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Distribution of spray applied to a cereal crop and the effect of application parameters on penetration

by

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CONTENTS

1. ABSTRACT

A series of trials were carried out, both in the field and in a wind tunnel, to investigate the distribution in a winter wheat canopy of a spray application, to identify the factors which influence the distribution, in particular, the quantity of spray depositing on the lower stem.

Increasing application volume was shown to have no influence on the quantity of active ingredient reaching the lower part of the canopy. Recommendations to increase volumes to improve penetration of a dense canopy cannot, therefore, be justified.

The best application system, of those tested in this study, to achieve high penetration into a canopy, as well as good overall plant deposits, was a small droplet air-induction nozzle operating at 100 L ha^{-1}.

Other factors that influence deposition of spray in the lower part of the canopy are wind speed and potentially boom height. Use of an air-induction nozzle effectively eliminated the effect of wind speed and so would be likely to deliver a more uniform distribution over the canopy. An 80° nozzle also increased penetration, but its effect might be reduced by the need to increase boom height with narrower angle nozzles in order to maintain a uniform distribution.

2. SUMMARY

2.1. Introduction

The performance of an agrochemical application to a crop depends upon achieving appropriate targeting of the spray, i.e. maximising the quantity reaching the appropriate site on the plant. Information about placement within the canopy is not readily available and different sources (such as agrochemical or spray nozzle manufacturers) tend to suggest different solutions. Most commonly, the use of high water volumes is recommended to increase penetration into the canopy, although there is little data to support this. Other suggestions have included increasing pressure, angling sprays and using larger droplets.

The distribution of spray within a canopy will depend upon the canopy structure itself – techniques that increase penetration in a cereal crop, where the structure is relatively upright, are unlikely to increase penetration in a potato crop, for example. This project was, therefore, primarily focused on cereals but the results may also have implications for other crops that have a predominantly vertical structure.

There are a number of situations where penetration into a canopy is important, for example, the application of fungicide for the treatment of eyespot. Under HGCA project 3362, 'Forecasting eyespot development and yield losses in winter wheat', a small field trial was undertaken to investigate the possibility of improving penetration into a winter wheat canopy in order to increase the deposit on the lower stem and potentially allow treatments for eyespot to be applied at a later growth stage. This study identified important potential improvements in deposit with particular nozzle designs and that increasing water volumes would be unlikely to improve penetration (HGCA Project Report 491).

A series of investigations were therefore undertaken, both in the field and in the wind tunnel at Silsoe Spray Applications Unit: to investigate the distribution in a winter wheat canopy of a spray application, to identify the factors which influence the distribution, and in particular, to measure the quantity of spray depositing on the lower stem. The hypotheses to be tested were that:

- Increasing application volume would not increase the deposit in the lower part of the canopy
- A more vertical droplet trajectory would increase the deposit in the lower part of the canopy; and
- Small droplet air induction nozzles would give a good level of deposit in the lower part of the canopy.

2.2. Materials and methods

2.2.1. Field experiments

Plots of winter wheat, (variety Oakley) 6 m wide by 8 m long, with 8 m gaps between, were sprayed with a solution containing a non-ionic surfactant at 0.1% by volume, and 2 g L^{-1} of a tracer dye (Green S) using a 24 m boom sprayer.

Treatments were partially randomised and there were five replicate plots per treatment. Following the spray application, 20 plants were taken randomly from each plot, excluding the area 1.0 m from the edge, which were subdivided into two samples, making a total of 10 samples per treatment.

2.2.2. Wind tunnel experiments

Trays of winter wheat (variety Scout) were grown outdoors to growth stage (GS) 37 and arranged in a 4 x 3 array in the wind tunnel underneath a track sprayer with a three-nozzle boom. The trays were 0.3 x 0.25 m and 0.15 m deep. The two central trays were used to obtain samples, with one sample per tray. There were three replicate runs for each treatment, making six replicate samples per treatment.

2.2.3. Sample handling

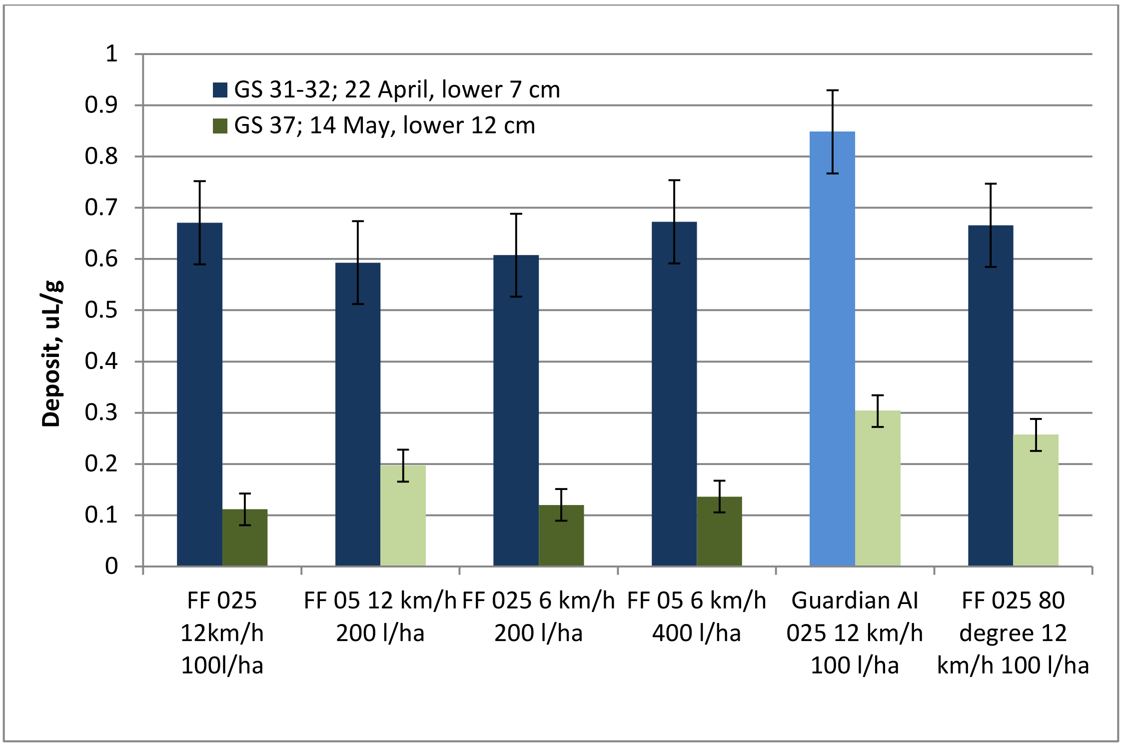
Plants were divided into three sections, bottom, middle and top, and leaves separated from stems. Each bag of samples was stored in cool, dark conditions until analysis. Each sample was weighed, and then a known volume of deionised water was placed in the bag and was shaken to remove the deposited dye. The rinsate was decanted into test tubes and the concentration compared with that of the tank samples using spectrophotometry to determine the quantity of original spray liquid deposited on the lower stems.

Applications were made between BBCH GS 31-and 37 (BBCH, 2001). A range of nozzles were selected to give different volumes and spray characteristics, and combined with different forward speeds (6 – 12 km/h) and boom heights (0.6 – 0.75 m above the crop).

2.3. Results

2.3.1. Initial results from Project 3362 (HGCA Project Report 491)

Measurements of the deposit on the lower stem of wheat plants are shown in Summary Figure 1 for the two growth stages.



