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Review of application for sugar beet

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SUMMARY

Review of application for sugar beet

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A review of application techniques for sugar beet has shown that there has been little research that is relevant to this crop and there is therefore much scope for optimisation.

The greatest number of studies have been for herbicides, where, in addition, recommendations for other crops can be easily extrapolated to sugar beet.

Studies on application of fungicides to other crops have shown that there is often no loss of performance by moving from 200 to 100 L/ha combined with the use of small droplet air induction nozzles, particularly for systemic products. Angling nozzles has also been shown to improve the distribution over the plant in some situations. It seems likely that similar results would apply to sugar beet, although some supporting data, either from laboratory or field studies, would be valuable.

The application of Insecticides has not been well studied for any UK crop, and therefore this is an area where more work is needed if there is evidence that application might be limiting performance. In particular, the label recommendation of a minimum of 600 L/ha application volume for some products needs investigation because this is highly unlikely to be the optimum for any product.

It will be important to engage with manufacturers in any attempt to move away from label recommendations to ensure that restrictions required because of environmental or human safety are not breached.

Some basic steps for optimising application in general are outlined, and some examples of nozzle choices are given. We have also highlighted a number of new technologies that are under development and that may have a role in application in the future.

Some suggestions for possible further work are made, but focussed on areas where there are the largest knowledge gaps, and starting with cost-effective laboratory work to develop hypotheses that can be tested in more challenging field trials.

Recommendations to growers

Timeliness is important, and good work rates are therefore essential,l but this can be at the expense of drift control and uniformity of dose.

Drift can be controlled by ensuring that:

- Booms are kept as low as possible (and never more than 0.5 m above the target) and stable;
- A drift reducing nozzle is chosen;
- Wind speed is within the Defra code of practice.

For products that require a spray zone that uses 3* technology, speed, pressure and boom height must be controlled within this zone. We suggest some options for how this could be delivered where there is concern that 3* drift reduction might compromise efficacy and so would not be applied across the whole area.

An important component in achieving good performance of PPP is applying the correct dose, not just on average, but uniformly across the treated area. There are many factors in achieving this, including sprayer calibration and ensuring nozzles are used within their rated pressure range.

Wind is not constant, but continuously fluctuates, potentially resulting in an uneven and unpredictable distribution under the boom. Smaller droplets will be affected most and therefore the most even distribution will be achieved with larger droplets in all but very still conditions. Thus drift-reducing nozzles can give benefits to efficacy by reducing variability. It is important to recognise that it is not the drift itself that compromises efficacy – the quantity of product that is lost to spray drift is relatively small – but that the nozzles which reduce drift also improve uniformity.

The AHDB nozzle chart for cereals and oilseeds (AHDB, 2010) remains a useful resource for identifying nozzle design for particular applications.

- Small droplet air induction nozzles are a good default option for all PPPs, examples of which are given in Table 3. Exceptions are herbicides applied to small weeds and some contact-acting fungicides and insecticides, where conventional nozzles will give higher quantities of deposited a.s. and better spray coverage.
- 100 L/ha application volume gives optimum performance in most situations, apart from some specific contact-acting products, where a higher level of coverage is needed.

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1. Objectives

To undertake a review of current knowledge and published research into optimising application for pest, disease and weed control in sugar beet.

1.1 Review methodology

In order to establish the state-of-the-art in application for sugar beet, we have done the following:

a. Met with Mark Stephens to discuss the main issues relating to application in sugar beet and had a phone discussion with Mike May. BBRO literature was made available to us.
b. Review traditional peer-review published literature. In the UK since 2000, this is rarely the route for dissemination of application studies, so it was not expected to discover much of value.
c. Review conference proceedings. The Association of Applied Biologists (AAB) biennial conference 'International Advances in Pesticide Application' is the main conference on application relevant to the UK. We have searched conference proceedings back to 1997.
d. Review other literature – websites, manufacturers' guidelines, labels, other information, farming press.

All of the information has been combined with our own knowledge of application technology, based on work with other crops, in the following review.

2. Introduction

2.1 Basic understanding – facts, myths and unknowns.

There are many myths about the interaction between application and performance of plant protection products (PPPs) which have developed over a long period of time and are difficult to refute. Many of them have some intuitive substance, but have never been proven, or have indeed been disproven. Others have no substance whatsoever. These myths are often fondly held to by many spray operators, advisors, regulators and manufacturers of both sprayer technology and PPPs. It is difficult to move forwards in optimisation of application if we continue to cling to these and so in this section, we discuss the fundamental principles that we know govern PPP performance, which can be supported by either evidence, or at least a plausible hypothesis, and highlight areas where unfounded beliefs might be limiting our ability to improve and innovate.

Two main parameters – droplet size and application volume - influence the quantity of PPP on the plant, change the form of the deposit on the plant surface, and can alter the distribution of the deposit over the plant. Understanding the effect of these on efficacy is crucial in optimising application for any crop/target/product combination.

Droplet velocity – which encompasses both speed and angle or trajectory – is a third parameter, which we will also give some limited consideration to. Droplet speed tends to be correlated with droplet size (for a given nozzle design and pressure) so that smaller droplets slow down more rapidly after leaving the nozzle and are therefore travelling slower when they reach the target than larger droplets. The assumption that these larger droplets are less likely to be retained on plants is at least in part because they are travelling faster. Different nozzle designs, however, produce droplets with different velocities and therefore these can influence performance without necessarily changing droplet size. Finally, spray trajectory or angle interacts with the crop or weed structure to influence the total quantity retained and the way it is distributed over the plant and can be important in some circumstances.

'Coverage' is often discussed as something which is important to maximise, and sometimes appears on labels, but there is rarely a definition of what this term means and how it should be measured. Some people use the term 'good coverage' to represent 'reaching all parts of the crop' (e.g. penetrating into the crop or PPP being distributed over all leaves of a plant). We would prefer the term 'distribution', for this, and measurements suggest that the most important factor influencing distribution is the structure of the crop or plant itself.

We use 'coverage' in this report with a relatively narrow definition – meaning the percentage of the surface area that has visible spray covering it, and it would usually be measured with flat horizontal surfaces, such as in Figure 1, so is unaffected by plant structure. It is strongly affected by droplet size, spray volume, surface characteristics and properties of the tank mix.

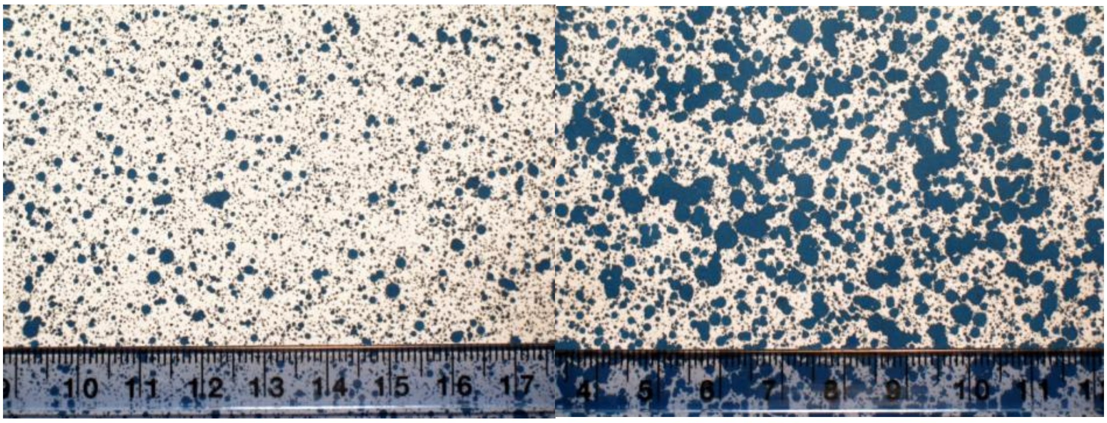

Figure 1. Coverage of a flat horizontal paper surface by 100 L/ha with a flat fan nozzle (left) and 200 L/ha with a flat fan nozzle (right)

Maximising the quantity deposited on a plant

We know that reducing droplet size (and velocity) and reducing spray volumes will increase the quantity of active substance on the plant for a given applied dose. This has been shown with many different crops and in many different circumstances and appears to be true right down to very low volumes (50 L/ha and lower). Therefore there are advantages to using small droplets and low volumes where this is possible.

