medium quality spray is not needed to give high levels of efficacy with pre-emergent sprays, users would be able to use air-induction nozzles for such applications with substantial advantages relating to a reduced risk of drift and potentially a wider application window.

Taking the results from this project together with those from associated work undertaken at the National Agronomy Centres, enables the following key messages to be defined:

- Efficacy is likely to be higher when using 100 L/ha rather than 200 L/ha and this also gives timeliness advantages;
- There is flexibility in nozzle selection when applying the 100 L/ha such that using an air-induction nozzle will represent a good option for delivering high efficacy and acceptable drift control: the use of this nozzle design will potentially improve timeliness and the uniformity of deposits when travelling at higher forward speeds;
- There are no differences in the application requirements for chemicals having primarily root or shoot uptake modes of action;
- In coarser seedbeds, there may be some advantages from using application systems that generate mixing of the spray during delivery (such as the “Hawk” nozzle operated forwards and backwards) to improve the uniformity of coverage at the soil surface;
- It is important that factors influencing the spray volume distribution pattern below the boom including nozzle pressure, boom stability and forward speed are managed to keep the larger scale deposit distribution as uniform as practicable.

3.5. Acknowledgements

Thanks are due to:

- Staff from Agrovista Ltd for helpful discussions at all stages of the work and for help with managing field trials at two of the sites;
- Other member of the NIAB TAG staff who contributed to the work and particularly the trials teams for help in conducting the field trials;
- Mr Clive Tuck from Silsoe Spray Applications Unit for measurements of the droplet size distributions from the nozzles used in the study.

3.6. References

Butler Ellis, M.C.; Swan, T.; Miller, P.C.H.; Waddelow, S.; Bradley, A.; Tuck, C.R. (2002). Design factors affecting spray characteristics and drift performance of air induction nozzles. *Biosystems Engineering* **82**, (3), 289-296.

HGCA Nozzle Guide (2010). AHDB-HGCA London (now Stoneleigh).

Miller, P.C.H.; Butler Ellis, M.C. (2000). Effects of formulation on spray nozzle performance for applications from ground-based boom sprayers. *Crop Protection*, **19**, 609-615.

Miller, P.C.H.; Lane, A.G.; O'Sullivan, C.M.; Tuck, C.R.; Butler Ellis, M.C. (2008). Factors influencing the risk of spray drift from nozzles operating on a boom sprayer. . International Advances in Pesticide Application, *Aspects of Applied Biology*, **84**, 9 – 16

Tuck, C.R.; Butler Ellis, M.C.; Miller, P.C.H. (1997). Techniques for measuring droplet size and velocity distributions in agricultural sprays. *Crop Protection*, **16**, (7), 619- 628.

Webb, D. A.; Parkin, C.S.; Andersen, P.G. (2002). Uniformity of the spray flux under arable boom sprayers. *Aspects of Applied Biology*, 66, International Advances in Pesticide Application, 87 – 94.

Webb, D. A.; Parkin, C.S.; Taylor, W. A.; Taylor, B. P. (2004). The influence of nozzle design, application speed and air-assistance on the variability of spray deposits under arable boom sprayers. *Aspects of Applied Biology*, 71, International Advances in Pesticide Application, 83 – 90.