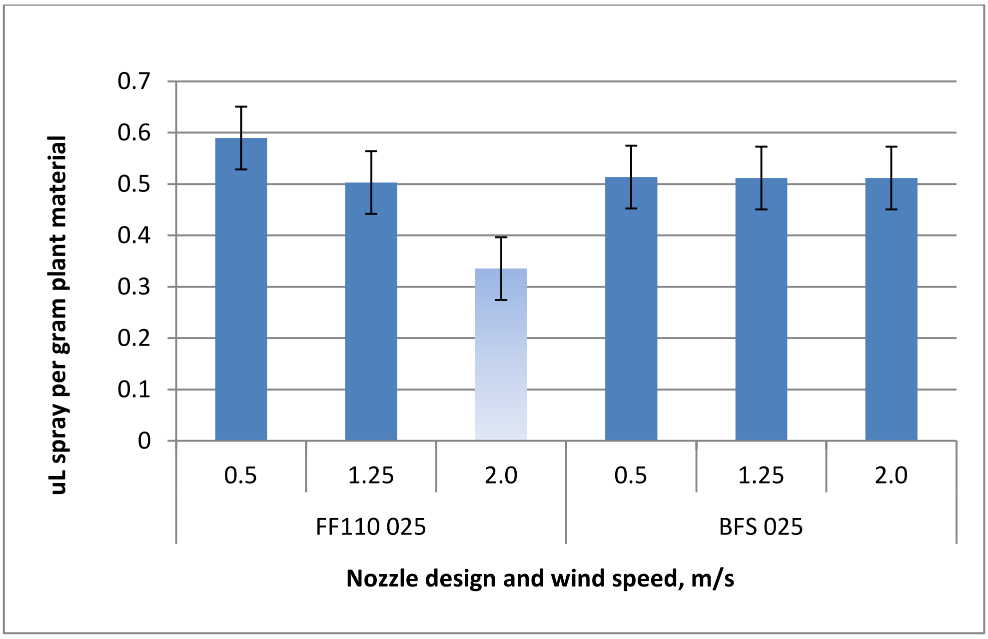
Summary Figure 1. Normalised spray deposit (µL/g fresh weight per 100 l/ha applied) on lower stem of winter wheat plants after an application at GS31-32 (left bars, or colour) and at GS37 (right bars, other colour). Error bars indicate LSD/2. Lighter bars indicate statistically significant differences from the FF025 at 12 km h^{-1} (100 L/ha) at the same growth stage.

2.3.2. Results from wind tunnel tests (2010)

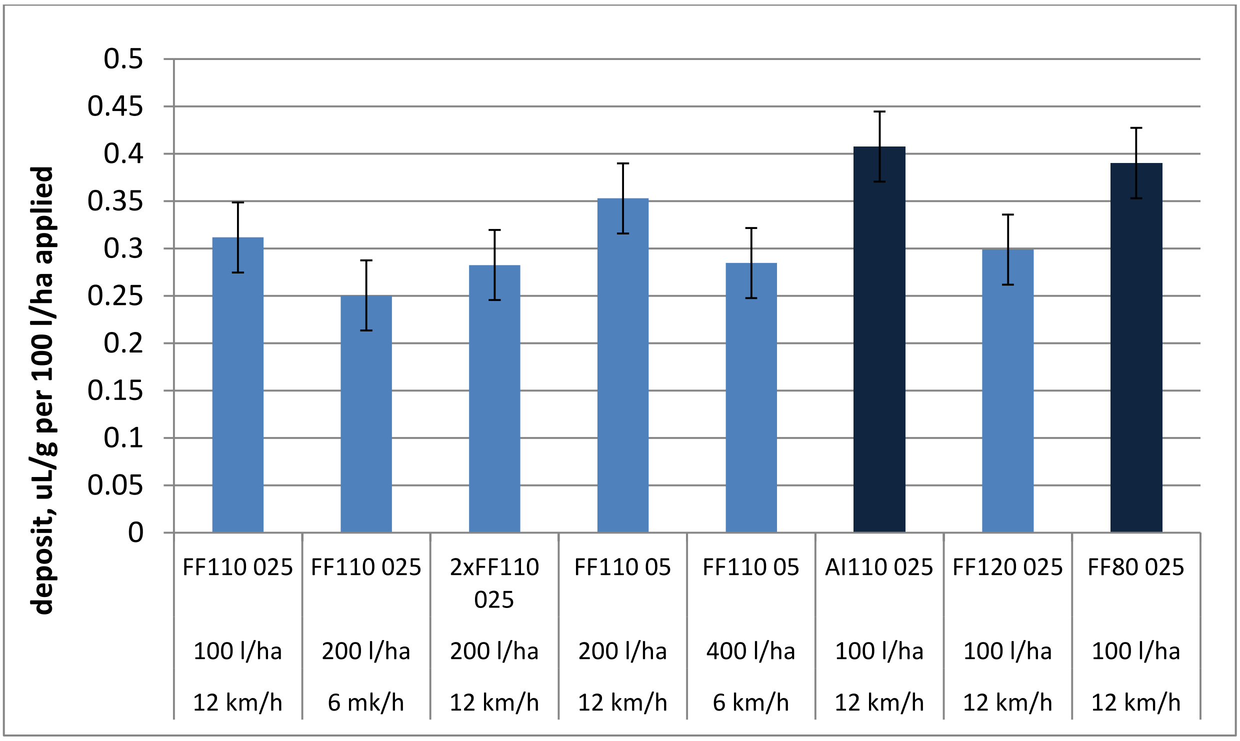
Measurements of deposit on the lower stem of tray-grown plants sprayed in the wind tunnel with a range of wind speeds are shown in Summary Figure 2. This shows that as wind speed increases, the amount of spray reaching the lower part of the canopy is reduced with a conventional nozzle design, but is unaffected when spraying with a small-droplet air-induction nozzle.

2.3.3. Results from field trials (2010)

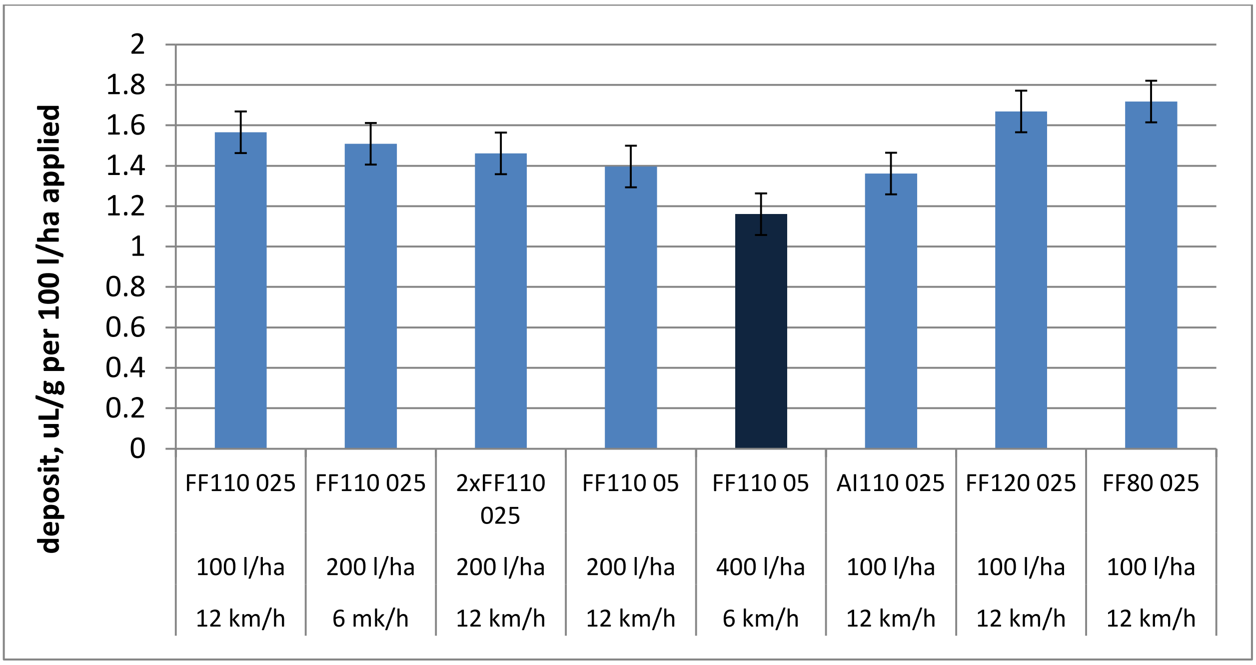
A field trial investigated the effect of increasing water volume from 100 to 400 L ha^{-1} through a combination of nozzle size and forward speed, and also the effect of nozzle design on the deposits within the canopy. Summary Figure 3 shows the deposit on the lower stem, and Summary Figure 4 the deposit on whole plants.