Spray angle can also influence the quantity retained by a crop or plant *where the plant has a predominantly vertical structure*. The main benefit of this is in early growth-stage grass weed control, where there is clear data showing not only increased quantity deposited on the plants but also improved performance with angled nozzles (Jensen, 2010), reproduced in Figure 2.

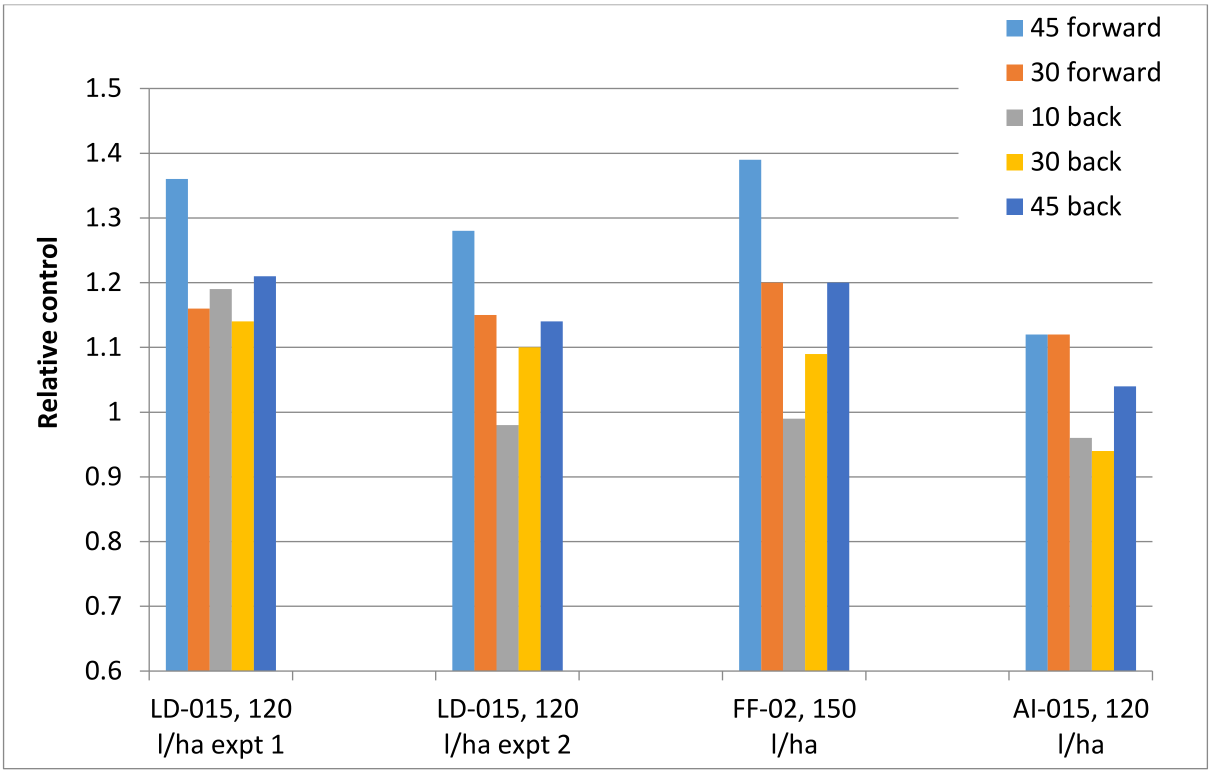

Figure 2. Effect of nozzle angle on relative performance of herbicide on perennial ryegrass (from Jensen, 2010)

Higher quantities retained on a plant will result in better performance. While this seems like an obvious statement to make, whether this can be observed in practice is dependent upon being on the steep part of the dose-response curve and ensuring that the deposit is reaching the correct part of the plant. It is often difficult to see in field trials, which may be due to the noise from the biological variability swamping relatively small improvements in performance. In particular, since the maximum permissible dose is often set so that relatively poor application still provides an acceptable level of control, field trials should be conducted at a lower dose – possibly half or even lower – than the maximum permitted on the label in order to discern differences in performance due to application.

Maximising coverage

Reducing droplet size and increasing application volumes increases the percentage of the area of a flat horizontal surface which is covered by spray liquid (Figure 3) although the slope of the relationship reduces as the area covered gets closer to 100%.

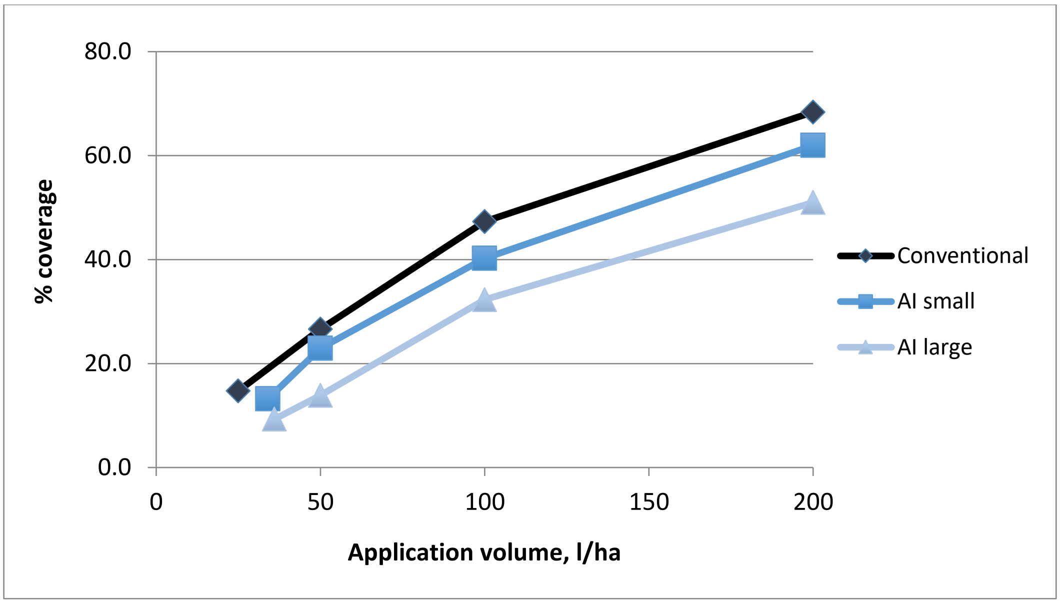

Figure 3. Effect of droplet size and volume on the percentage area of a flat horizontal paper surface covered by water. AI small refers to an air induction nozzle producing a small droplet, although still much larger than the conventional nozzle, and AI large is one producing a very large droplet

It is widely believed that better coverage equals better performance. This may be true in some circumstances but often the evidence is extremely weak, or completely absent. There are a number of reasons for this:

- In practice, increased coverage due to a higher volume will correspond with a lower concentration, and a lower quantity retained, which could counteract any 'coverage' benefits;
- Measurements such as those in Figures 1 and 3 relate to the coverage of the spray liquid, not the active substance. Where the active substance is present as solid or emulsion particles, then adding more water makes no difference to the coverage, although it could make a difference to the distribution of those particles over the leaf. A simple measure of coverage will not capture this, however.

It is often thought that higher volumes are required with larger (drift-reducing) droplets to maintain coverage, and 200 L/ha with an AI nozzle would be a comparable alternative to 100 L/ha with a conventional nozzle. It can be seen from Figure 3 that this is factually correct. There is little published evidence to suggest that this translates into performance, but many reputable advisors will not be shifted from this view. To some extent, there might be an element of 'risk aversion' in this approach. If the only available efficacy data is based on 200 L/ha with a medium quality spray, then moving both volume and droplet size may be a step too far.

