Project Title	Reducing herbicide use in row crops with targeted application methods treating detected weeds in small patches or spots.
Project number:	FV 307(a) HL 01102
Project leader:	Dr Paul Miller
Report:	Second Annual report of a LINK project
Previous report	First annual report (March 2011)
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Project coordinator:	Dr David Cole
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The following are members of the Consortium for LINK project HL 01102:

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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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GROWER SUMMARY

Headlines

This project has developed an experimental machine capable of applying spot herbicide applications to detected single weeds or patches of weeds.

Background and expected deliverables

EU legislation (e.g. the revision of 91/414 EEC and the Water Framework Directive) is reducing herbicide availability - the limited range of herbicides remaining does not cover the 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 – 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 may exacerbate 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.

Our previous work has been successful in developing an image analysis based weed detection system linked to a spot spray control mechanism. This system was initially 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 used a new fluidic nozzle design 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 EAMU'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 applicationor 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.

A new nozzle cartridge system designed in the first year of this project was successfully developed and used in field trials. 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 (e.g. grass weeds at an early stage of growth) when detected as patches in row crops.

The decision to develop the cartridge approach with two nozzle tips was taken after measurements with different nozzle designs in the first year of the project 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. Further measurements of the droplet size distributions from both the “Alternator” and “Even-spray” tips were made in the second year of the project and confirmed that the “Even-spray” tip would create a fine spray at pressures above 3.5 bar. Some problems with leakage between components of the cartridge assembly were identified during the period covered by this report and addressed by re-molding some parts in a different, more compliant, plastic material.

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. Studies in this second year of the work have investigated the potential for crop contamination by splash and concluded that for most formulation types the addition of components to modify the physical properties of the spray liquid (e.g. viscosity) was not justified.

A new solenoid developed in conjunction with the manufacturer proved to be significantly more reliable when used with emulsion based formulations than the valve used previously and which was specified for soluble formulations such as glyphosate.

Weed detection algorithms have continued to be developed based on increased field experience. Work in this second year specifically involved:

a) The development and construction of a stereo camera system particularly for the detection of weed beet by height discrimination. Preliminary analysis of image pairs collected in field conditions have given promising results, but the stereo analysis algorithms will require further refinement if the technique is to progress to a practical sensing technique.
b) A preliminary assessment of the performance of the weed patch detection algorithm in a crop of rape established with a wide (500 mm) row spacing.

Results from field experiments conducted during the second year of the project:

a) Confirmed that high levels of control (>90%) of large weeds such as volunteer potatoes in onion and leeks could be achieved by spot application of selective and non-selective herbicides. Non-selective formulations gave a more rapid and complete weed kill with acceptable levels of crop damage.
b) Showed that spray deposits on target weeds treated by spot application were at least an order of magnitude greater than on crop plants in the vicinity of treated weeds.
c) Investigated the treatment of weed beet by simulating spot application to the base of a detected plant deflected forwards by a rubbing bar. Results from this work showed that variable levels of control were likely with no correlation between the response to the application and weed size and the amount of leaf at lower levels on the weed.

A key factor influencing the commercial uptake of the system will relate to the regulatory position concerning herbicide use. Discussions have been held with The Chemicals Regulation Directorate as part of project work in this second year with a view to obtaining an EAMU relating to spot application in a range of vegetable crops.

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 thanfor 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

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 prototype machines available commercially for subsequent seasons.

Exploitation and future applications

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 second 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 range of vegetable crops, particularly onions and leeks. The project is also investigating the application of the approaches developed to the control of weed beet in sugar beet crops. The study follows an earlierLINK 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 vegetable 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.

Work in the first year of this project (Miller et al, 2011):

(i) Reviewed options for generating sprays and concluded that large weed targets should use a nozzle capable of generating very large droplets with relatively low release velocities. Small grass weed targets should be treated with a nozzle capable of generating a spray with a medium/fine spray quality.

(ii) A nozzle arrangement based on a cassette with different inserts was developed to meet the criteria for both spot and patch application

(iii) Reviewed options for controlling spray movement from nozzle to target and concluded that use of large droplets directed by control of their initial velocity best suited the requirement for spot application.