Summary Figure 2. Deposit on lower 100 mm of plants (µL/g fresh weight per 100 l/ha applied) for different nozzles and wind speeds, measured in the wind tunnel. Error bars denote LSD/2. Lighter bars indicate significant differences from the same nozzle in a wind speed of 0.5 m s^{-1}.



Summary Figure 3. Normalised spray deposit (µL/g fresh weight per 100 L ha^{-1} applied) on lower stem of winter wheat plants sprayed in the field at GS37. Error bars indicate LSD/2. Darker bars indicate significant differences from the 110 025 flat fan nozzle at 12 km h^{-1} (100 L ha^{-1}).



Summary Figure 4. Total normalised spray deposit (µL/g fresh weight per 100 L ha^{-1} applied) on whole winter wheat plants sprayed in the field at GS37. Error bars indicate LSD/2 Darker bars indicate significant differences from the 110 025 flat fan nozzle at 12 km h^{-1} (100 L ha^{-1}).

2.4. Discussion

Field trials and wind tunnel tests showed clearly that increasing spray volume did not improve the quantity of spray deposited on the lower parts of plants but did reduce the quantity of spray deposited over the whole plant. This suggests that the proportion of retained spray reaching the lower part of the canopy might be greater at the higher volumes, but this is not sufficient to compensate for the lower deposits overall.

It is common to read label recommendations stating that volumes up to 400 L ha^{-1} should be used to achieve penetration into dense cereal canopies, and there is sometimes uncertainty among spray operators about whether 100 L ha^{-1} would give adequate control. However, the results presented here show that the recommendation to growers to increase volume in order to improve penetration of cereal crops cannot be justified.

The type of nozzle that gave the greatest deposit on the lower part of the canopy in field trials was a small droplet air-induction nozzle. These gave slightly lower deposits on the whole plant which were, although not statistically significant, consistent with other studies with air-included droplets. However, this has been shown in previous work to have no significant reduction in a T2 fungicide performance. We can therefore conclude that an air induction nozzle is likely to give good penetration into a cereal canopy at growth stages 32−37 without risk of compromising the performance of a fungicide application.

Applications at the later growth stage (GS37) resulted in significantly less deposit on the lower stem per gram plant material than at the earlier growth stage (GS31-33): on average 0.19 $\mu L\ g^{-1}$ compared with 0.68 $\mu L\ g^{-1}$. This demonstrates that even with the best nozzle and application conditions, a later application cannot achieve the levels of deposit in the lower part of the canopy that an earlier application can achieve, and canopy structure is the most important factor influencing penetration.

Current recommendations in the HGCA nozzle chart indicate a small droplet air induction nozzle and or a medium quality spray, at a volume of 100 – 200 $L\ ha^{-1}$ would give optimum performance for a fungicide application after GS 32. The findings of this work support this recommendation and, furthermore, suggest that there could be significant advantages to using volumes closer to 100 $L\ ha^{-1}$ in terms of total deposit retained on the plant. This is likely to give the best coverage of all parts of the plant compared with typical commercially-available nozzle designs.

The performance of a pesticide application does not depend solely on the quantity of active ingredient reaching the target site. The size of droplets may also be an important factor for some products and therefore it is important to validate the findings of this project by undertaking some efficacy testing with commercial products.

3. TECHNICAL DETAIL

3.1. Introduction

The performance of an agrochemical application to a crop depends upon achieving appropriate targeting of the spray, i.e. maximising the quantity reaching the appropriate site on the plant. One of the key components in optimising an application of pesticide is the application technique, which includes nozzle choice and sprayer settings. In selecting the best application technique, the spray operator has to balance a number of factors, such as spray drift, target retention and coverage, penetration into a canopy, work rate and timing. Frequently, for both practical and economic reasons, a number of products that may have slightly different application requirements have to be applied in a single tank mix, making decisions about application technique even more complicated.

Research into both spray drift, and retention and coverage on a target weed or crop has provided information to spray operators that can be used to assist in decision-making. However, information about placement within the canopy is not readily available and different sources (such as agrochemical or spray nozzle manufacturers) tend to suggest different solutions. Most commonly, the use of high water volumes is recommended to increase penetration into the canopy, although there is little data to support this. Other suggestions have included increasing pressure, angling sprays and using larger droplets.

Clearly, the distribution of spray within a canopy will depend upon the canopy structure itself – techniques that increase penetration in a cereal crop, where the structure is relatively upright, are unlikely to increase penetration in a potato crop, for example. This project was therefore primarily focused on cereals but the results may also have implications for other crops that have a predominantly vertical structure.

There has been previous research into penetration into cereal canopies, such as that undertaken at Long Ashton in the early 1980s (e.g. Cooke *et al*, 1985). This work employed application techniques that are no longer relevant, was based on canopy densities that have also changed, and consequently the results may no longer be appropriate. In particular, the conclusion that increasing application volume from 100–200 L ha^{-1} leads to an increase in penetration into the crop is not supported by more recent data (e.g. Marshall *et al*, 2000, and Butler Ellis *et al*, 2007).

There are a number of situations where penetration into a canopy is important, for example, the application of fungicide for the treatment of eyespot. Under HGCA project 3362, ‘Forecasting eyespot development and yield losses in winter wheat’, a small field trial was undertaken to investigate the possibility of improving penetration into a winter wheat canopy in order to increase the deposit on the lower stem and potentially allow treatments for eyespot to be applied at a later growth stage. This study measured only deposits on the lower stem, and identified important potential improvements in deposit with particular nozzle designs, and that, contrary to current recommendations, increasing water volumes would be unlikely to improve penetration (HGCA Project Report 491).

A single field trial is generally insufficient to form robust conclusions and therefore this additional project aimed to repeat the eyespot study, but also investigate some of the basic mechanisms involved in allowing spray to reach the lower part of a cereal canopy. In addition, recognising that in practice eyespot treatments are likely to be applied together with other treatments and therefore a good distribution of spray over all parts of the plant is necessary, deposits on leaves and upper parts of the plant were also quantified in this work. The pesticide applications that are likely to benefit from improvement in the ability to penetrate a cereal canopy at growth stages 31 and beyond also include fusarium control, plant growth regulators and control of spring-germinating broadleaved weeds such as cleavers, chickweed and poppies.

A series of investigations were therefore undertaken, both in the field and in the wind tunnel at Silsoe Spray Applications Unit; to investigate the distribution in a winter wheat canopy of a spray application, to identify the factors which influence the distribution, and, in particular, to measure the quantity of spray depositing on the lower stem. The hypotheses to be tested, based on results from project 3362 (HGCA Project Report 491), were that:

- Increasing application volume would not increase the deposit in the lower part of the canopy
- A more vertical droplet trajectory would increase the deposit in the lower part of the canopy; and
- Small droplet air induction nozzles would give a good level of deposit in the lower part of the canopy.

The results from the earlier project, 3362 (HGCA Project Report 491), are presented alongside the results from this project in order to provide a complete set of results from which conclusions can be drawn and recommendations given.