Whether or not coverage *per se* influences performance of a PPP depends very much on the mode of action of the active substance, and it is important to understand this before assuming that coverage will be important. It is known that some product/target/crop combinations definitely require good surface coverage (potato blight is one example) but it is worth recognising that much of the evidence for this was obtained some years ago when application practices (and the available nozzles) as well as product formulations were different and therefore the sensitivity to this might have changed.

Distribution over a plant or crop canopy

The main factor influencing the distribution over a crop canopy is the shape, size and structure of the canopy itself.

We believe it is a myth that higher volumes give better penetration into a crop canopy, despite it often being stated on labels. There is no supporting evidence for this. When using a conventional boom sprayer, it is very difficult to reach targets that are shaded by the crop, and pretty much impossible to reach the underside of leaves. Changes in application can have only a very small effect. The use of air-assistance is one proven method for improving penetration, and its benefits are variable and crop-dependent. There is a number of studies that demonstrate improved distribution of spray over a potato crop with the use of air-assistance (e.g. Scudeler and Raetano, 2006, Piché, et al, 2000, Leonard et al, 2000)

Air assistance works by changing the speed and trajectory of droplets. Changing the trajectory through modifying the nozzle angle is an alternative (and cheaper) approach where hard-to-reach parts of the plants need to be targeted. Because of the strong influence of plant structure on this, there can be no generic recommendations, and might even differ between plant varieties, but there is some data suggesting that angling nozzles can improve the distribution over the plant (Robinson, 2000). The ultimate change in droplet trajectory would come from the use of 'droplegs', which allow sprays to be delivered upwards and from within the crop and have shown to be successful for the treatment of potato blight (Basil, 2001). These have never been popular, despite being available for many years, but it is likely that this is one of the most effective ways of spraying the underside of leaves, or targeting the lower part of the canopy, where this is required.

Syngenta undertook a small study in 2011 to investigate distribution of spray over a sugar beet plant (James Thomas, personal communication). A sugar beet crop was sprayed in early July with a tracer, using a number of different application techniques, with volumes of 50 – 400 L/ha and including air induction and angled nozzles. Plants were sampled and segmented to determine the quantity deposited on the top, middle and bottom of the plant (no clear definition of this terminology has been provided).

While only mean values have been made available so no assessment of statistical significance can be given, the effect of volume on total deposit on plants follows the pattern already described for many other crops, with less normalised deposit (i.e. relating to the active substance, rather than spray liquid) reducing with increased volume (Figure 4). The increased volume was achieved by different sizes of 'variable pressure' flat fan nozzles (015, 025, 05 and 10), so as well as volume increasing, droplet size increases too, which can also reduce the quantity retained.

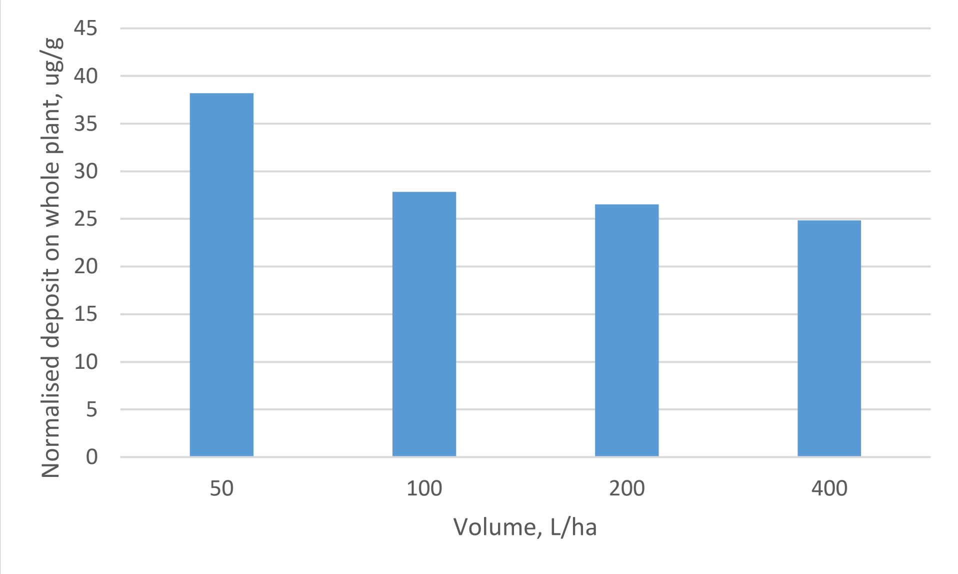

Figure 4. The effect of volume, delivered with a conventional flat fan nozzle, on the normalised deposit on sugar beet plants. Data provided by Syngenta (James Thomas, personal communication).

Comparing the 100 L/ha treatments, where traditional flat fan nozzles were compared with Syngenta's own nozzles, shown in Figure 5, it seems that an air-induction nozzle (025 AZ) deposited more than the flat fan, and the angled nozzle (Defy 03, alternately forward and back) deposited the most. At 200 L/ha, the Syngenta potato and veg nozzles deposited more than the traditional flat fan. [Note that the '04' veg nozzle would not give 200 L/ha, so there is either a mistake and it was an '05' nozzle, or the volume was actually 160 L/ha]. This suggests that nozzle angling (the potato nozzle is also angled) can increase the total deposit.

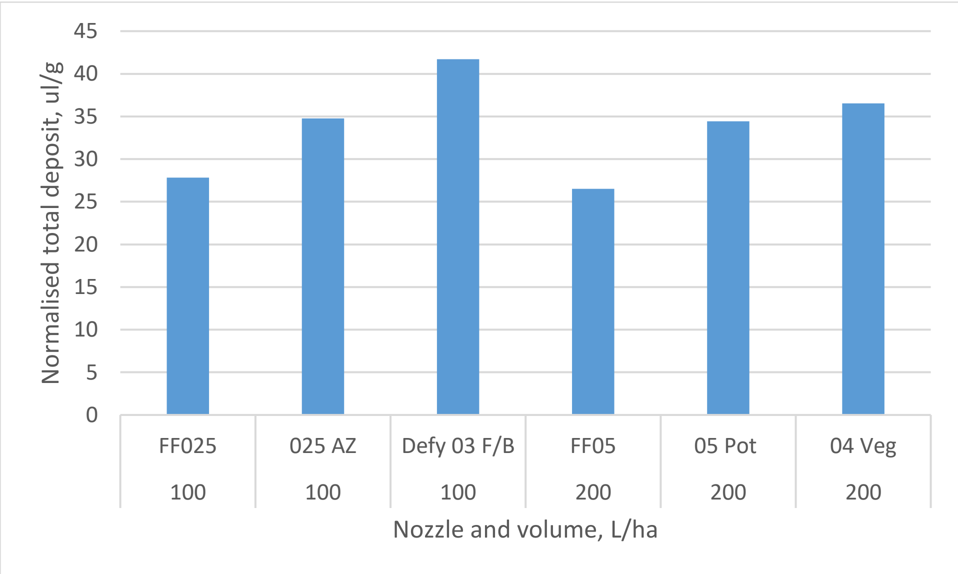

Figure 5. The effect of nozzle type and angle on the normalised deposit on sugar beet plants. Data provided by Syngenta (James Thomas, personal communication).

When considering the proportion of spray that reaches the bottom part of the plant, there are unlikely to be statistically significant differences because this is very variable. The three treatments which give the largest deposit on the bottom of the crop were the 50 L/ha with a flat fan, 100 L/ha with the Defy nozzle (i.e. a very angled trajectory) and 200 L/ha with the Veg nozzle (65° nozzle, with a very vertical trajectory). This makes little scientific sense, and further work is clearly needed.

