Project title:	Reducing herbicide use in row crops with targeted application methods treating detected weeds in small patches or spots.
Project number:	HL 01102, FV 307a
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Report:	First Annual report
Date commenced:	1st April 2010
Expected completion date:	31st December 2012
Key words:	Spot spraying, patch spraying, image analysis, control, herbicide, targeted application, weed control.

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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

GROWER SUMMARY

Headline

- Building on HDC project FV 307, this project is refining the spot spraying technology for the control of weeds in onion, carrots and parsnip crops.

Background and expected deliverables

EU legislation (e.g. the revision of 91/414 EEC and the Water Framework Directive) is reducing herbicide availability. Furthermore the limited range of herbicides remaining does not cover the full weed spectrum encountered and for some weed species there is, or soon will be, no means of control. There are very few new herbicides in the pipeline even for cereals.

This is a particular problem for horticultural crops because high quality is required and growers cannot risk leaving weeds if it could result in crop rejection, loss of product quality and of income.

Mechanical weed control is now more widely practised, but there are a number of circumstances when these methods are unsatisfactory eg in wet weather, and for control of perennial weeds and species with a strong tap root.

Chopping up roots of some target weeds such as creeping thistle exacerbates the problem. Repeated cultivations may also have adverse effects on the environment both in terms of energy use and greenhouse gas emmissions.

Flame and steam weeding are damaging to invertebrates and consume large amounts of energy. Hand labour has now become expensive and scarce.

Targeted application of herbicides to weeds that are difficult to control mechanically is an attractive option potentially providing good control with minimum chemical quantities and thus a low cost and environmental impact.

Systems for guiding precision banded applications including band spraying are commercially established although limited work has quantified the spray distribution in narrow bands (see Lund and Jensen, 2002) and the sharpness of the cut-off at the edge of the band.

Previous work has successfully developed an image analysis based weed detection system linked to a spot spray control mechanism. This system has been developed around the specific problem of treating volunteer potatoes within onion, carrot and parsnip crops.

Discrimination of live plant material from background was on the basis of colour and a number of criteria were used to determine if plant material was crop or weed. As implemented during field trials conducted in 2009, these criteria included; distance from crop row (located using a band-pass filter), feature size (volunteer potatoes tend to be larger) and feature shape (overall aspect ratio rather than leaf profile).

The experimental rig developed in the previous LINK project (FV 307) used a new fluidic nozzle design (The "Alternator" nozzle) to generate very large droplets (>1000 μm in diameter) that were applied to detected weed targets to give levels of control in field trials of typically 90 to 95% of volunteer potato plants within the selected size range at the time of treatment.

While the spot treatment of detected weeds in row crops offers to deliver large savings in herbicide use and maintain good levels of control, there are implications for product approvals where existing approvals or SOLA's are not relevant. For this, and reasons associated with offering greater flexibility and weed control options in a wider range of conditions, there is a need to examine the use of the approach with:

- All major formulation types
- A wider range of weed species
- A wider range of crops

The expected major deliverable from the project is therefore the basis for the design and operation of a commercially viable unit for detecting individual large weeds that can be treated by spot application or patches of smaller weeds that can be patch sprayed particularly in onion, leek and sugar beet crops. It is expected that the techniques developed will have application to other crops, particularly carrots and parsnips, and a key component of the work is to develop a system that will operate with a wide range of herbicide formulations.

Summary of the project and main conclusions

This LINK project has built on the results from a previous LINK project (Miller et al., 2010) that specifically addressed the issue of controlling volunteer potatoes in crops of onion, carrot and parsnip.

The work in this first year of this project involved:

- Conducting field trials with the experimental rig developed as part of the previous project but with modifications to the control of the nozzle solenoid valves and liquid supply system so that selective herbicide formulations could be used.

- Examining how the requirements to generate sprays with different characteristics for both spot and patch application could be met based on existing nozzle designs.

- Reviewing approaches to controlling the movement of sprays from the nozzle to the target in a way that minimised the risk of crop contamination and damage.

- Developing a new nozzle system involving the manufacture of prototype units and the measurement of the performance of existing units over a wide range of operating pressures.

- The further development of the weed detection algorithms to:
  (a) Refine the individual weed tracking algorithm to give improved spot spraying accuracy
  (b) Establish approaches to the detection of patches of small weeds in row crops
  (c) Identify approaches to the detection of tall weeds, particularly weed beet, on the basis of height

- Assessing the extent to which additional selectivity could be gained when treating a large weed target (e.g. volunteer potatoes) in a small crop (e.g. onions) due to the large droplet size used.

The weed detection algorithm for spot application has been refined during the period covered by this report and tested in crops of sugar beet, onions and leeks. The associated changes to the control algorithms increased the speed of solenoid operation (reduced the cycle time) by a factor of two. An algorithm for detecting weed patches in row crops has been written but not yet tested.

A new nozzle cartridge system has been designed and prototype units manufactured for use in field trials with the experimental rig. The cartridge unit enables one of two nozzle tip designs to be fitted, namely:

(a) a version of the "Alternator" nozzle design creating very large droplets appropriate for treating large weeds with spot applications;

(b) an "Even Spray" tip generating a medium/fine quality spray appropriate for treating small weeds (eg. grass weeds at an early stage of growth) when detected as patches in row crops.

Figure 1. Testing the prototype in the field

The decision to develop the cartridge approach with two nozzle tips was taken after measurements with different nozzle designs showed that it was not possible to achieve the range of spray characteristics needed for both spot and patch application from a single nozzle design.

A review of the options for controlling spray movement from nozzle to target concluded that, for spot application, the use of large droplets delivered with a controlled trajectory was the best option. For application to patches where a medium/fine spray quality is needed, less control may be needed when selective herbicides are applied and trajectory control is probably still the most appropriate. This conclusion will be reviewed following field experiments treating patches of small weeds.

Results from field experiments showed that good control of large weeds could be achieved with spot applications of selective herbicides with little risk of crop damage. Accurate targeting of spot applications enabled herbicides to be used for which there was no, or reduced, crop tolerance (eg glyphosate) and that could give improved levels of weed control. Flumioxazine applied at full rate gave improved control of volunteer potatoes when compared with a fluroxypyr + ioxynil mixture applied at 500 ml/ha each.