3.2. Materials and methods

3.2.1. Field experiments

Plots of a winter wheat crop, (variety Oakley) 6 m wide by 8 m long, with 8 m gaps between, were sprayed with a solution containing a non-ionic surfactant at 0.1% by volume, and 2 g L^{-1} of a tracer dye (Green S) using a 24 m boom sprayer. This spray tank mixture had previously been evaluated for its use in laboratory work using artificial targets (O'Sullivan *et al*, 2010). Further tests were undertaken to establish the levels of recovery from plant material and the stability of the mixture for longer periods of experimental work, which led to a change in experimental protocols to ensure that spray mixtures were used within 24 hours.

Treatments were partially randomised (treatments have to remain on the same side of the boom for practical reasons, and were matched so as to spray two treatments simultaneously, one on each side). There were five replicate plots per treatment. Following the spray application, 20 plants were taken randomly from each plot, excluding the area 1.0 m from the edge, which were subdivided into two samples, making a total of 10 samples per treatment.

3.2.2. Wind tunnel experiments

Trays of winter wheat (variety Scout) were grown outdoors to BBCH GS 37 and arranged in a 4 x 3 array in the wind tunnel underneath a track sprayer with a three-nozzle boom. The trays were 0.3 x 0.25 m and 0.15 m deep. In 2009, two rows of plants were sown along the length of the tray. Results then suggested that this led to an insufficiently dense canopy, so in 2010 the planting scheme was changed, with three rows of plants in each tray with 0.1 m spacing, with seeds planted at 400 m^{-2}. The two central trays were used to obtain samples, with the plants being selected only from the middle of each tray to avoid edge effects, with one sample per tray. There were three replicate runs for each treatment, making six replicate samples per treatment.

3.2.3. Sample handling

Plants were divided into three sections, bottom, middle and top, and leaves separated from stems. Each bag of samples was stored in cool, dark conditions until analysis. Each sample was weighed, then a known volume of deionised water was placed in the bag and was shaken to remove the deposited dye. The rinsate was decanted into test tubes and the concentration compared with that of the tank samples using spectrophotometry to determine the quantity of original spray liquid deposited on the lower stems (UKAS accredited Test Procedure 2 – Appendices I and II 'Quantification of Green S by UV/visible spectrophotometry', using the UV/visible spectrophotometer UV510 S/N 104303). Three replicate samples were taken from untreated areas of the crop before the applications, to provide background readings.

3.2.4. 2008 field treatments (project 3362)

Applications were made both on 22 April (BBCH GS 31-32, beginning of stem elongation, timing A) and 14 May (BBCH GS 37, end of stem elongation, timing B) 2008 (Table 1). Deposits only on lower stems were determined in this work; the deposits on other parts of the plant were not recorded.

Table 1. Treatments for 2008 field trial

Treat No.	**Volume L ha^{-1}**	**Nozzle Type**	**Nozzle Size**	**Speed km h^{-1}**	**Boom height m**
1	100	Flat fan 110^{o}	025	12 [1]	0.6
2	200	Flat fan 110^{o}	05	12	0.6
3	200	Flat fan 110^{o}	025	6	0.6
4	400	Flat fan 110^{o}	05	6	0.6
5	100	Air –induction (Amistar/Guardian Air)	025	12	0.6
6	100	Flat fan 80^{o}	025	12	0.6

All treatments applied at both timings.

3.2.5. 2009 treatments (wind tunnel)

A range of nozzles were used to evaluate the effect of fan angle, air inclusions, volume and other factors influencing droplet trajectories (Table 2). All treatments were operated at 10 kph forward speed, 3 bar nozzle pressure (unless otherwise stated); wind speed of 0.5 m/s and a boom height of 0.65 m.

Table 2. Treatments used in 2009 wind tunnel tests

	Nozzle	Angle	Nozzle size	Spray angle*
Standard treatment:				
1	standard flat fan	110	03	v
Effect of fan angle:				
2	Flat fan	80	03	v
3	Lechler flat fan	120	03	v
Effect of air inclusions:				
4	Guardian air	110	03	-10^{o}
5	Guardian air vertical	110	03	v
6	Hardi Injet	110	03	v
Effect of volume:				
7	Multiple 03 nozzles	110	03 x 2	v
8	Flat fan 06 nozzles	110	06	v
Other nozzles:				
9	Spraying systems AITTJ60	110	03	$\mp 30^{o}$
10	Hollow cone DC04 – CR 25	90	pressure adjusted to give 1.2 l/min	v

* v = vertical; negative = backwards angled; positive = forward angled

3.2.6. 2010 treatments

Wind tunnel

Wind tunnel experiments were conducted to determine whether wind speed could influence the deposit over the crop and the penetration into the canopy. Two nozzle designs were selected, a conventional flat fan (FF) nozzle (F110/1.0/3.0) and a small droplet air induction nozzle (BFS BubbleJet) both an '025' size, operated at 3.0 bar and 10 km h^{-1}. Wind speeds between 0.5 and 2.0 m s^{-1} were applied during spraying as a head wind, i.e. in the opposite direction to the travel.

Field

A field trial was also conducted to evaluate the effect of nozzle design and applied volume (Table 3), applied at GS 37. A higher boom height was used for the 80^o nozzle to ensure an even distribution.

Table 3. Treatments for 2010 field trial

Treat No.	Volume L ha^{-1}	Nozzle Type	Nozzle Size	Speed km h^{-1}	Boom height m
1	100	Flat fan 110^o	025	12	0.6
2	200	Flat fan 110^o	025	6	0.6
3	200	Twin cap, Flat fan 110^o	2 × 025	12	0.6
4	100	Flat fan 80^o	025	12	0.7
5	200	Flat fan 110^o	05	12	0.6
6	400	Flat fan 110^o	05	6	0.6
7	100	Air-induction (BFS BubbleJet)	025	12	0.6
8	100	Flat fan 110^o	025	12	0.7

3.2.7. 2011 treatments (field)

A field trial was conducted to evaluate the effect of nozzle design and boom height (Table 4), applied at approximately GS 37. In addition to plant samples, long drinking straws were placed in the base of the canopy as an additional measure of the quantity of spray reaching the ground.

Table 4. Treatments for 2011 field trial

Treatment No.	Nozzle	Nozzle size	Boom height, m	Forward speed, km h^{-1}	Volume, L ha^{-1}
1	FF 110	025	0.5	12	100
2	AI - BFS BubbleJet	025	0.5	12	100
3	AI - Guardian Air	025	0.5	12	100
4	FF 110	025	0.75	12	100
5	FF 80	025	0.75	12	100

3.3. Results

3.3.1. 2008 (project 3362)

The quantity of spray liquid deposited on the lower stem is shown in Figure 1, with the data normalised for applied volume. The early timing (GS31-33) resulted in significantly more spray liquid per gram of plant material being deposited on the lower stem than at the later timing (GS37). Spray deposit increased by a factor of approximately six for the 110º flat fan nozzle, but only by a factor of around three for the air-induction nozzle and the 80º flat fan. Averaged over all treatments, the early timing resulted in higher deposits by a factor of four.