2.2 State of the art in generic application advice

The HGCA nozzle chart (AHDB, 2010) – obviously aimed only at cereals and oilseeds – was first produced in 2004 and most recently updated in 2010. It still captures the best of current UK knowledge and is a useful resource for selecting nozzle design for different application targets. The advice on herbicides will apply to all crops, and it is likely that the recommendations for oilseed rape would be similar to those for sugar beet, had a sugar beet chart been developed at the same time. It is no longer being promoted by AHDB and can be difficult to find on their website.

The chart does not include 'volume' as a variable, and so fails to provide an essential piece of information to growers. The chart was based on an assumed volume of 100 – 200 L/ha to be relevant to as many cereal growers as possible.

SSAU and others have been relatively vigorous in promoting 100 L/ha as the 'default' application volume. Some spray operators have been reluctant to embrace this, perhaps because of fears over excessive drift and/or poor coverage, but many have done so, and gone lower still, with, anecdotally, no loss of performance. There are significant benefits to reducing volumes by (a) increasing work rates, which will improve the timeliness of applications as well as being more economically efficient, and (b) reducing the need for large spray tanks which, when full, are very heavy and therefore can cause soil compaction problems and have a narrower window of ground conditions for successful operation.

Recently, the campaign by Syngenta to increase volumes to 200 L/ha initially for pre-emergence soil-applied herbicide application, and possibly now extending to foliar-applied post emergence, has caused a significant degree of confusion and concern, because this is contrary to previous advice. The use of 90% drift-reducing nozzles is also strongly promoted. Our view on this is as follows:

- We understand and support the advice to move to drift-reducing nozzles for soil-applied herbicide application. This is entirely consistent with the HGCA nozzle chart. However, we have seen no data that supports 200 L/ha over 100 L/ha.
- Foliage-applied herbicides can be delivered successfully across the 100 – 200 L/ha range, using the nozzle recommendations in the HGCA chart. We understand the concept that 200 L/ha volume might compensate for any reduction in performance compared with 100 L/ha when moving to drift-reducing nozzles, but there is insufficient evidence to support this. Increasing volume should not be at the expense of timeliness of application.
- 90% drift-reducing nozzles will deposit significantly lower quantities of a.s. on a plant compared with a conventional nozzle.

The acceptable volume range is defined on the product label. This is usually determined by the data available when the regulatory submission was made. Since small plot trials are difficult to conduct at volumes less than 200 L/ha, this is often the lowest volume specified. This does not necessarily mean that this is the optimum, merely that there is no data for lower volumes. However, volumes can be reduced if there are no health and safety concerns for a more concentrated tank mix but, depending on the manufacturer's advice, this could be at the user's own risk for efficacy. The Defra Code of Practice (2006) provides the guidance for whether a product is suitable for reducing volume.

3. Current knowledge relating to application technology for sugar beet

3.1 Herbicide application

Much of research into application for weed control will be applicable to sugar beet, independent of the crop, although clearly the products and active substances may differ. There is only a small number of trials aimed at weed control in sugar beet.

Knoche (1994) undertook a very extensive review of how two application parameters (volume and droplet size) influence the performance of foliage-applied herbicides, but some important changes have happened since: air-induction nozzles are now widely used and are the most common form of drift control; active substances have changed significantly, with more than 50% of those used in the studies being no longer available in the UK, and only one used an a.s. appropriate to sugar beet. This study, by Chandrasena and Sagar (1989), on the application of fluazifop to *Agropyron repens* showed increasing control with reducing droplet size and reducing volume but was conducted with artificially large droplets and therefore is of minimal practical relevance.

Knoche's findings were that effects were often not consistent across different studies, and therefore clear trends are often difficult to identify. Herbicide performance tended to improve with reducing droplet size, and this was most consistent for systemic herbicides. Volume effects were not so clear:

- Optimum volume between 100 and 400 L/ha
- Effects were most consistent for difficult-to-wet plants
- Glyphosate had consistently better performance for reduced volume

Reviewing more recent work in UK and Europe suggests no strong volume or droplet size effect. For example, Norbo et al (1995) found no effect of volumes between 70 and 180 L/ha when comparing a wide range of nozzles with 3 herbicides no longer available. Air-induction nozzles were not included.

Rice et al (2002) considered volumes of 110 and 220 L/ha with two designs of air-induction nozzle compared with a conventional nozzle and found only small differences in performance, which were rarely significant. The authors suggested a trend of larger droplets giving inferior control, and the lower volume being superior, however.

Nuyttens et al (2009) found no effect of volume or nozzle in a study looking at weed control in a range of crops including sugar beet, with volume rates between 160 L/ha and 320 L/ha, and three nozzle designs, including air-induction.

Therefore, despite there being evidence that smaller droplets and lower volumes are likely to give higher deposits on plants, there is little evidence to suggest that this translates into better performance. Similarly, smaller droplets and higher volumes give higher levels of coverage, but this does not result in measurable improvements in performance.

Product labels for sugar beet herbicides commonly allow relatively low volumes – down to 80 L/ha. Some have a minimum volume of 200 L/ha. Maximum volumes are as high as 500 L/ha. We would recommend using volumes at the lower end of the range wherever possible.

Many product labels specify a fine spray, or fine/medium spray. We recommend exercising extreme caution in using fine sprays for any outdoor application, because both drift and variability in applied dose cannot be kept under control (see section 6 below). In particular, many of the broad-leaved weed control products that are recommended to be sprayed with a fine spray also have a LERAP 'B' status, and these are mutually exclusive without sophisticated technology. Some suggestions for how these products could be sprayed to allow a reduction in the 6 m buffer zone are given in Section 6 Table 3. An alternative approach is to maintain the 6 m buffer zone, and then legally, the products can be sprayed with a fine spray. However, the aquatic risk assessment for PPPs is not based on a fine spray, but one which drifts much less, more consistent with a spray in the middle of the 'medium' band. We would recommend that all outdoor applications are conducted with sprays no finer than 'medium'. There is no evidence that a fine spray would give improvements in performance that could justify the additional risk of exposure to spray drift for humans or the environment.

The AHDB nozzle chart recommends that, for grass weeds < 4 leaves and broadleaved weeds smaller than 5 cm diameter, conventional nozzles are optimum where drift control is not required. For larger weeds, small-droplet air induction nozzles can deliver a good balance of performance and drift control.

3.2 Fungicide application

We were unable to find any studies relevant to fungicide application in sugar beet. We have therefore taken our best knowledge of fungicide application in other crops – particularly potato blight, where there are several publications – and extrapolated to generic recommendations. Clearly there are many differences in crop, products and pest which might invalidate this approach and this is therefore an area where any resources for future work could be focused.

Jensen (2008) found no difference between 160 and 320 L/ha spray volume in late blight control, nor between nozzle types (including air-induction) despite large differences in droplet size and coverage.

Prokop and Veverka (2006) found that no effect of droplet size in a mix of contact and systemic fungicides, but that control increased with reducing droplet size with contact-only products, with the larger droplet size requiring larger spray volumes for good efficacy. However, the largest droplet size was potentially very large indeed and no information was provided for the nozzles used. Volumes were 300 – 600 L/ha. Michielsen et al (2008) found, in laboratory experiments, that in general a coarse spray quality provided less control than a fine spray, but further experiments (Stallinga, 2010) showed no difference between conventional and air-induction nozzles at recommended doses, but potentially a reduction in control with the air induction nozzle at lower doses.

Recommendations for potato blight control in the UK, given by Syngenta, suggest a volume of 200 L/ha, with 100 L/ha being acceptable in early season. They also recommend the Syngenta potato nozzle, which is a conventional nozzle angled at 30^{o} from the vertical, alternately forward and backwards along the boom, to improve the distribution through the canopy.