Measurements comparing the spray deposits on onion plants with those on large flat surfaces treated with a prototype version of the “Alternator” nozzle spraying a tracer dye in very large (>1000 µm) droplets showed that the onion plants were likely to retain only 1/3 of the spray volume that would be retained on a horizontal surface. The use of large droplets is therefore giving additional selectivity when treating large weeds such as volunteer potatoes in a small crop such as onions.

The project consortium is working to develop concepts and a framework within the project such that prototype machines can be trialed during the 2013/14 seasons with commercial machines being available after this date.

Financial benefits

An economic analysis was conducted using experience gained in field trials with the full-scale rig in the previous LINK project. As no economic analysis has yet been conducted as part of the current project, this previous analysis is repeated here, with some up-dating, for completeness.

The cost of treatment based on this technology has been estimated to be £44/ha
based on the following assumptions:

- A 5.4 m machine operating at 5 km/h with a field efficiency of 75% giving a work rate of 2.0 ha/h.

- Seasonal and weather conditions limit operation to 20 8h days yielding a treatment capacity of 324 ha (this would increase if the machine was used to treat a wider range of target crops and weeds).

- Capital cost is estimated at £35,000 which depreciated at 20% p.a. gives an annual repayment charge of £9,240.

- Tractor and driver costs are assumed to be £19/h, the cost of glyphosate at £1.0/ha and maintenance £1,750 p.a.

On this basis, total costs are £37.00/ha if spread over the capacity area. Although these figures are higher than for the overall application of sprays to arable crops (at £10.90/ha to £20.00/ha – Nix, 2011), they are lower than for tractor hoeing (at £48.50/ha) and should therefore provide an economic alternative when chemicals used for overall application become limited or are withdrawn. The economics of operation improve further if utilisation can be extended through the season on multiple crops and weed targets – which reflects the aim of work on the current project.

Action points for growers

There are currently no action points for growers. However, the project is on track to produce the technology necessary for the production and operation of a commercial prototype system for the detection and treatment of large weeds by spot application and patches of weeds using patch spraying approaches. Further field scale evaluation will take place in the 2012 growing season with manufacturing partners aiming to have machines available commercially for subsequent seasons.

The project consortium is working to develop concepts and a framework within the project such that prototype machines can be trialed during the 2013/14 seasons with commercial machines being available after this date.

SCIENCE SECTION

Introduction

This report details progress within the first year of a LINK project that aims to further develop and demonstrate the technology that uses weed detection and the targeted application of minimum quantities of herbicide formulations to control a range of weed species in a number of vegetable crops, particularly onions and leeks. The project is also investigating the application of the approaches developed the control of weed beet in sugar beet crops. The study follows an earlier LINK project that was specifically concerned with the control of volunteer potatoes by the targeted application of a total herbicide.

The background to the current work with regard to the main aspects of the project was given in previous reports (Miller et al, 2006; Miller et al, 2010) and included the following main points.

(a) The need to control volunteer potatoes in vegetables relates to both yield and quality considerations that are difficult to quantify in financial terms because of the variability in growing situations. Control of volunteer potatoes is also important in relation to the carry-over of disease in the potato crop.

(b) Significant progress has been made in the last decade in relation to the use of image analysis for machine guidance and control particularly leading to the commercial introduction of the Garford "Robocrop".

(c) Weed detection has been the subject of much research effort aimed at developing systems that will minimize pesticide use. The most successful approaches have been those operating in widely spaced row crops including vegetables.

(d) There is little published information about the performance of wiper applicators in terms of herbicide transfer or crop contamination. The height differential between weed and crop is crucial to the performance of such systems and accurate control of operating height is therefore necessary.

(e) Pulsed nozzle designs have been developed for selective chemical thinning operations and although not exploited commercially on a wide scale, some of the under-pinning research is relevant to the current project.

Work in the previous LINK project (Miller et al, 2010):

(i) Developed methods for weed detection in row crops based on image analysis that defined the position of crop rows, identified the positions of relatively large weed plants with respect to the detected rows and defined a treatment area (as a polygon) around each detected weed;
(ii) Developed nozzle systems for spot application that would minimize contamination and damage to crop plants close to treated weeds: specifically work, mainly by Hypro EU Ltd, developed a nozzle, the “Alternator” nozzle, operating on fluidic principles to create very large droplets (mean size > 1000 μm) delivered from a narrow well defined spray fan operating at relatively low pressures;
(iii) Conducted field trials in crops of onion, carrot and parsnip examining the control of volunteer potatoes using applications of the total herbicide, glyphosate: Results from these field trials showed that the system was able to achieve high levels of control (90-95% of weeds above the size threshold at the time of treatment) with levels of crop damage that were judged to be commercially acceptable.

The work in the period covered by this report therefore aimed at:

(i) Reviewing options for generating sprays against the criteria for treating both large weeds with spot applications and smaller weed in patches;
(ii) Designing a nozzle arrangement to meet the criteria for both spot and patch application based on theoretical considerations and measurements with prototype units;
(iii) Reviewing options for controlling spray movement from nozzle to target so as to minimise crop contamination and damage;
(iv) Revising weed detection algorithms so as to:
    - improve the accuracy of detection of a range of species and treatment;
    - detect patches of small weeds in row crops;
    - detect weeds without reference to crop rows;
(v) Conducting field trials with an experimental rig built as part of a previous LINK project but modified to allow operation with a range of formulation types and to examine spot spraying performance with selective herbicides.

Progress, results and discussion (by objective)

Identifying spray generation options

An analysis of the requirements for spray generators to deliver herbicides to both individual detected weeds as a spot treatment and to treat patches of weeds indicated that there was need to be able to deliver sprays with a wide range of spray qualities (droplet size distributions). Previous studies as part of a LINK project had shown that large weeds (volunteer potatoes) could be effectively treated using sprays from a fluidic nozzle design that generated very large droplets (>1000 μm) that were well outside the range used to classify the performance of agricultural spray nozzles (Doble et al., 1985). These large droplets gave good control of the drift risk even in wind conditions that were above those regarded as satisfactory for crop spraying. It can be concluded that such sprays are appropriate for the treatment of relatively large weeds that are detected and treated as spots. However, the requirement to treat patches of weeds may involve herbicide applications to much smaller weed targets such as grass weeds at an early stage of growth. A number of studies have shown that spray retention on such small targets is a function of droplet size and that a droplet size representative of the fine/medium spray quality in the BCPC classification scheme (Doble et al., 1985) is needed if high levels of retention are to be achieved.