(iv) Revised the 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) Conducted field trials with both selective and non-selective herbicides and showed that the former was generally more effective at controlling weeds at the cost of some risk of crop damage and loss close to target weeds. The later gave lower levels of control, but with no detectable crop damage.

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

(i) Finalising spray generation and directing options for treating both large weeds with spot applications and smaller weed in patches;

(ii) Finalising the nozzle and solenoid designs to meet the criteria for both spot and patch application and build prototype units for testing;

(iii) Conducting further field trials to:
  - Evaluate weed detection algorithms
  - Evaluate nozzle performance under field conditions
  - Obtain more data on the effects of spot application of both selective and non-selective herbicides
  - Obtain more data on the risks of crop contamination and damage.

(iv) Commencing discussions with the Chemicals Regulation Directorate such that issues relating to the approvals of products, particularly the total herbicide glyphosate, can be progressed.

Progress, results and discussion (by objective)

Identifying spray generation options

Most of the work defined under this objective had been completed prior to this reporting period (see Miller *et al.*, 2011) but with further measurements of nozzle performance made in this period as part of Objective 3 – see below.

Identifying spray directing options

The performance of the spray direction control options as implemented using the “Alternator” and prototype “Even-spray” nozzles was assessed in wind tunnel experiments. A single nozzle was mounted on a transporter and moved across a tray that contained a single target plant at a speed of 4.0 km/h. The nozzle was arranged to deliver a pulse of spray of a tracer dye to the target plant. The movement of spray to under and either side of the plant due to splash and drift was monitored by using 25 mm wide strips of chromotography paper placed with a 10 mm gap between strips such that the spray distribution over a region 300 mm wide could be mapped by analysing spray deposits using spectrophotometry. Dye deposits could also visualised on the collecting papers – see Figs. 1 & 2.

Figure 1. Dye deposits monitored on a plant surface treated with the “Alternator” nozzle operating 400 mm above the target, at a pressure of 0.75 bar and travelling at a speed of 4.0 km/h in still air conditions. (Note: Little evidence of secondary splash from treated leaves).

Figure 2. Dye deposits monitored on a plant surface treated with the "Even-Spray" nozzle operating 400 mm above the target, at a pressure of 3.00 bar and travelling at a speed of 4.0 km/h in still air conditions. (Note: The larger footprint compared with the "Alternator" nozzle and little evidence of secondary splash from treated leaves).

Results from these experiments showed little evidence of splash from treated leaf surfaces with either nozzle with most of the spray being deposited within a 100 mm wide strip centred on the target plant. Plant leaves were shown to good interceptors of the spray with penetration through the plant only corresponding to gaps between plant leaves.

A review of the literature and discussions following the presentation of conference papers (see Section 4 of this report) suggested that the risk of splash and secondary spray generation associated with large droplets hitting a large leaf target may be reduced by changing the physical properties of the spray liquid. Two series of experiments were conducted examining the effect of increasing liquid viscosity by adding Xanthan gum and methyl cellulose to the spray liquid both jointly and as separate components – these materials being specified in International Standards associated with evaluating crop sprayer performance. The results showed that using liquid with a relatively high viscosity (achieved by adding 0.5% Xanthan Gum) through the "Alternator" nozzle reduced the ability of this nozzle design to operate effectively resulting in a much reduced spray pattern width. The addition of methyl cellulose (at circa 0.2%) gave a smaller increase in viscosity and enabled the nozzle to operate without a substantial reduction in pattern width. While increasing the viscosity made some difference to the risk of splash as assessed visually when spraying a white paper target with a coloured tracer dye, the improvement was relatively small and may not be practically and commercially relevant.

Work in conjunction with Monsanto (initially outside of the project) developed formulations of glyphosate that are less prone to drift when sprayed through conventional pressure nozzles. The commercial launch of such a formulation has enabled this to be used within the project and samples for field experiments were supplied by Monsanto UK Ltd.

Some further work before the end of the project is likely to be required to verify that the control of the spray direction is adequate in a range of defined wind conditions but the results from the work to date indicate that control of spray trajectory is a good solution to control spray direction particularly for the “Alternator” nozzle design.