Looking at fungicides applied to cereals, Butler Ellis et al (2007) found no effect of volume on performance of a tank mix of epoxiconazole and azoxystrobin on winter wheat, but a reduction in performance with a large droplet air induction nozzle. Jensen (2001), also on winter wheat, found that in general, biological efficacy with low volume low-drift nozzles was comparable to that of a standard flat-fan nozzle. Armstrong-Cho et al (2007) working on blight in chickpea found that volume was not critical under low to moderate disease pressure, but with high disease pressure, higher volumes were beneficial. Karolewski et al (2009) investigating fungicide applications to winter oilseed rape found that neither volume (200 vs 400 L/ha) nor spray quality influenced performance. Bretthauer et al

(2008) found soyabean rust was also unaffected by volume (comparing 47 and 140 L/ha) and only a very coarse droplet spectrum at the higher volume resulted in yields not significantly different from the untreated control.

While this is probably only a subset of all the studies undertaken on different crops to evaluate the effect of application on fungicide performance, the message is clear: it is difficult to identify any general effect of volume, but there is a small amount of evidence that the coarsest sprays (e.g. the largest droplet air-induction nozzles) might compromise performance. It does not necessarily follow that this applies to all products, however. There is some evidence that some contact-acting only products do require higher volumes and/or finer sprays, and so there can be no universally-acceptable generic advice.

Label recommendations for sugar beet fungicides have 200 L/ha as the lowest volume. These products are generally systemic in action, although Priori Xtra has some contact action. Difure Pro should not be used at lower than 200 L/ha because of safety concerns.

100 L/ha should be possible with all others but it is important to check first with the manufacturer or supplier. Opera can be used down to 100 L/ha but the label states that there is no efficacy or crop safety data. Where recommendations are not given below 200 L/ha, this is usually because there is a lack of supporting data, rather than evidence that this volume is optimum.

Generic rules for application suggest that lower volumes and smaller droplets will put the maximum on plants; higher volumes and smaller droplets give better coverage of exposed areas (e.g. uppermost leaves). Performance will depend on whether quantity or coverage is the most important factor, which might vary between products. Conventional wisdom suggeststhat contact-acting fungicides need good coverage, but there is no definition of what makes good coverage. Improved product formulation or use if adjuvants can result in high levels of spray liquid spreading, but there is no information about whether this translates into better control.

There is evidence that there is a zone of control around a droplet (Hislop, 2008; Washington, 1999) although not with triazole or strobilurin fungicides. This would suggest visible measures of coverage may underestimate the area over which control will be achieved. This might explain why there is little evidence of a correlation between such measures and performance for some products.

Little information is available about the balance between timing and performance, but many publications indicate that application timing can be crucial. We suggest using an application which can ensure good timing is likely to be the optimum approach which might in many cases include modest drift reduction and volumes of the order of 100 L/ha. But it would be wise to avoid extremes – for example, 50 L/ha may be effective, but there is insufficient evidence to show this, and most advisors would not be comfortable with the potential risk. 90% drift reduction is unlikely to give optimum performance, whereas 50% would probably be indistinguishable from a conventional nozzle. Since all sugar beet fungicide products are Lerap B and have a relatively high toxicity to aquatic species, if buffer zones are reduced to 1 m, a 3-star nozzle is required for the adjacent 12 m swath. Some examples of how this might be achieved in practice are given in Table 1

3.3 Insecticide application

Volumes recommended on insecticide product labels for sugar beet are in some cases very high indeed and could be considered excessive. We would question whether anyone actually does apply insecticides to sugar beet at these volumes, and it would be challenging to find an application technique that can deliver 600 L/ha with a medium quality spray at a sensible forward speed. Required volumes for insecticides are not listed in the BBRO Pest weed and disease charts, unlike herbicides and fungicides. Table 1 shows the volumes and spray quality taken from the label for the spray-applied products, and some comments on whether a reduction in volume might be possible based on safety considerations.

Table 1. Recommended volumes and spray quality for sugar beet insecticides.

Product	Label volume for sugar beet, L/ha	Spray quality	Comments
Cythrin 500 EC	600-1000	Medium	Other crops allow volumes down to 100 L/ha
Decis Forte	200-400	Medium	Operator safety probably limits volume reduction
Decis Protech	200 - 400	Medium	No operator safety issues identified
Fury 10EW	600 - 1000	Medium	Other crops allow down to 200 L/ha with a higher dose
Hallmark Zeon	200	None recommended	Higher concentration allowed in other crops

There is very little information about the real requirements of insecticides for application on any crop; again, it is always *assumed* that high levels of coverage are needed for contact-acting active substances, and this is reflected in the AHDB nozzle chart. There is little data to support this assumption and it is interesting that Clorpyrifos always required a fine spray until the a.s. came under threat, and the industry quickly established that insect control could be achieved with 75% drift-reducing nozzles (Roberts and Harris, 2014), apparently with no reduction in performance.

There are many studies, going back decades, which concluded that applications using ultra-low volumes, which would undoubtedly have had lower levels of coverage, were successful (using CDA, electrostatics and aerial applications). These suggest that there is no fundamental reason for requiring volumes as high as 600 L/ha. Like fungicides, systemic insecticides may not need as high levels of coverage as those which are contact-acting;

No useful studies relating to application for sugar beet pests have been identified. However, an article relating to mangold fly (White, 2016) identified that spray timing was an important component in control and this is likely to be the case for many insect pests. Applications that allow good work rates will help with achieving optimum timing.

Because of the intrinsically higher hazard with insecticides, it would be risky to make applications in a way that is substantially different from those on the label. The lowest volume permitted should be the aim, but discussions with the manufacturers could identify the reasons for volumes higher than 200 L/ha, and whether there is scope for reducing volumes.

All of the insecticide products listed in the 2018 BBRO pest, disease and weed charts have aquatic buffer zone restrictions and some also have arthropod buffer zone restrictions. Some of the aquatic buffer zones also require 3 star drift reduction to be used on part of the sprayed area, and others allow the buffer zone to be reduced if drift-reducing technology is used. Because of the danger to aquatic species and non-target arthropods, the use of drift-reduction across the entire treated area would be best practice, if sufficient control can be achieved.

The requirements for arthropod buffer zones can be confusing. Labels wording such as 'respect' a buffer zone, or ' do not spray' indicate a mandatory unsprayed area, whereas 'avoid' is advisory. Cythrin 500C and Hallmark Zeon use 'respect'; Fury 10 EW uses 'do not' and therefore the buffer zones are mandatory. Decis Forte and Decis Protech use both 'respect' and 'avoid' in different sections of the labels, and clarification should be sought from Bayer, but are likely to be mandatory. The arthropod buffer zone distances are given in Table 2.

Table 2. Buffer zones for non-target arthopods

Product	Unsprayed distance at the field edge to protect arthropods
Cythrin 500 EC	5 m
Decis Forte	5 m
Decis Protech	5 m
Fury 10EW	6 m
Hallmark Zeon	5 m

A useful poster summarizing the buffer zone requirements, and assisting with interpretation of labels, has been produced by Syngenta (https://www.syngenta.co.uk/buffer-zones).

4. Novel application techniques

While the study did not aim to include any techniques other than conventional boom spraying, there has been a number of developments in technology which might have potential applications for sugar beet, which are outlined below. This is not a comprehensive review, however.

4.1 Targeted herbicide application

Inter-row hoeing, band spraying, spot spraying and patch spraying are all technically possible and commercially available. For example, Tillet and Miller (2013) evaluated the Garford Robocrop spot sprayer for weed control in sugar beet (Figure 6). Targeted application based on vision guidance has been most successful in row crops, where distinguishing between weed and crop is easiest, but more developments in image analysis technology is likely to enable similar approaches in non-row crops in the future.

Take up of these techniques is still limited, and this is probably because herbicides are still available and too cheap to make these alternatives cost-effective. Continued loss of herbicides might drive further development of such techniques, but the need for regulatory data for use of non-selective herbicides, and the pressures to reduce the use of glyphosate, are significant obstacles.