In considering spray generation systems that could be used for applications to both spot and patch targets it was therefore necessary to consider systems that could create sprays with very large droplets for spot application and a medium/fine spray quality for treating patches of smaller weeds. The option of using a single nozzle design to deliver the full range of spray qualities required was initially explored by examining the performance of the fluidic "Alternator" nozzle over a wider range of operating pressures.

Further measurements with the fluidic "Alternator" nozzle

Measurements of the droplet size distribution with the original design of the "Alternator" nozzle operating at pressures up to 9.0 bar showed that increasing the pressure decreased droplet size as expected (Figure 1). Measurements were made with the nozzle supplied both from a pump and from a pressurized canister because it was thought that small pressure pulsations in the supply from a pump may influence the performance of the nozzle. Results indicated no differences when the supply was from the pump or pressurized canister.

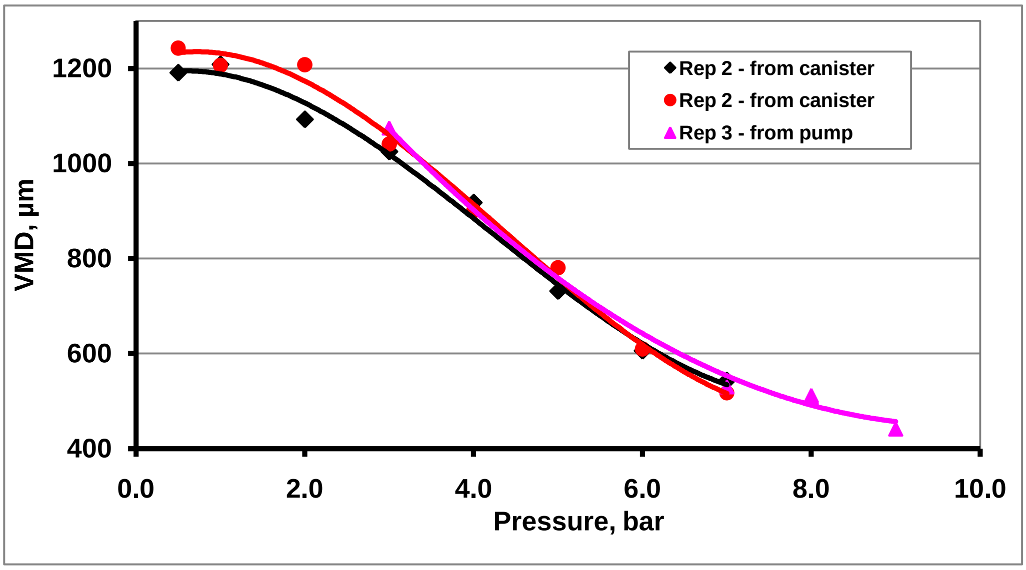

Figure 1. The mean droplet size (as Volume Median Diameter) from the "Alternator" nozzle at different pressures

The reduction in mean droplet size did not give a VMD value for the measuring system used (Oxford Lasers Ltd "Visisizer" with the spray scanned by moving the nozzle on an x-y transporter) that was comparable with that of a fine/medium spray quality sampled in the same way (VMD of 272 µm). However, it was recognized that the effective spray fan angle from the "Alternator" nozzle design was much narrower than that for the conventional reference nozzle designs and therefore the droplet size distributions were further analysed to compare the droplet size/flux relationships that would be relevant to a 60 mm wide strip immediately below the nozzles. The droplet size distributions plotted in Figure 2 show that as the pressure is increased, the distributions span a wider range of droplet sizes with evidence of bi-modality particularly at pressures of 3.0 and 5.0 bar. At a pressure of 8.0 bar the proportion of spray volume in droplets around <400 µm in diameter is increased but there is still a substantial proportion of the spray in very large droplets particularly when compared with conventional nozzles giving a fine or medium spray quality – see Figure 3. An analysis of the flux on a 60 mm wide strip below the nozzles is summarised in Table 1 and shows that, at a pressure of 8.0 bar, flux values from the "Alternator" nozzle in the 100 to 200 µm range are comparable with those from the conventional flat fan nozzles. However, the presence of the larger droplets in the spray could influence the efficacy when treating small targets and will represent a reduction in efficiency of the application process.