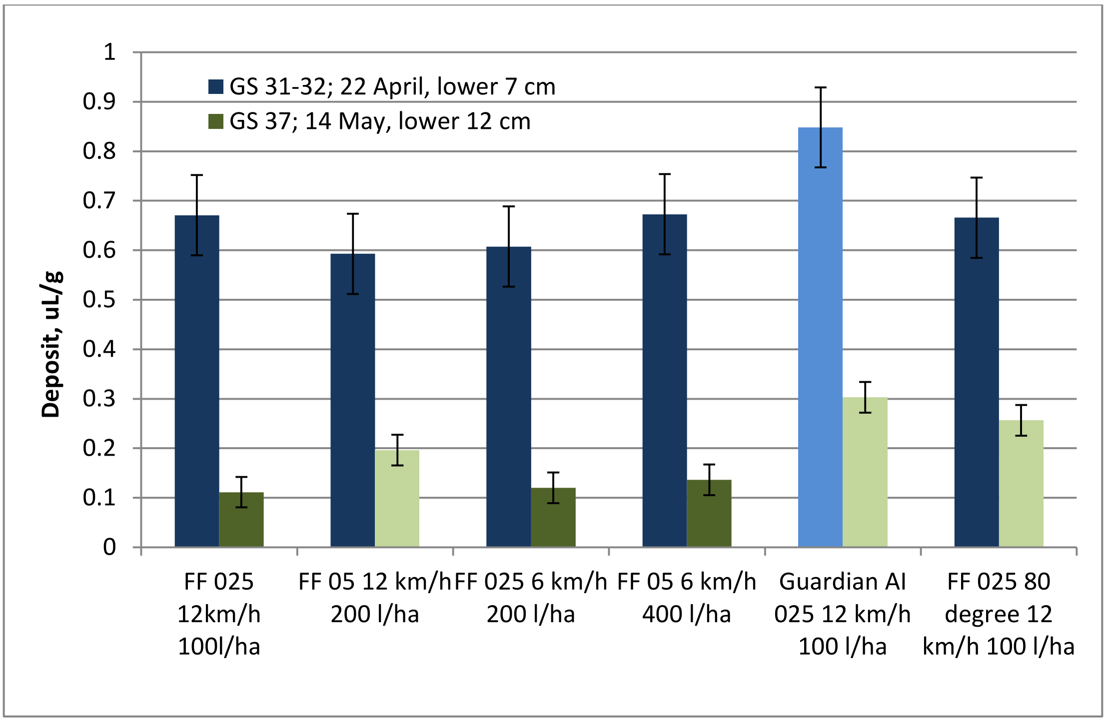


Figure 1. Normalised spray deposit (µL/g fresh weight per 100 L ha^{-1}) on lower stem of winter wheat plants after an application at GS31-32 (left bars, or colour) and at GS37 (right bars, other colour). Error bars indicate LSD/2. Lighter bars indicate statistically significant differences from the FF025 at 12 km h^{-1} (100 L ha^{-1}) at the same growth stage.

At the early timing (GS31-33), the deposit from the air-induction nozzle was significantly greater than all other treatments and there were no other significant differences. The air-induction nozzle put approximately 30% more on the lower stem than the other treatments. Increasing the spray volume applied with the standard flat fan nozzles from 100 to 400 L ha^{-1} had no effect on lower stem deposits.

At the later timing (GS37), the air-induction nozzle and the 80 degree flat fan nozzles both achieved significantly higher deposits on the lower stem, as did the 05 flat fan at 12 km h^{-1}. The air-induction nozzle deposit was approximately 2.7 times and the 80 degree nozzle 2.3 times that of the standard flat fan 025 nozzle at 12 km h^{-1}.

3.3.2. 2009 (wind tunnel)

Deposit on the lower stem is shown in Figure 2. Statistically significant differences from the standard treatment of a flat fan 110 03 single boom are shown as a lighter colour. The normalised values are consistent with those achieved in the field trial under project 3362 (HGCA Project Report 491), although they are closer to the earlier growth stage value, despite being sprayed at a growth stage nearer to the later value. This is probably due to the differences between a tray-grown crop and a field crop, and also differences between variety and growing conditions.

However, the same trends in deposit were not observed with the different nozzles, and one of the hypotheses we were testing, i.e. that a more vertical trajectory would result in greater deposits on the stem, was not supported. The TTJ-AI-03, which had two spray fans angled at 30 degrees, forwards and backwards and therefore with the least vertical trajectory, had one of the highest levels of deposit on the lower stem. Also the Guardian Air nozzle, which had the most vertical trajectory, did not increase the deposit on the lower stem.

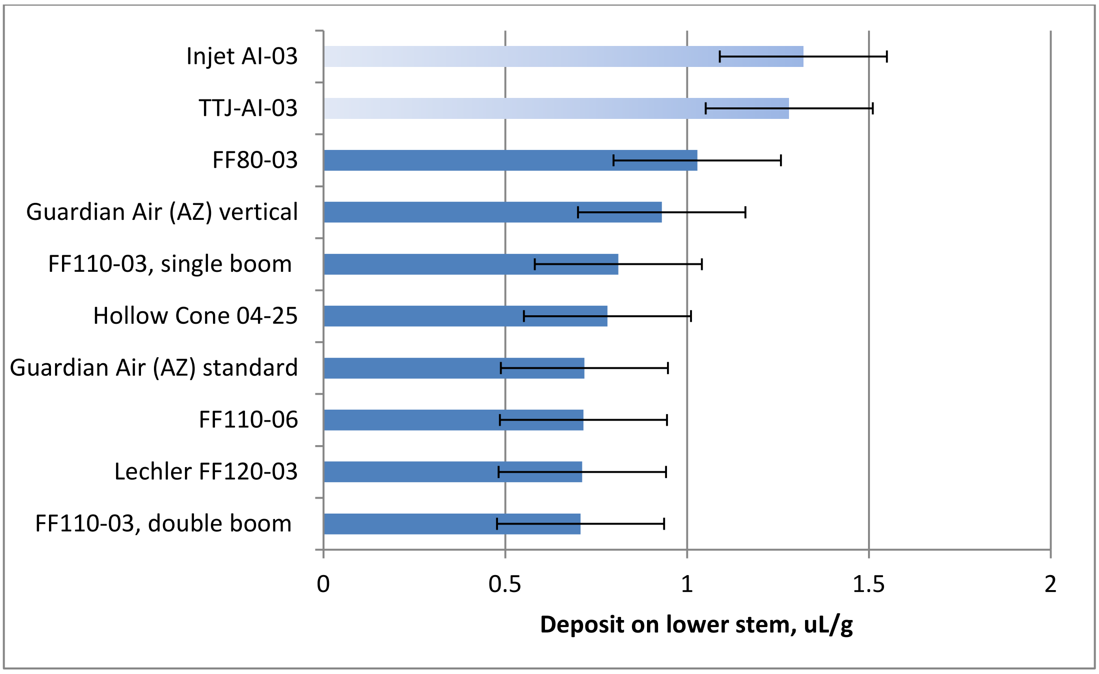


Figure 2. Normalised spray deposit (µL/g fresh weight per 100 L ha^{-1} applied) on lower stem of winter wheat plants after an application at GS32-37. Error bars indicate LSD/2. Lighter bars indicate statistically significant differences from the FF110 03 at 10 km h^{-1} (144 L ha^{-1}).

The results did show, however, that an increase in volume had no effect on deposit in the lower part of the canopy. While this was not significant, when the leaves on the lower part of the plant were also taken into consideration, the reduction in deposit with volume was more apparent (Figure 3).

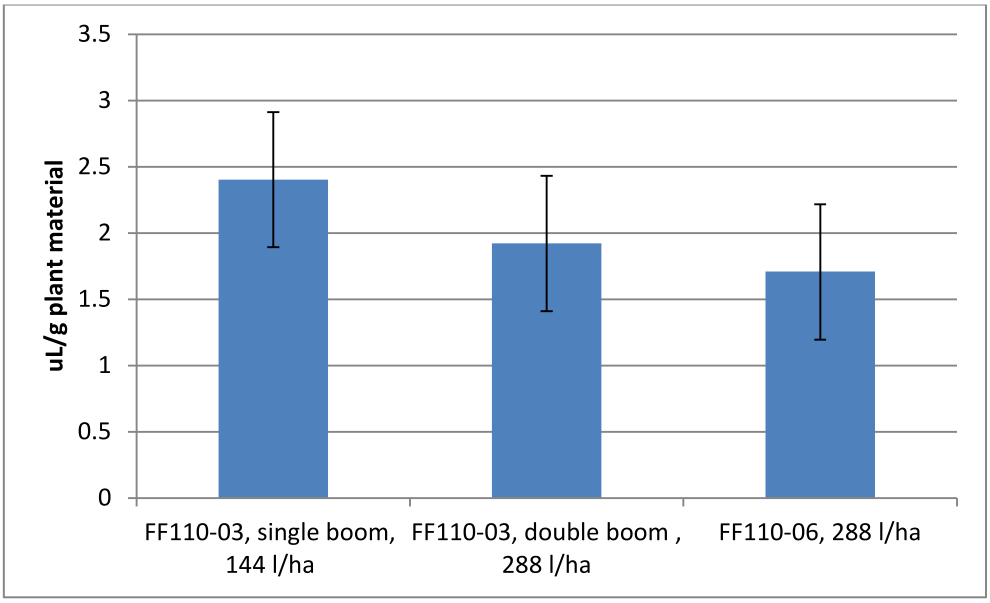


Figure 3. Normalised deposit on lower stem and leaves – effect of volume only. Error bars indicate LSD/2

Only one treatment resulted in a significantly different total deposit on the plants compared with the standard treatment – the relatively wide angled Lechler FF120-03. However, there was a trend of a reduction in deposit with volume.