Development of nozzles – laboratory scale

Measurements of the droplet size, velocity and spray volume distributions were made with the new cartridge design of both the “Alternator” and “Even-spray” tips produced for use in field trials. Measurements were made with at least three nozzles of each design sampling the whole of the spray at a distance of 250 mm below the orifice with a laser-based analyser.

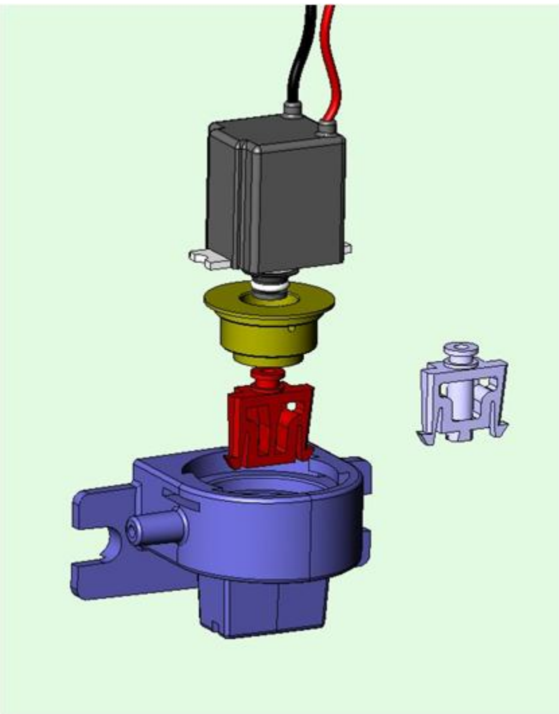

Figure 3. Cartridge arrangement for mounting the “Alternator” tip (red) and the “Even Spray” tip (light blue) together with the controlling solenoid.

Results for the “Alternator” design showed that performance was consistent with earlier versions of this nozzle with very large droplets generated and delivered with narrow spay fan angles. At a pressure of 0.75 bar, the mean droplet size, expressed as a VMD, was 1160 μm delivered with a mean spray angle of 15.3° with equivalent figures of 1139 μm and 17.0° at a pressure of 1.5 bar. Some problems with leakage around the cartridge components were confirmed as also observed in the field experiments – see Objective 7 below. A typical scan through the spray is shown in Fig. 4 indicating that the spray again tended to be bi-modal and with a substantial proportion of the spray in droplets >1000 μm in diameter.