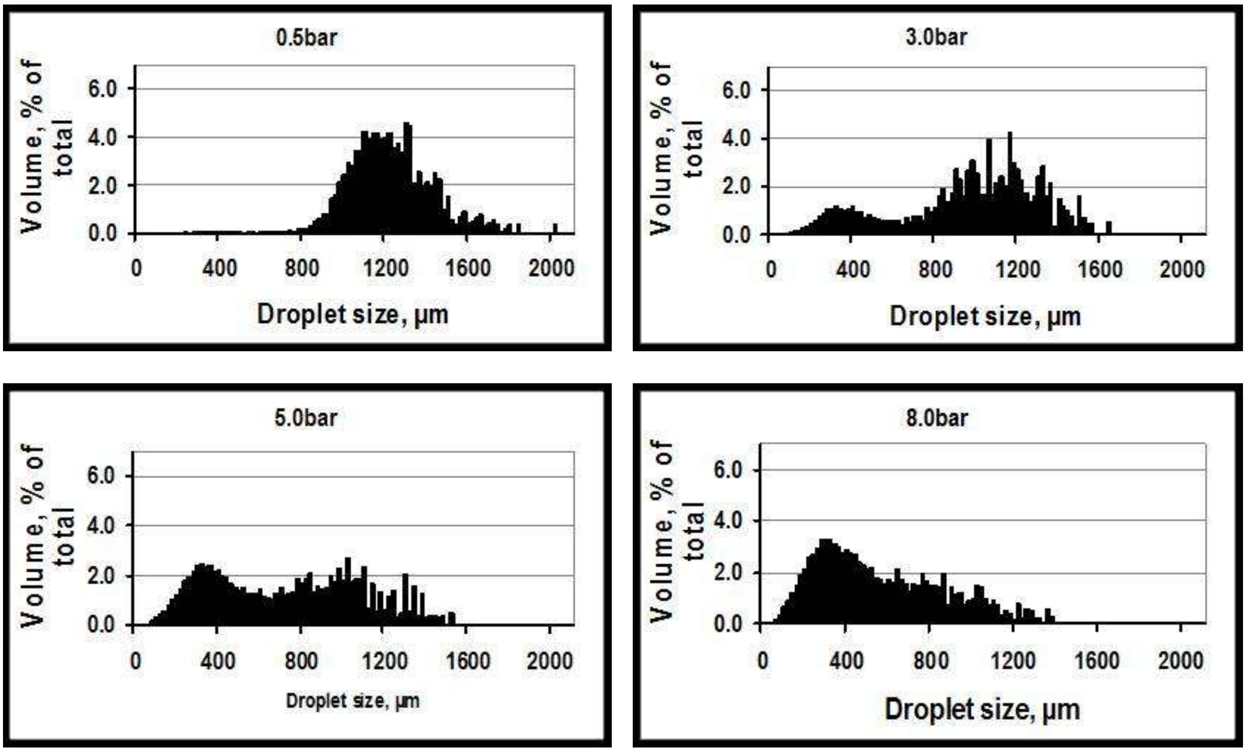

Figure 2. Droplet size distributions from the “Alternator” nozzle at different pressures

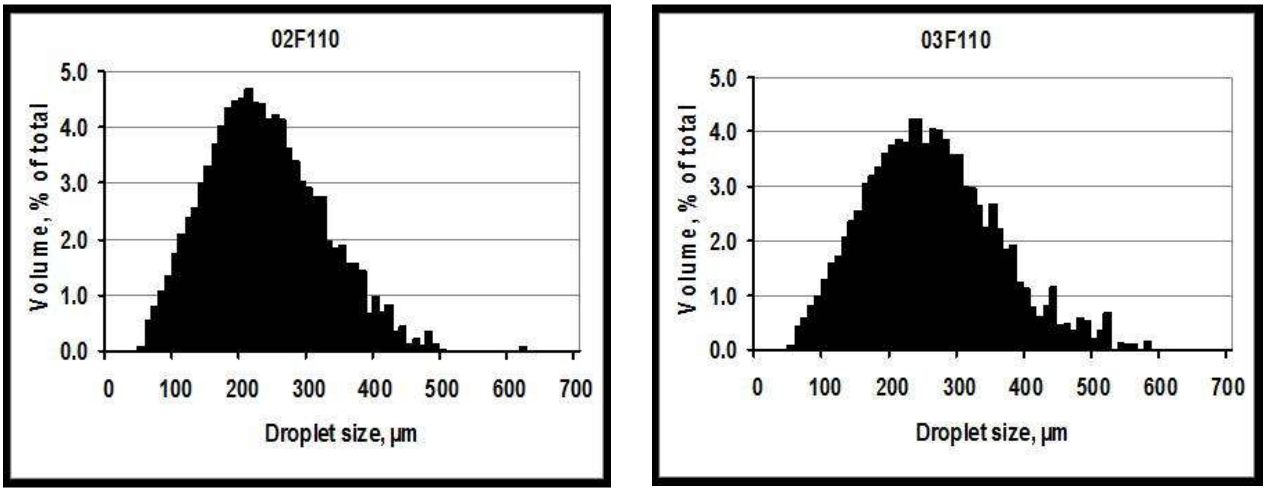

Figure 3. Droplet size distributions measured with conventional nozzles operating at 3.0 bar pressure to give fine (02F110) and medium (03F110) spray qualities.

Table 1. Comparison of flux levels on a 60 mm wide strip sprayed with different nozzle conditions

Nozzle	Flow rate, L/min	% of volume in 100-200 µm	Flux in 60 mm wide strip in 100-200 µm, L/min
"Alternator" at 0.5 bar	0.135	0.05	0.000068
"Alternator" at 8.0 bar	0.507	6.18	0.031
"02" 110⁰ Flat fan	0.83	32.38	0.033
"03" 110⁰ Flat fan	1.12	24.96	0.036

It was also recognized that droplet velocities may be important particularly with regard to droplet splash from the target. Measured droplet size/velocity correlations for the "Alternator" nozzle plotted in Figure 4 show the expected increase in velocity of the main part of the spray with increasing pressure.

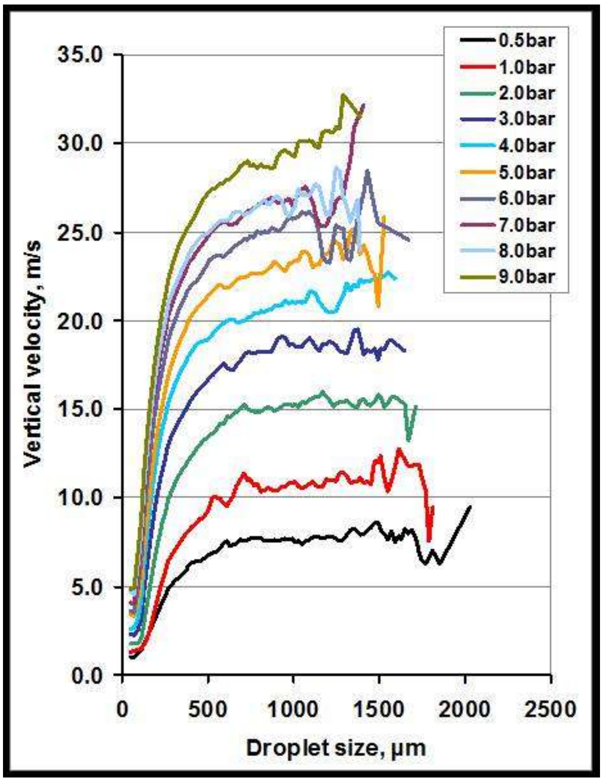

Figure 4. Measured droplet size/velocity profiles for the "Alternator" nozzle with the spray sampled 250 mm below the nozzle outlet.

It was concluded that although operating the “Alternator” nozzle at increased pressures moved the performance envelop towards that required to treat a range of weed targets, it was not appropriate to use this nozzle design to treat all of the targets needed with a spot and patch spraying system.