Figure 6. The Garfords Robocrop Spot Sprayer. https://www.bcpc.org/wp-content/uploads/2017/11/Weeds-2017-Garford.pdf

4.2 Variable rate application - fungicides

Adapting fungicide application to the crop has been discussed for many years, and recent developments mean that this is now technically possible and commercially available. For example, multi-nozzle bodies that can switch from one nozzle to another (e.g. auto-nozzle select, fitted to Househam sprayers, https://househamsprayers.co.uk/technologies/auto-nozzle-select/) allow both dose and spray characteristics to be adjusted according to an application map; pulsed width modulation (PWM) (Giles, 1997) allows dose to be adjusted without significantly altering spray characteristics. These have benefits even when trying to deliver a uniform application, because this can be challenging at the sprayer speeds that are now typical in the UK (12 km/h and greater).

However, the agronomic benefit of variable rate fungicide application is still dubious. A review of precision application techniques (Knight et al, 2009) concluded that 'there is little to be gained from attempting to apply variable rate fungicides to combinable crops given our current capabilities and understanding'. In a nutshell, fungicides are currently too cheap, the agronomic rationale is not well defined and therefore the risks are too great.

More recently, Jensen (2018) showed that there were justifications for reducing fungicide use for lower biomass with cereals, but not for potato blight on potatoes. 10 years on from Knight's review, it might be that our understanding has improved so that we can now derive benefits (either in reduced inputs, or in increased yields) from variable rate fungicide application, but most developments appear to be in the continued improvements in technology for delivery, rather than in the underpinning agronomic science.

4.3 Other developments in technology

Drones and robots

There is much discussion, publicity and 'hype' relating to applications by drones and robots. These merely change the delivery platform, not the basic application, and at this stage are likely to be a step backwards in terms of optimising efficacy because appropriate application techniques for these kinds of delivery platform have not yet been identified and developed. Regulatory difficulties of approving chemical application through drones are likely to make this technology very slow to become available in the UK. The slow speed of current field robots is likely to result in a return to high application volumes and/or small nozzle sizes, although developments such as PWM might overcome some of the disadvantages. While many growers are probably 'watching this space' with interest, it seems unlikely that these approaches will provide short-term solutions to any of the problems faced by sugar beet growers.

Biopesticides

Biopesticides are seen as a potential solution to loss of effective chemicals – particularly fungicides and insecticides – and the number of products available is growing rapidly. However, they are being targeted currently at high-value, and most often, protected crops where the environment can be well controlled and pesticide residues are a particular problem.

Optimising application for biopesticides is an area where much further work is required – the current 'Amber' project (https://warwick.ac.uk/fac/sci/lifesci/wcc/research/biopesticides/amberproject/), funded by AHDB Horticulture has identified many of the problems but the limited resources have not been able to provide any solutions yet.

This is an area to keep a watch on, so that any products that might become available can be developed and optimised for sugar beet, but timescales for this are unlikely to be short.

Non-chemical weed control

There are many studies of alternative methods of weed control, including electrical, microwave, steam, hot foam, lasers (Brodie, 2018) but the cost, effectiveness and health and safety implications for these physical techniques rule them out in UK arable agriculture without significant advances in technology.

5. Potential further research

Optimising application of any plant protection product has to be undertaken on an individual product basis (since mode of action and formulation will make a large difference) and over a period of time in order to give sufficient data to form robust conclusions. It also requires the use of full scale equipment on relatively large plots. This is costly and, as we have seen from reviewing the literature, often results in no statistically significant differences. It is imperative, therefore, when conducting field studies, to ensure that there is a clear hypothesis to be tested, and a rationale for the treatments chosen, otherwise testing all possible application variables is an impossible task, and picking variables randomly is unlikely to give useful data. Well-conducted field trials give the most valued information for growers, however, so some targeted studies could be undertaken. A useful approach is to evaluate some aspects of spray behaviour under laboratory conditions in order to develop hypotheses for limited testing in field trials.

5.1 Evaluation of the physical behaviour of sprays for fungicide application

Commercial work at SSAU indicates that new products are formulated to spread and provide good coverage, even when used at low volumes and large droplet size, but older products do not, and therefore could be more vulnerable to application effects. For example, the Bayer sugar beet guide (Bayer, 2011) indicates that oil is usually included to improve wetting of the leaves and this is especially important with modern-day formulations of phenmedipham that no longer contain isophorone as a solvent, whereas Betanal maxxPro is a modern formulation with improved spreading characteristics.

It could be instructive to establish the degree to which specific sugar beet products spread on sugar beet leaves prior to doing field work, particularly those which have a significant contact action.

A number of tests are possible, using different tracers that work alongside the actual product:

- Retention on whole plants;
- Distribution over the plant;
- Surface area covered of individual leaves;
- Droplet spreading – time lapse photography.

These have been successfully conducted with plants (oilseed rape and cereals) pulled, dug, or cut from field-grown crops. While we have never done this work with sugar beet, there seems no reason why this would not be effective. Some examples of the photographic results obtained are given below in Figure 7.

Such laboratory tests could be conducted to explore, for example, the effect of angled nozzles on distribution, volume and droplet size on retention and coverage, how different products spread on a sugar beet leaf, and the potential benefits of adjuvants.

5.2 Fungicide efficacy trials

Since evaluation of fungicide efficacy (a) requires there to be disease pressure, and (b) can be confounded by many other variables, the effect of application from field trials can easily be lost in the experimental ’noise’.

Given the limitations and costs of such trials, alluded to above, it would be difficult to recommend a large programme of field trials. However, some field testing might be useful to ‘ground-truth’ recommendations. For example, a four-way trial, which considers 100 vs 200 L/ha, and conventional spray vs drift-reducing nozzle would enable us to evaluate the extent to which application might influence efficacy for a given product. A number of such trials over a number of seasons with a single product would probably provide the most valuable information.