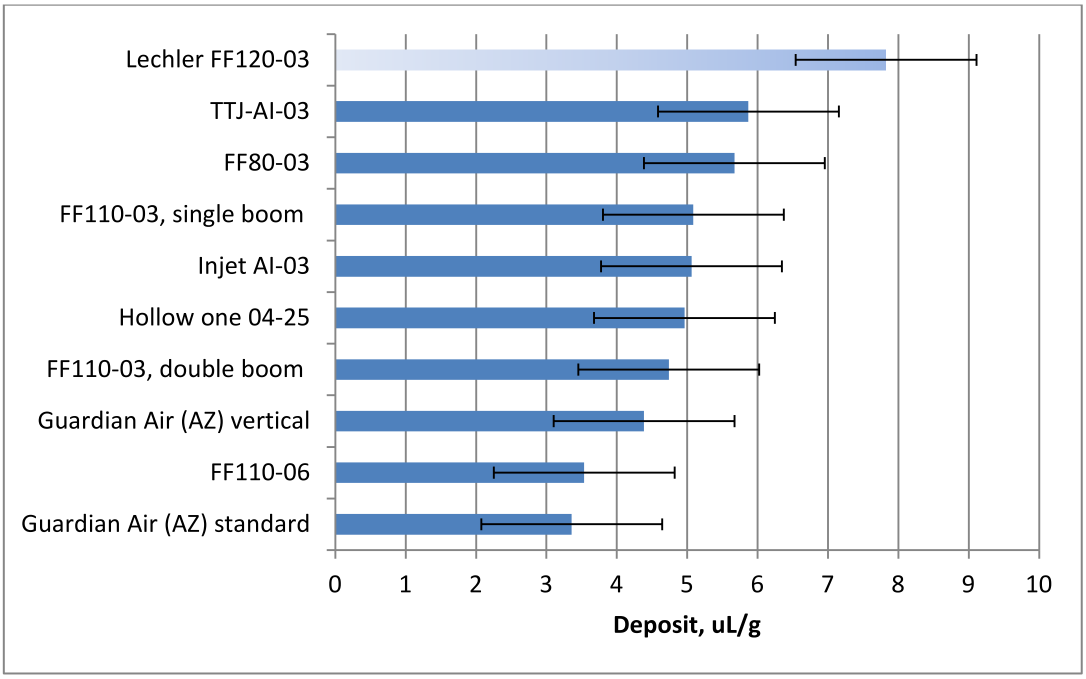


Figure 4. Normalised spray deposit (µL/g fresh weight per 100 L ha^{-1} applied) on whole winter wheat plants after an application at GS32-37. Error bars indicate LSD/2. Lighter bars indicate statistically significant differences from the FF110 03 at 10 km h^{-1} (144 L ha^{-1}).

3.3.3. 2010 trials

Figures 5 and 6 show the spray deposits on plant material for the wind tunnel experiment, with an effect of windspeed on both total deposit and deposit on the lower stem apparent for a conventional flat fan nozzle. Figures 6 and 7 show spray deposits on plant material for the field experiment, with a similar increase in deposit on the lower stem with the air induction nozzle and the 80^{o} nozzle (31% and 25% respectively) to that seen in 2008 (HGCA Project Report 491) at the earlier growth stage.

3.3.4. 2011 trials (field)

There were no significant differences between treatments in 2011: because of an exceptionally dry spring, the crop was relatively short and open, and therefore it was potentially unable to differentiate well between the different application types. Further analysis was undertaken with treatments grouped into ‘air induction nozzles’ (Guardian Air and Billericay BubbleJet) and ‘0.75 m boom height’ (110^{o} and 80^{o} flat fans), and compared with the standard treatment of 110^{o} nozzle at 0.6 m boom height, shown in Figures 6 and 7.

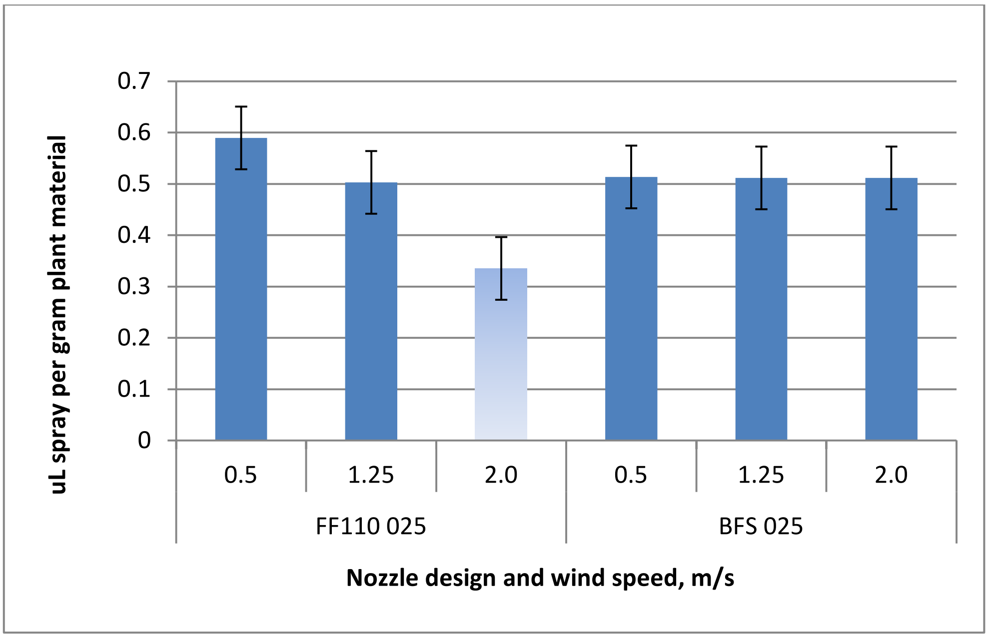


Figure 5. Deposit on lower 100 mm of plants (µL/g fresh weight per 100 L ha^{-1} applied) for different nozzles and wind speeds, measured in the wind tunnel. Error bars denote LSD/2. Lighter bars indicate significant differences from the same nozzle in a wind speed of 0.5 m s^{-1}.