After considering a number of alternative options it was decided that:

- Large weed targets that can be treated with spot applications should use a nozzle capable of generating very large droplets with relatively low release velocities and that the “Alternator” design was appropriate for such applications; the nozzle should then have a spray angle in the order of 15 to 25^o (lower spray fan angles will allow the nozzles to be operated at greater heights) and a nominal flow rate at the working pressure in the range of 0.3 to 0.4 L/min (lower flow rates than this range would involve smaller output orifices and so pose an unacceptable risk of blocking when operating with a range of formulation types);
- Weed patches that may include relatively small grass weed targets should be treated with a nozzle capable of generating a spray with a medium/fine spray quality and that an “Even Spray” tip was appropriate for such applications; this nozzle to have a flow rate and spray angle specification similar to that of the “Alternator” nozzle as defined above.

For conventional flat fan and “Even Spray” nozzles, mean droplet sizes increase as the orifice size (and therefore flow rate at a given pressure) increases and as the spray fan angle decreases. It was not therefore obvious whether an “Even Spray” nozzle with a small orifice size and small spray fan angle would generate fine/medium quality sprays at an appropriate range of operating pressures. To examine the potential for such a design to achieve the required performance, a prototype unit was made by Hypro EU Ltd using a resin setting system operating in conjunction with a computer-aided design system and the performance of this unit was then measured with established techniques.

Measurements of the performance of a prototype “Even Spray” nozzle design

The results from droplet size measurements made with a laser-based analyser (Oxford Lasers “Visisizer”) with the nozzle mounted on an x-y transporter system so that the whole of the spray could be sampled, showed that the “Even Spray” design could generate a fine/medium quality spray at a pressure of approximately 3.5 bar – see Figure 5. The results are plotted on a spray quality grid generated from measurements with reference nozzles using the same instrument and sampling procedures.

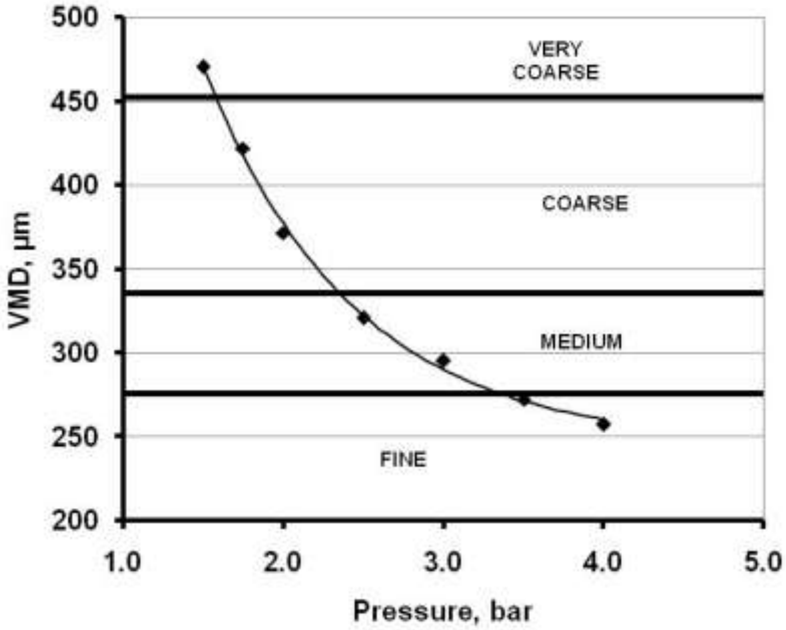

Figure 5. Mean droplet sizes (as a Volume Median Diameter) for the prototype "Even Spray" nozzle compared with results from reference nozzles defining spray quality classes of fine, medium, coarse and very coarse.

Results from detailed measurements of the spray structure from the prototype "Even Spray" nozzle operating at a pressure of 3.5 bar and sampling 250 mm below the nozzle are shown in Figure 6.

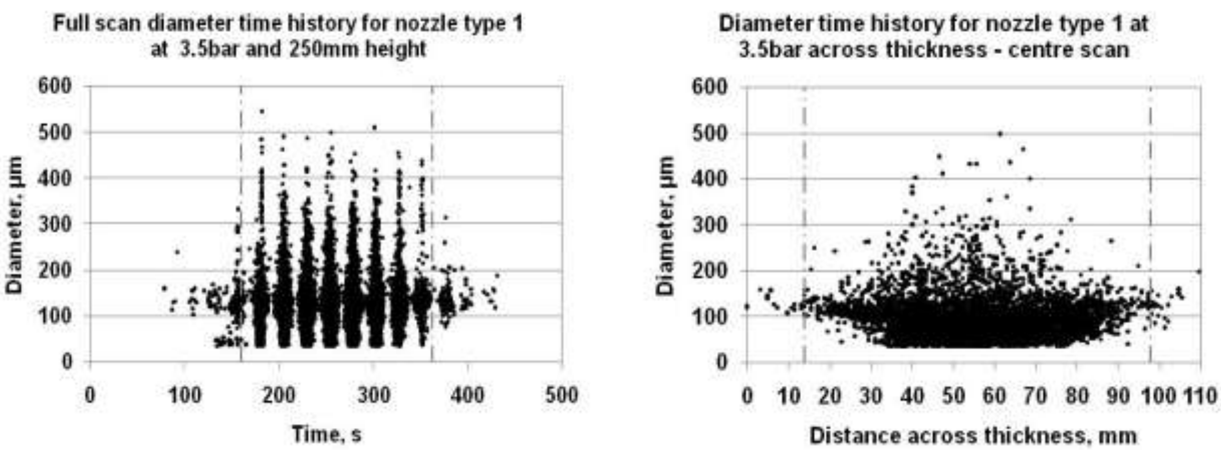

Figure 6. Results from detailed measurements of the spray structure with the prototype "Even Spray" nozzle.

The results shown in Figure 6 indicated that the spray had a fan angle (across the spray fan) of 24^o and an angle through the centre of the fan of 19^o.

Identifying spray directing options

Four main options have been considered for directing the spray from a nozzle to the target with the aim of minimising off-target movement and therefore crop contamination and damage.