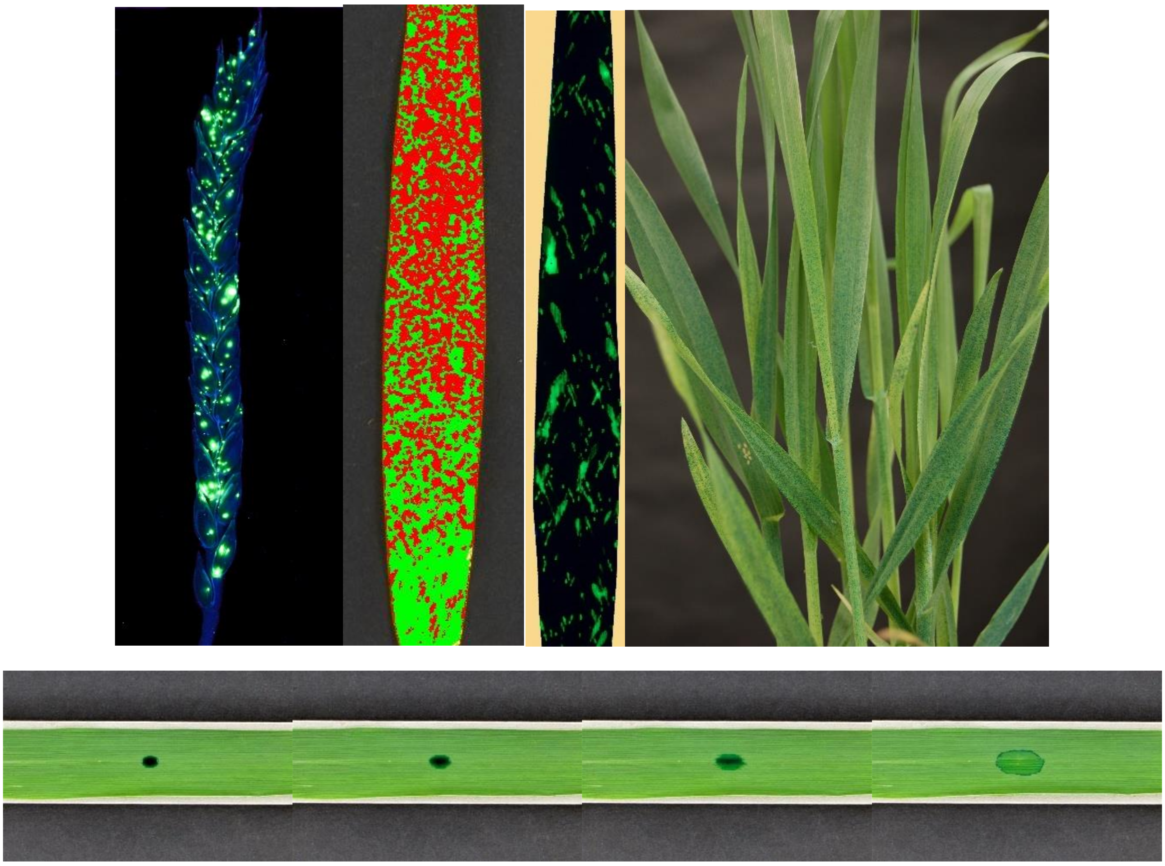

Figure 7. Examples of images used to describe the physical behaviour of sprays. Top, left to right: product sprayed onto a wheat ear, with a fluorescent tracer; product sprayed onto an artificial wheat leaf, with a pigment tracer, followed by image analysis; product sprayed onto a real wheat leaf with a fluorescent tracer, prior to image analysis; product sprayed onto a whole wheat plant with a pigment dye, prior to washing off and quantifying the total spray liquid retained. Bottom, time lapse photos of a single droplet spreading on a wheat leaf.

6. Recommendations to growers

Timeliness is important, and good work rates are therefore essential. Larger booms, faster speeds, larger tanks, lower volumes and wider booms are all components in this but can also potentially compromise performance by increasing drift and reducing the uniformity of the applied spray across the field. We therefore begin by addressing drift and uniformity in general, and then move on to some specific recommendations for applications to sugar beet.

6.1 Drift

Drift can be controlled by ensuring that:

- Booms are kept as low as possible (and never more than 0.5 m above the target) and stable;
- A drift reducing nozzle is chosen;
- Wind speed is within the code of practice (Defra, 2010).

This should be in addition to any legal requirements for the products (such as LERAP B products, which require drift-reduction only within a 12 m swath upwind of the water course). Public perception is an important factor in determining government policy in relation to pesticides, and a medium/fine spray will give significant levels of visible drift which can cause alarm, even if the majority deposits within the cropped area. A drift-reducing nozzle produces less drift and, importantly, much less *visible* drift, giving less cause for concern to any local observers. There are benefits to the whole industry if all users can undertake applications without alarming the public, and therefore we recommend that steps are taken to minimise drift above and beyond the legal requirements wherever this will not compromise efficacy.

The recent 'low, slow and covered' campaign by Syngenta has potentially misled spray operators into thinking that forward speed *per se* is an important component in creating spray drift. In fact forward speed itself has a relatively small effect on drift, particularly once speeds are over around 8 km/h. However, for sprayers with rate controllers, once out in the field, increasing speed results in increasing pressure, which is likely to increase drift. Boom stability is also likely to be affected by speed, thereby affecting drift, so it is important to use a forward speed that allows boom height to be maintained for the given sprayer, boom width and terrain. However, by suitable nozzle choice and appropriate boom suspension, drift can be controlled at high forward speeds.

For products that require a spray zone that uses 3* technology (i.e. PPPs that are LERAP B and the buffer zone is to be reduced to the minimum; or PPPs with buffer zones > 6 m and where a mandatory 30 m 3* zone is specified on the label), speed, pressure and boom height have to be controlled within this zone. As an example, Table 3 gives some options for how this could be delivered where there is concern that 3* drift reduction might compromise efficacy and so would not be applied across the whole area. These should not be taken as recommendations for specific nozzles, and there are likely to be other options available. The strategy is to use drift reducing nozzles at pressures of 3 – 4 bar across the main part of the field, but then slow down and drop the pressure to comply with 3-star requirements.

Table 3. Example options for complying with the 3-star drift requirement in an area adjacent to the no spray zone, whilst maintaining performance on the rest of the field. Boom height must be no greater than 0.5 m above the crop in the 3-star zone.

		Main field		3-star zone	
Manufacturer	Nozzle	Speed	Pressure	Speed	Pressure
200 L/ha					
Teejet	AIXR 110 05	12-14 km/h	3-4 bar	≤ 11.7 km/h	≤ 2.9 bar
Lechler	IDK 05	12-14 km/h	3-4 bar	≤ 8.4 km/h	≤ 1.5 bar
Hypro	Guardian Air 05	12-14 km/h	3-4 bar	≤ 8.4 km/h	≤ 1.5 bar
Billericay	Bubble jet 05	12-14 km/h	3-4 bar	≤ 9.7 km/h	≤ 2.0 bar
100 L/ha					
Teejet	AIC 025 VP	12-16 km/h	2–4 bar	≤ 9.7 km/h	≤ 2.0 bar
Lechler	IDK 025 (ceramic tip only)	12-14 km/h	3-4 bar	≤ 8.4 km/h	≤ 1.5 bar
Hypro	Guardian Air 025	12-14 km/h	3-4 bar	≤ 8.4 km/h	≤ 1.5 bar
Billericay	Bubble jet 025	12-14 km/h	3-4 bar	≤ 9.7 km/h	≤ 2.0 bar

While it might be tempting to select a nozzle where, to meet 3* criteria, the required reduction in speed is small, in practice those that require a larger speed reduction will probably be delivering a smaller droplet size at the higher speed over the main part of the field, and therefore potentially delivering better efficacy. The nozzles listed in Table 3 would all be considered 'small droplet air induction nozzles' in the AHDB nozzle chart. They would be expected to have a higher level of efficacy than larger droplet air induction nozzles (such as those giving 90% drift reduction) in situations where droplet size is important.

6.2 Accurate dosing and uniformity

An important component in achieving good performance of PPP is applying the correct dose, not just on average, but uniformly across the treated area. There are many factors in achieving this.

For accurate dosing, sprayer calibration is essential, including regular testing and calibration of pressure gauges and flow meters. Nozzles must be replaced when worn or damaged. Making sure that these basics are right is the most important factor in optimising application.

Using nozzles within their rated pressure range.

At lower pressures, the fan angle of the spray will collapse and the uniformity under the boom will decline, potentially leading to 'stripes', particularly if there is a lack of boom stability so that it dips too low. (Figure 8)

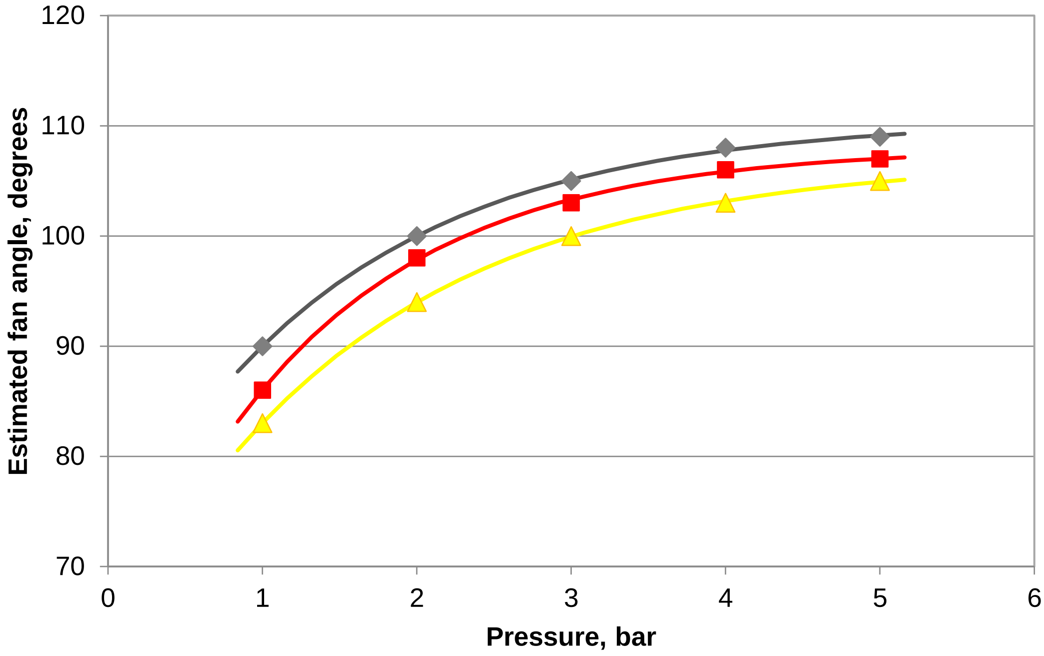

Figure 8. Fan angle as a function of pressure for a commercial brand of flat fan nozzle: 02 (yellow), 04 (red) and 06 (grey) sizes.