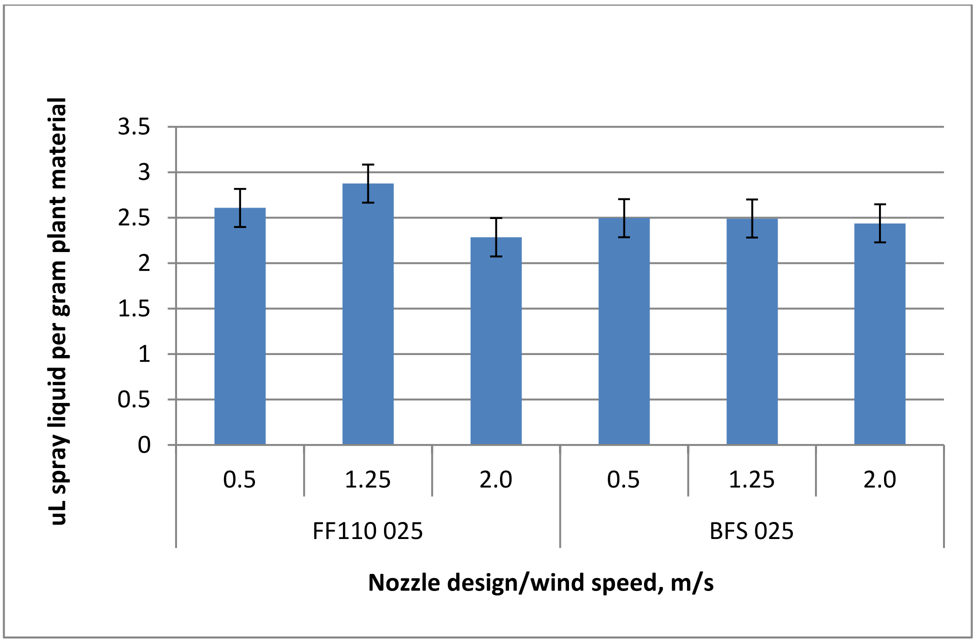


Figure 6. Total deposit on whole plant for different nozzles and wind speeds, measured in the wind tunnel. Error bars denote LSD/2. No significant differences.

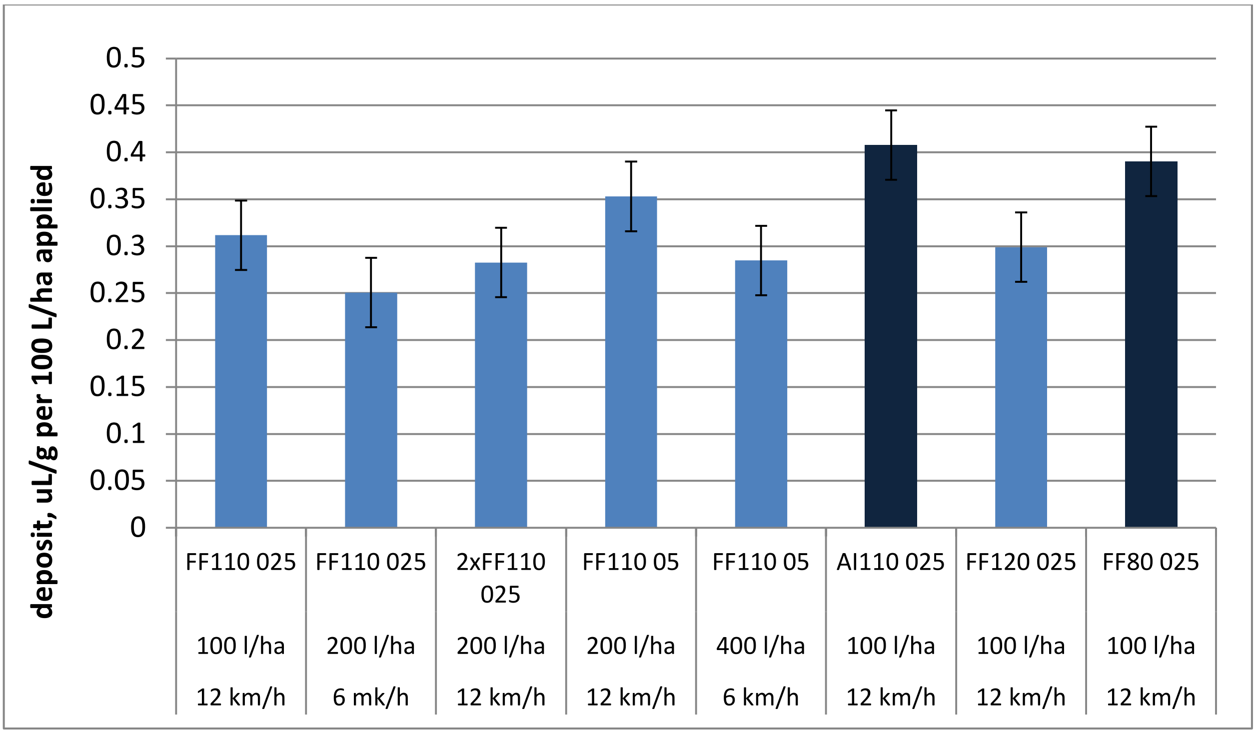


Figure 7. Normalised spray deposit (µL/g fresh weight per 100 L ha^{-1}applied) on lower stem of winter wheat plants sprayed in the field at GS37. Error bars indicate LSD/2. Darker bars indicate significant differences from the 110 025 flat fan nozzle at 12 km h^{-1} (100 L ha^{-1}).

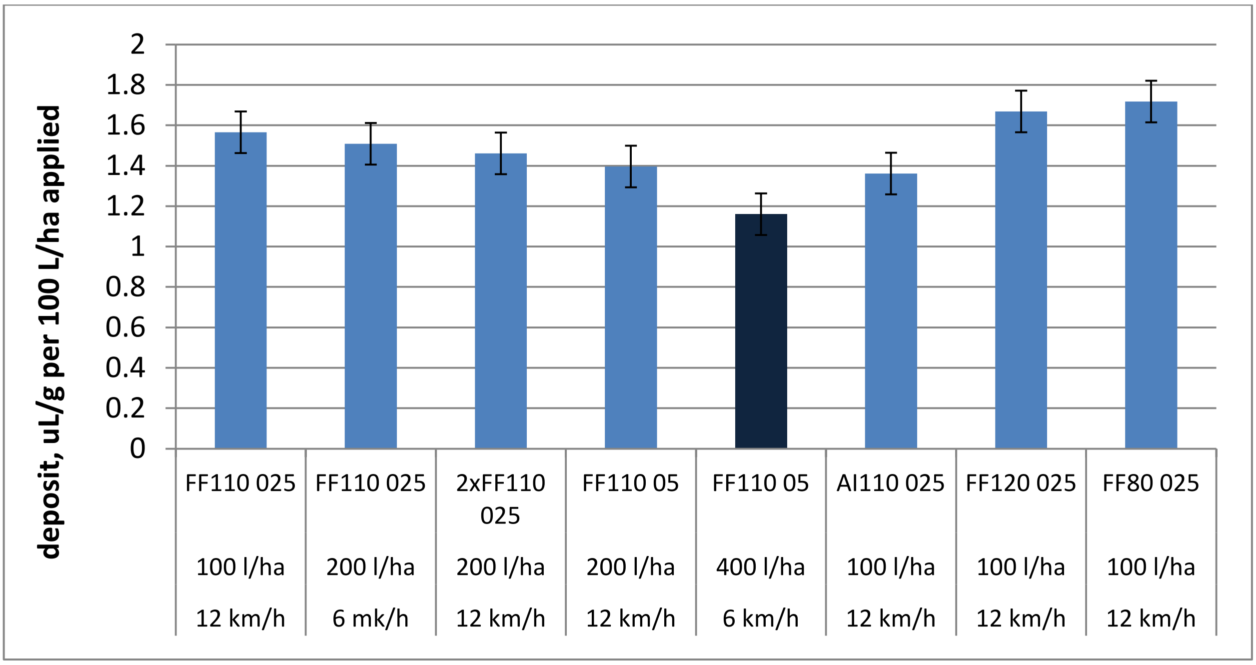


Figure 8. Total normalised spray deposit (µL/g fresh weight per 100 L ha^{-1} applied) on whole winter wheat plants sprayed in the field at GS37. Error bars indicate LSD/2 Darker bars indicate significant differences from the 110 025 flat fan nozzle at 12 km h^{-1} (100 L ha^{-1}).