The use of droplet trajectories

Where large droplets are generated, as for example by the “Alternator” nozzle, then sprays can be directed to the target by controlling the initial velocity and angle of release from the nozzle. Studies in the previous LINK project indicated that designs of the “Alternator” nozzle could maintain droplet trajectories from a moving nozzle in wind speeds up to 3.0 m/s at nozzle height and hence minimise crop contamination due to drift. The fine/medium quality spray from the “Even Spray” nozzle is likely to be more influenced by wind effects although the applications based on patch treatments are also likely to be less sensitive to off-target contamination effects.

The use of electrostatic charging

Electrostatic charging has been shown to control the movement of small droplets and in agricultural spraying applications has given deposits on under-leaf surfaces and stems that are difficult to achieve by other methods. However, the technique is most effective when:

- using small droplets (circa 100 μm in diameter);
- when operating with strong electrostatic fields that can be generated externally or from an induced field as a result of a cloud of charged droplets.

Such small droplets and high electrostatic field strengths are unlikely to be relevant to spot and patch spraying in agricultural environments and it was considered that such approaches were not appropriate for further development, experimentation and evaluation as part of this project.

The use of controlled air flows

The use of air flows to control spray trajectories has been used in horticultural and agricultural applications and has been shown to reduce the risk of drift. The design of such systems needs to recognise:

(i) The need to match air flow characteristics to the crop/weed canopy to be treated so as to avoid bounce;
(ii) The relationship between the spray source and the air flow such that the air does carry spray to the target;
(iii) The power requirements associated with moving high volumes of air.

It was concluded that air-assistance may have a role if work later in the project, particularly with the fine/medium quality spray from the "Even Spray" nozzle, showed that control over spray movement other than by controlling the initial trajectories was needed.

The use of physical shields

The use of shields and side guards is well established for use with band spraying applications and would provide control across crop rows. As with air-assistance, it was concluded that such guards would not be required if droplet size distribution and trajectories could be adequately controlled. This situation would be reviewed at later stages in the project work.

Development of nozzles – laboratory scale

A cartridge system was designed and developed by Hypro EU Ltd that enabled both types of spray tip to be mounted immediately below the controlling solenoid valve – see Figure 7.

Sixty of the cartridge units were manufactured in prototype form by Hypro EU Ltd together with "Alternator" tip inserts and assembled for mounting on the experimental rig – see below.

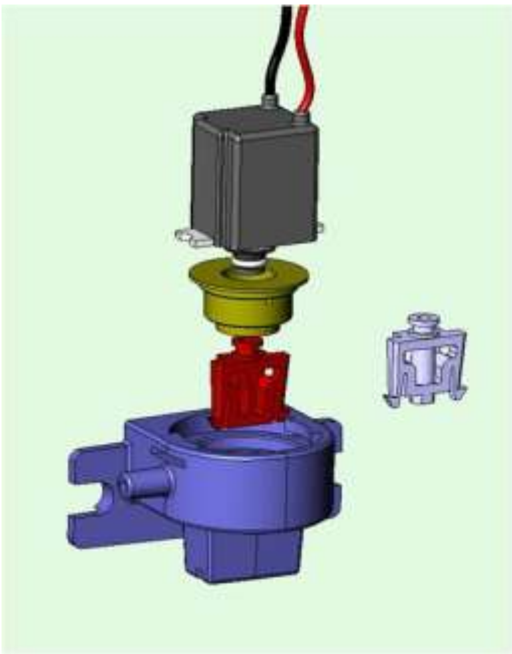

Figure 7. Cartridge arrangement for mounting the "Alternator" tip (red) and the "Even Spray" tip (light blue) together with the controlling solenoid.

Experience from the previous project showed that the design of a solenoid valve originally used on the experimental rig was not well suited to operation with liquids that were not complete solutions. Hence, although the rig operated well when applying glyphosate to volunteer potatoes, the use of other formulations based on emulsions such as a Starane + Totril mix resulted in some valve failures with the nozzles spraying continuously. Working with the solenoid valve manufacturers, a new valve design was produced mainly by using different materials from which to form the key components in the valve. This new valve design was tested in the laboratory by spraying a liquid containing 0.5% of a simulated emulsifiable concentrate formulation on a continuous cycle through three nozzle/valve assemblies for more than 25 hours of operation. Satisfactory performance at the end of this period indicated that the re-designed valves were appropriate for fitting to the experimental rig for use in experiments in the 2011 cropping season.

Development of nozzles for field scale experiments

Nozzles used in the first year of experimental work (2010 cropping season).

With the project starting in April 2010, it was not possible to research and produce new nozzle designs specifically for the applications of interest to the study. The experimental "Alternator" nozzles developed by Hypro EU Ltd for the previous project were therefore used in the first season of field experiments in this project. Modifications were made to:

(a) The method of driving the solenoid valves such that they were powered both on and off rather than relying on the latching mechanism – in this way the failures due to the solenoid valve remaining open when operating with liquids that were not pure solutions, referred to above, were eliminated pending the development of a new nozzle design but at the expense of an increase in electrical power consumption;

(b) Provide two liquid supplies so that for example, nozzles mounted over a crop row could be supplied with a different spray liquid to those positioned between crop rows.

The availability of nozzles was such that only half the machine width was fitted nozzles and 6.0 m wide beds (eg. 3 of 2.0 m wide beds) were treated by travelling in both directions across the field.

Conduct nozzle field trials

Experiments were conducted in the onion crop in the 2010 cropping season in which the deposits on onion plants were compared with those on horizontal surfaces for both the experimental "Alternator" nozzle operating at a pressure of 1.0 bar and an "Even Spray" "01" size nozzle with a spray angle of 25^{o} and operating at a pressure of 3.0 bar. It was thought that the large droplets from the "Alternator nozzle" would be less well retained on the small onion plants than the smaller droplets from a more conventional nozzle design and the experiments sought to quantify the possible extent of this additional selectivity due to a droplet size effect.

Filter paper discs were laid on the surface of the soil and on a platform that corresponded to the top of the crop plants. These discs were positioned over the centre of the crop row (see Figure 8) and were sprayed by driving the rig down the crop row at a speed of 4.0 km/h using nozzles also positioned over the crop row. Both nozzles sprayed a solution of a tracer dye ("Green S" – Sensient Colours Ltd) at 0.1%. Deposits were recovered from the centre sections of the filter papers corresponding to the sprayed strip and from samples of 25 onion plants that were taken from within the treated row. Three replicates of all samples were taken.