With rate controllers, the pressure will decline as the sprayer slows down at the end of each tramline. Figure 9 shows the relationship between pressure and speed. Some nozzles are rated only between 2.0 and 4.0 bar (shaded dark blue) which gives a very narrow speed band; others may go down to 1.0 bar and up to 5.0 bar (shaded light blue), extending the acceptable speed range. However, 5.0 bar pressure is likely to give high levels of drift and should therefore be avoided. As a rule of thumb, if a nozzle maintains its performance over a pressure range of 4.0 bar down to 1.0 bar, this allows speed to be halved.

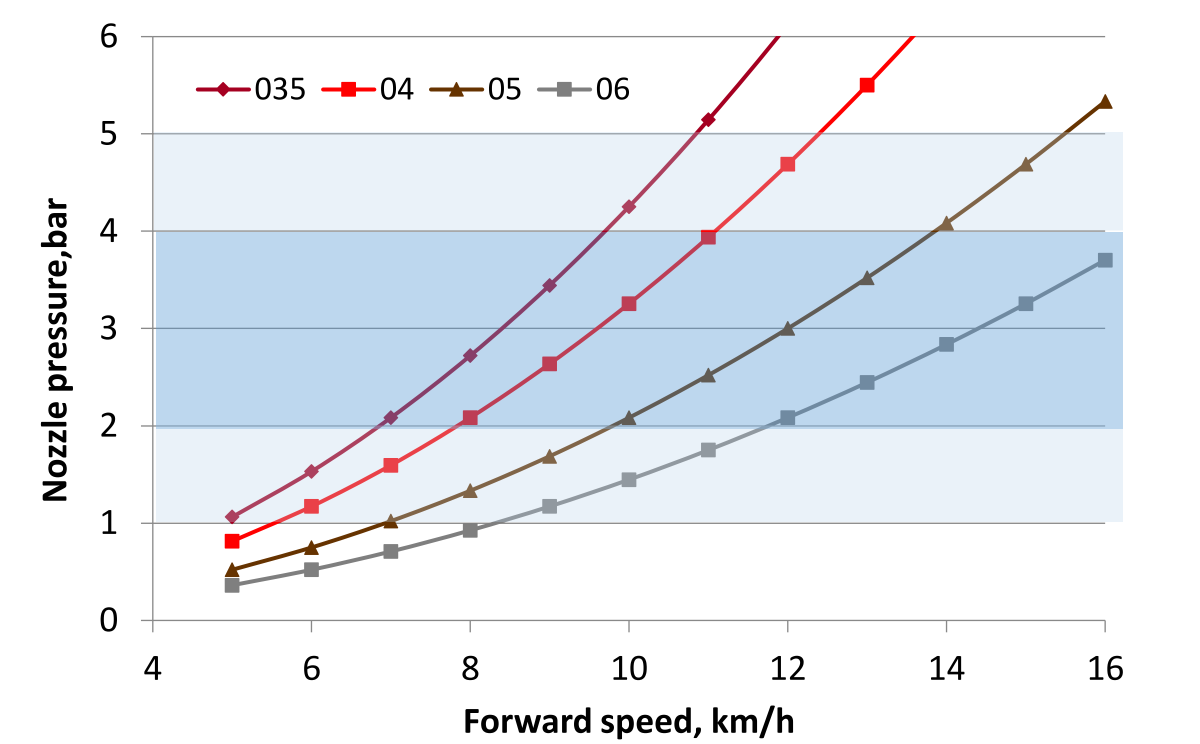

Figure 9. Relationship between nozzle size, forward speed and pressure for a nominal 200 L/ha application

Technology exists to extend the range of forward speeds for which dose remains constant and application technique remains acceptable – these include changing nozzle (e.g. Househam's Auto-nozzle select, https://househamsprayers.co.uk/technologies/auto-nozzle-select/ - many other manufacturers offer something similar) and Pulsed Width Modulation (Giles, 1997), which allows a reduction in flow rate by rapid pulsing of the nozzle. (e.g. http://www.teejet.com/literature_pdfs/bulletins/B140_DynaJet_Flex_7140.pdf; other systems are available). However, whatever the nozzle and the technology employed, sprayers need to be operated with care to ensure a constant and uniform dose applied across the field.

Variability caused by environmental factors

Wind is not constant, but continuously fluctuates, both in strength and direction. This will affect the trajectory of all droplets leaving the sprayer, resulting in an uneven and unpredictable distribution under the boom. Smaller droplets will be affected most and therefore the most even distribution will be achieved with larger droplets in all but very still conditions. Thus drift-reducing nozzles can give benefits to efficacy by reducing variability (Butler Ellis et al, 2017). Again, it is important to recognise that it is not the drift itself that compromises efficacy – the quantity of product that is lost to spray drift is relatively small – but that the nozzles which reduce drift also improve uniformity.

6.3 Specific recommendations for sugar beet applications

No evidence has been identified that suggests that PPPs for sugar beet require application techniques that are different from those for other crops. The AHDB nozzle chart for cereals and oilseeds (AHDB, 2010) remains a useful resource for identifying nozzle design for particular applications.

- Small droplet air induction nozzles are a good default option for all PPPs, examples of which are given in Table 3. Exceptions are herbicides applied to small weeds and some contact-acting fungicides and insecticides, where conventional nozzles will give higher quantities of deposited a.s. and better spray coverage.
- 100 L/ha application volume gives optimum performance in most situations, apart from some specific contact-acting products, where a higher level of coverage is needed.

Maximising work rates is important for achieving timely applications as well as for keeping costs down. Reducing volumes is one of the most effective ways of increasing work rate and has the least impact on performance. Increasing forward speed and boom width are less effective at increasing work rate.

However, label recommendations for many sugar beet products indicate minimum volumes of 200 L/ha (and higher for some insecticides) and require medium quality sprays. This is potentially constraining optimisation of application and further research to identify products where application recommendations can be improved would be helpful.

7. Conclusions

A review of application techniques for sugar beet has shown that there has been little relevant research and there is therefore much scope for optimisation.

The greatest number of studies have been for herbicides, where recommendations for other crops can be easily extrapolated to sugar beet.

Studies on application of fungicides to other crops have shown that there is often no loss of performance by moving from 200 to 100 L/ha combined with the use of small droplet air induction nozzles, particularly for systemic products. Angling nozzles has also been shown to improve the distribution over the plant in some situations. It seems likely that similar results would apply to sugar beet, although some supporting data, either from laboratory or field studies, would be valuable.

The application of Insecticides has not been well studied for any UK crop, and therefore this is an area where more work is needed if there is evidence that application might be limiting performance. In particular, the label recommendation of a minimum of 600 L/ha application volume for some products needs investigation because this is highly unlikely to be the optimum for any product.

It will be important to engage with manufacturers in any attempt to move away from label recommendations to ensure that restrictions required because of environmental or human safety are not breached.

Some basic steps for optimising application in general are outlined, and some examples of nozzle choices are given. We have also highlighted a number of new technologies that are under development and that may have a role in application in the future.

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