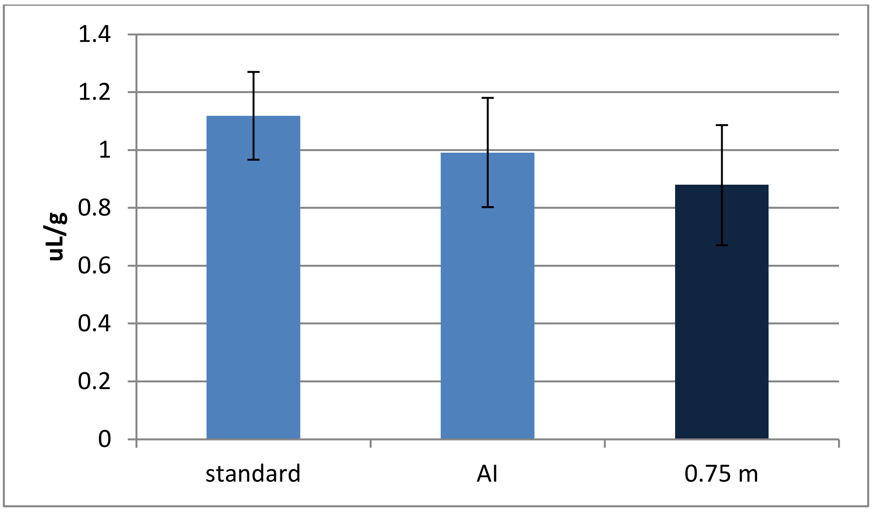


Figure 9. Total deposit (µL/g fresh weight per 100 L ha^{-1} applied) on whole winter wheat plants for standard flat fan nozzles at 0.5 m boom height, air induction nozzles at 0.5 m boom height and flat fan nozzles at 0.75 m boom height. Error bars indicate standard deviation. Darker bars indicate statistically significant differences from the standard treatment.

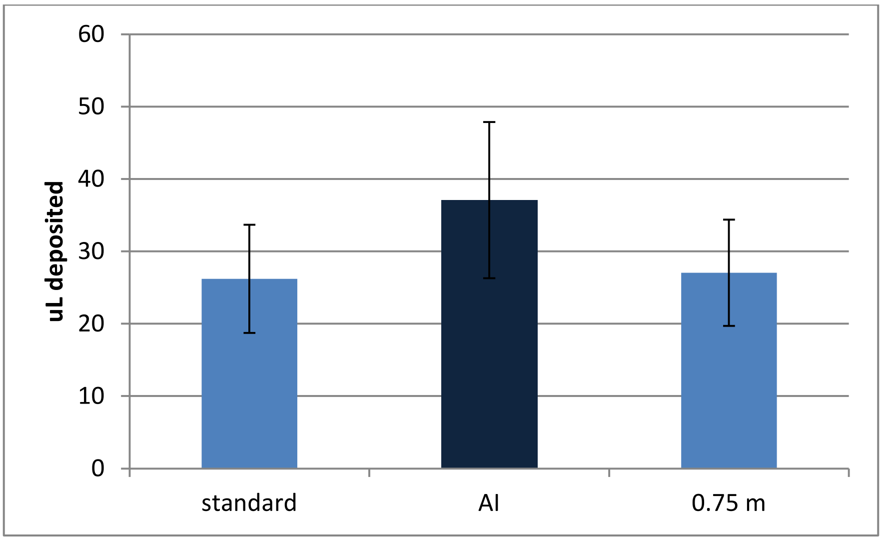


Figure 10. Deposit on drinking straws in base of canopy for standard flat fan nozzles at 0.5 m boom height, air induction nozzles at 0.5 m boom height and flat fan nozzles at 0.75 m boom height. Error bars indicate standard deviation. Darker bars indicate statistically significant differences from the standard treatment.

3.4. Discussion

Field trials in both 2008 and 2010, and in the wind tunnel in 2009, showed clearly that increasing spray volume did not improve the quantity of spray deposited on the lower parts of plants (Figures 1, 2 and 7), but did reduce the quantity of spray deposited over the whole plant (Figure 8). This suggests that the proportion of retained spray reaching the lower part of the canopy might be greater at the higher volumes, but this is not sufficient to compensate for the lower deposits overall.

It is common to read label recommendations stating that volumes up to 400 L ha^{-1} should be used to achieve penetration into dense cereal canopies, and there is sometimes uncertainty among spray operators about whether 100 L ha^{-1} would give adequate control. However, the results presented here show that the recommendation to growers to increase volume in order to improve penetration of cereal crops cannot be justified. It should be noted, however, that coverage of plant surface is increased with higher volumes, and therefore the higher volumes might be appropriate, and give greater levels of control, for some products. However, previous work (Butler Ellis *et al*, 2007) showed that, for the situations investigated, increasing volume did not improve disease control.

The effect of nozzle design was not consistent over all trials, reflecting the likelihood that nozzle design has a relatively small effect on penetration compared with other factors, particularly canopy structure and wind conditions.

Wind tunnel investigations to evaluate the potential of a wide range of commercially-available nozzles failed to show a consistent pattern that could be explained from the known physical characteristics of the sprays, and differed from the 2008 findings. Some consideration was given to the potential reason for these differences: the amount of spray deposited on plants was shown to be influenced by wind speed when spraying with a conventional flat fan nozzle (Figure 6). As wind speed increased, deposit increased, consistent with other studies using smaller, artificial targets (Miller *et al,* 2010), but a further increase of wind speed resulted in reduced deposits. However, with an air-induction nozzle, the quantity deposited was independent of wind speed. The spray deposit on the lower part of the plants was significantly reduced with wind speed for the conventional flat fan nozzle, but remained unchanged with the air-induction nozzle (Figure 5). This suggests that in the field, with fluctuating air flows, a more uniform deposit is likely to be achieved with a small droplet air-induction nozzle, as well as greater deposits on the lower part of the canopy. A component of the differences between wind tunnel and field measurements might have arisen from differences in the canopy structure due to tray-grown crops. The planting scheme was altered for 2010 to try and reduce gaps in the canopy.

The type of nozzle that gave the greatest deposit on the lower part of the canopy in field trials was a small droplet air-induction nozzle (Figures 1, 7 and 10). These gave slightly lower deposits on the whole plant (Figure 8), although not statistically significant, consistent with other studies with air-included droplets (Butler Ellis *et al*, 2004). However, this has been shown to have no significant reduction in a T2 fungicide performance (Butler Ellis *et al*, 2006). We can therefore conclude that an air induction nozzle is likely to give good penetration into a cereal canopy at growth stages 32–37, without risk of compromising the performance of a fungicide application.

An 80^{o} flat fan nozzle also gave significantly higher deposits on the lower part of the canopy (Figures 1 and 7), although in 2011 results suggested that the higher boom height necessary for a smaller angle nozzle might result in lower overall deposits (Figure 9).

Applications at the later growth stage (GS37) resulted in significantly less deposit on the lower stem per gram plant material than at the earlier growth stage (GS31-33) (Figure 1): on average 0.19 µL g^{-1} compared with 0.68 µL g^{-1}. This demonstrates that even with the best nozzle and application conditions, a later application cannot achieve the levels of deposit in the lower part of the canopy that an earlier application can achieve, and that canopy structure is the most important factor influencing penetration.

Current recommendations in the HGCA nozzle chart indicate that either a small droplet air induction nozzle or a medium quality spray, at a volume of 100 – 200 L ha^{-1}. would give optimum performance for a fungicide application after GS 32. The findings of this work support this recommendation and, furthermore, suggest that there could be significant advantages to using volumes closer to 100 L ha^{-1} in terms of total deposit retained on the plant. This is likely to give the best coverage of all parts of the plant compared with typical commercially-available nozzle designs.

The performance of a pesticide application does not depend solely on the quantity of active ingredient reaching the target site. The size of droplets may also be an important factor for some products and, therefore, it is important to validate the findings of this project by undertaking some efficacy testing with commercial products.

3.5. References

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