Figure 8. Experimental layout for sampling deposits on horizontal surfaces and onion plants in field conditions

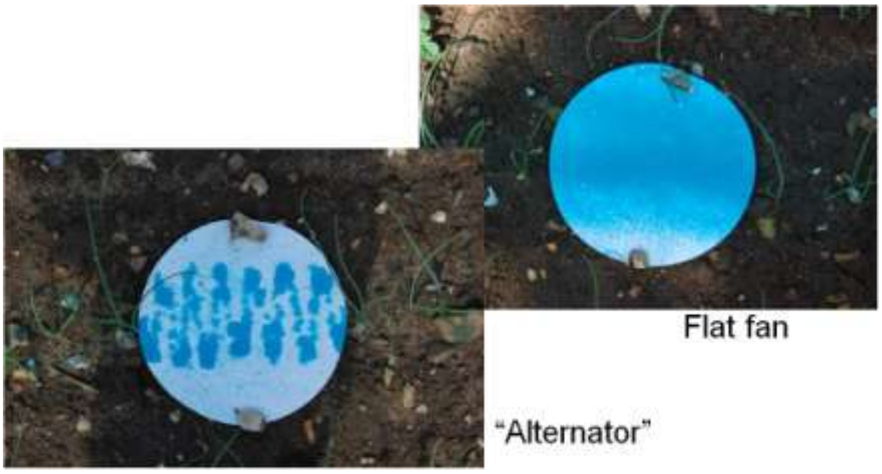

Figure 9. Deposits on the horizontal collectors sprayed with the two nozzles used in the study

The form of the deposit on the filter papers clearly showed the oscillating action of the "Alternator" nozzle (Figure 9) with a more conventional pattern from the "Even Spray" nozzle as expected. Deposits measured on the filter papers and onion plants are summarized in Table 2. Because the flow rates and patterns from the two nozzle designs were not directly comparable, deposits on both collector types have been expressed as a ratio. If both surfaces had comparable collection characteristics then this ratio should be a constant. Results in Table 2 show reasonable agreement in the deposit ratios for the paper collectors at the two positions (0.472 and 0.505) but with a much lower ratio for the onion plant deposits. This result indicates that deposits of the coarser spray from the “Alternator” nozzle were approximately one third of those of the finer spray and this difference in deposit on the onion plants could also be seen visually (Figure 10).

Table 2. Measured deposits on filter papers mounted on a platform and at ground level and on sampled onion plants

Nozzle	Platform deposits	Soil surface deposits	Onion plant deposits
Flat fan “Even Spray”	616	473	6.35
“Alternator”	291	239	0.87
Ratio “Alternator/ “Even Spray”	0.472	0.505	0.137

Figure 10. Examples of spray deposits on onion plants of the two spray types.
(a) left – from the “Alternator” nozzle.
(b) right – from the “Even Spray” nozzle.

Refine detection algorithms

Refined individual weed tracking for improved spot spray accuracy

An algorithm has been developed to directly track individual weeds with a Kalman filter such that their position and shape (expressed as a convex polygon) could be refined as they progressed down the image. This refinement included provision for cases where two or more weeds seen at the top of an image merge to form a single target by the time they are viewed for the last time. Conversely the case where what is perceived as one weed at the top of the image appears as two separate targets at the bottom was also handled correctly. The algorithm has been interfaced with a treatment map. This new approach to weed tracking has undergone basic testing on sequences of stored images and an artificial crop. The time resolution at which the spray nozzle solenoid controller operates has been improved from 1/30th of a second to 1/60th of a second. This will further improve treatment accuracy.

Detection of patches of smaller weeds

In previous work we showed that it is possible to estimate overall weed density in widely spaced (25 cm) cereal crops by measuring a green index in the inter-row zone prior to canopy closure (Hague et al., 2006). The earlier work generated weed maps from stored image sequences, but made no on-the-spot spray treatment decisions. During the reporting period of this project we have developed an algorithm to conduct weed patch detection in vegetables using the same technique and linked it to real time treatment. This work has been tested on sequences of stored images and is now ready for field testing.

Investigate height based discrimination, primarily for weed beet

We have identified two options for weed detection through height discrimination that will now be evaluated. The first is a relatively simple technique based on a low cost optical range sensor. We anticipate some reliability issues with this technique under field conditions, but hope that it may provide an adequate method of testing the effectiveness of spot spraying from above as a means of controlling tall weeds such as weed beet. The second approach is based on stereo computer vision in which disparity between two images taken from cameras set 12 cm apart can be used to calculate range. This is a challenging environment for stereo vision due to the lack of clear cut geometric features from which to deduce disparity. Apparatus to experimentally evaluate these two approaches is under construction. Stereo image pairs of weed beet will be taken using this apparatus in the summer of 2011.

Field trials in a range of crop conditions

Work in the onion crop – 2010 cropping season

An initial experiment in onions was conducted on 25th May 2010 in which a treatment comprising 500 mL/ha of fluroxpyr (as “Starane”) and 500 mL/ha of ioxynil (as “Totril”) were applied to detected volunteer potatoes in nominally 300 L/ha of water. The experimental rig travelled at a speed of 4.0 km/h and used a two camera configuration to treat 12 rows spaced at 0.17 m (1.5 beds) per pass (see Figure 11).

Figure 11. Experimental rig as configured for work in the onion crop in May 2010

Results showed levels of control that were comparable with those from an overall spray application although some small volunteer potatoes plants were missed by the detection routine probably because they were below the minimum size (3.0 cm) threshold at the time of treatment. Detection levels were estimated at between 90 and 95%. As expected, given that a selective herbicide mixture was being applied, there was no evidence of substantial crop damage.

The levels of control when using different formulations applied as a spot spray to volunteer potatoes was also examined in the onion crop in treatments applied on 28th May 2010. The experimental rig configuration was as used in the initial trial and shown in Figure 11. The following tank mixes were applied in nominally 300 L/ha of water:

(a) Fluoxypyr (as “Starane”) + ioxynil (as “Totril”) both at 500 mL/ha;

(b) As (a) above + bentazone (as “Basagran”) at 500 g/ha;

(c) Flumioxazine (as “Digital”) at 100 mL/ha.

Treatments were applied when travelling at 4.0 km/h with the system set to treat a minimum target size of 3.0 cm and apply spray to 75% of the target area. For each treatment, four random blocks each containing 25 volunteer plants were marked (100 plants in total) and were assessed and scored visually at 3 and 16 DAT.

The results shown in Figures 12 to 14 indicated that the treatment based on flumioxazine was more effective in controlling the volunteer potatoes and also acted more rapidly than the fluoxypyr + ioxynil mixture that is often sprayed overall in repeat applications to give control of volunteer potatoes in the onion crop.

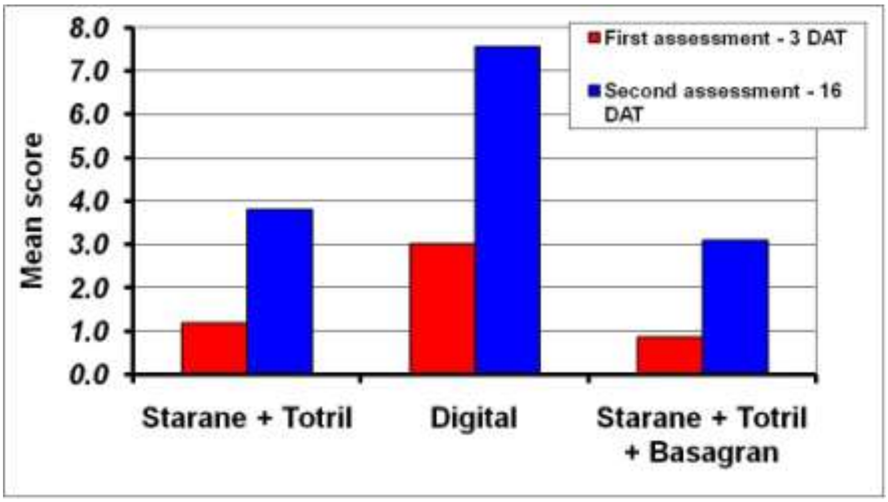

Figure 12. Mean scores for the control of volunteer potatoes treated by spot spraying different formulations as assessed visually at 3 and 16 DAT.

Starane + Totril **Digital**

Figure 13. Volunteer potatoes 3 DAT – spot sprayed with fluoxypyr + ioxynyl (left) and flumioxazine (right)

Starane + Totril Digital

Figure 14. Volunteer potatoes 16 DAT – spot sprayed with fluoxypyr + ioxynyl (left) and flumioxazine (right)

2.7.2 Work in the leek crop in the 2010 cropping season

The experimental rig was used in a crop of leeks on 15^{th} June 2010 spot spraying a mixture of fluoxypyr (as “Starane”) and clopyralid (as “Shield”) both at a rate of 500 mL/ha in nominally 300 L/ha of water to control volunteer potatoes and thistle. A 3 camera configuration was used with 26 nozzles treating 6 rows spaced at 0.5 m ($1^1/_2$ beds per pass) (Figure 15) at a speed of 4.0 km/h. The crop was relatively small and with some uneven emergence due to dry conditions and this necessitated using a relatively low forward looking camera angle so as to identify the crop rows. Treated plants were identified with stakes and were assessed to determine levels of control at 8 DAT.

Figure 15. Work in the leek crop in June 2010

The treatments were seen visually to be effective at the time of application with spray being well directed to the target plants. However, assessment of the levels of control achieved was confounded by previous treatments applied to control both volunteer potatoes and thistles but was judged subjectively to have been equivalent to a further overall spray application with the tank mix applied in spots.

Experiments in the sugar beet crop – June 2010

The experimental rig was set up with a single camera arrangement and nozzles mounted to treat four rows 0.5 m apart in a single pass – see Figure 16.

Figure 16. Work in the sugar beet crop – 4th June 2010.

The condition of the crop (leaves almost meeting in the row) and the weed populations (very low populations of large weeds between or within crop rows) meant that it was not feasible to spot spray in this crop with a total herbicide and no agronomic results were obtained. A separate camera was mounted on the rig (Figure 16) and used to collect further images that were used in the development of the detection algorithms.

Evaluate economic performance

No work on this objective was undertaken in the period.

Overall conclusions

(1) Field experiments have demonstrated the feasibility of applying selective herbicides and herbicide mixtures as spots to control detected weeds in vegetable crops grown in rows.

(2) When spot spraying large weeds such as volunteer potatoes in a small narrow-leaved crop such as onions, an element of selectivity in addition to that achieved by detection and delivery nozzle control is achieved due to the spray characteristics – from the very large droplet sizes used to achieve spray drift control.

(3) An individual weed tracking algorithm has been refined to give improved spot spraying accuracy and an improved time resolution within the controller.

(4) Algorithms have been written to detected patches of smaller weeds within row crops and to enable spot spray control strategies to be implemented without reference to crop rows.

(5) Options for detecting weeds based on height discrimination have been identified particularly for weeds such as weed beet in sugar beet.

(6) Measurements of the performance of the experimental “Alternator” nozzle over a range of pressures indicated that it was not practical to achieve the full range of spray characteristics needed for both spot application to large weeds and patch application to small weeds with a single nozzle design.

(7) A cartridge-based nozzle system with options to have either an “Alternator” nozzle giving a very coarse spray or an “Even Spray” tip giving a medium/fine spray quality has been developed: this includes a mounting for a revised solenoid design capable of operating with the full range of spray liquids containing herbicide formulations.

(8) An analysis of methods of controlling spray trajectories to minimise off-target and crop contamination indicated that using large droplets and retaining control of the initial trajectory offered the best practical option for achieving acceptable levels of control.

(9) Results of treatments applied to control volunteer potatoes in an onion crop showed that the use of the flumioxazine (as “Digital”) gave visually better and more rapid control than a mixture of fluroxypyr (as”Starane”) + ioxynil (as “Totril”).

Technology transfer

- Features of nozzle development for spot application presented at “Cereals 2010” in June 2010
- Presentation at “EuroOnion” in October 2010
- Elements of the project work included in a presentation at the “Crop World” event in December 2010
- Aspects of the project work on weed detection included in a presentation at the “Smart Sensors” event organized by IAgrE in March 2010
- Project work included in a presentation to the Horticultural LINK Programme Management Committee in March 2010.

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