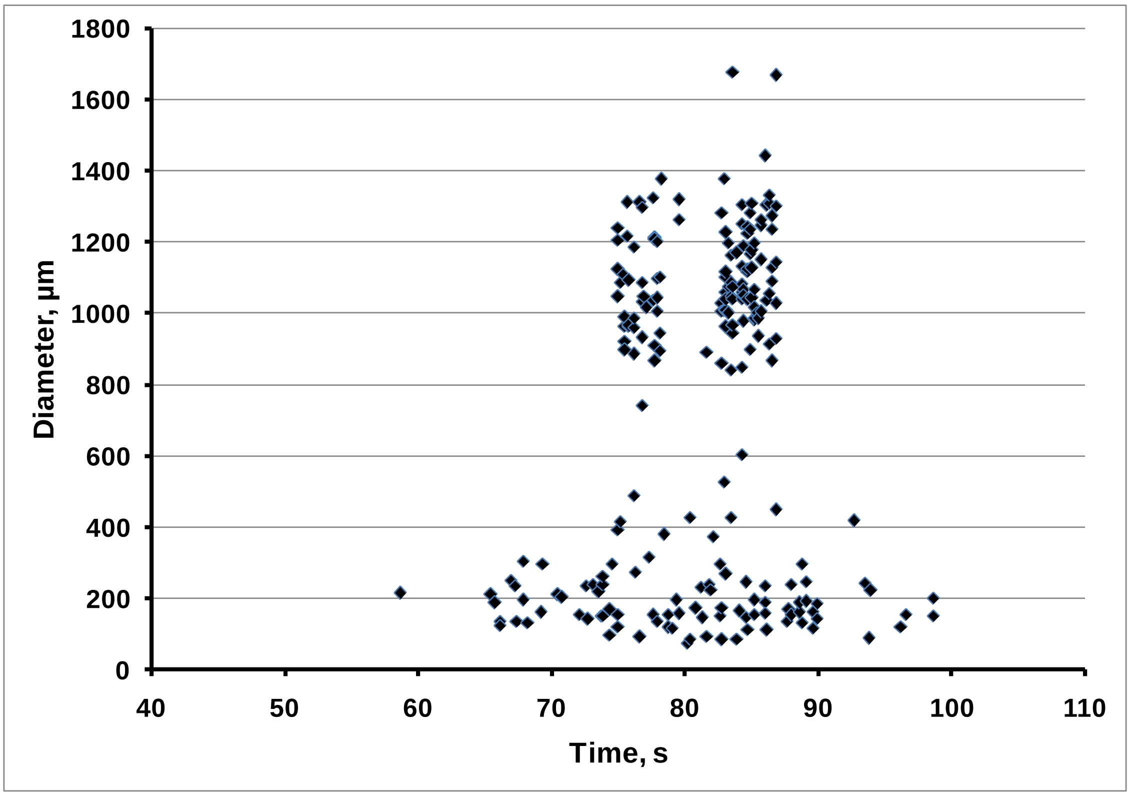

Figure 4. Measured droplet sizes on a scan through the spray from the “Alternator” nozzle operating at a pressure of 0.75 bar – measurement made 250 mm below the nozzle.

Results for the moulded version of the “Even-spray” nozzle gave a much smaller droplet size as expected with a mean VMD of 279 μm and a mean spray fan angle of 33.6° (Figs. 5 & 6). This spray fan angle was larger than that in the initial specification (25°) and this may therefore be reviewed. The results shown in Figs. 5 and 6 also showed that the spray footprint was larger than expected particularly in the direction at right angles to the main fan pattern (Fig. 6).

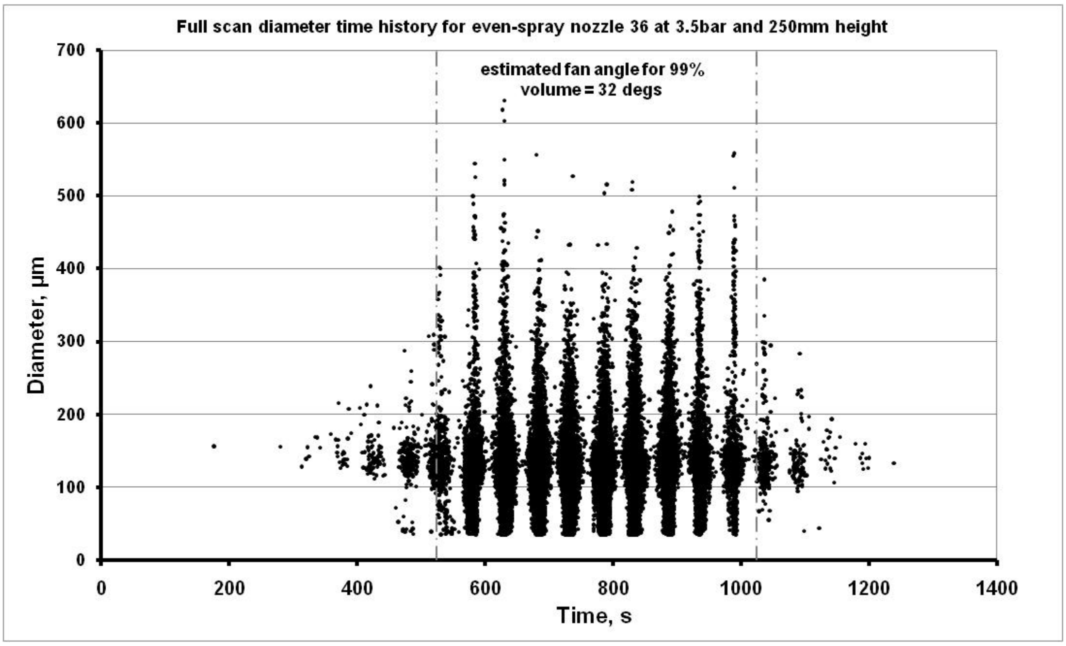

Figure 5. The droplet size distribution measured by scanning across the full spray pattern of the “Even-spray” nozzle operating at a pressure of 3.5 bar – sampling 250 mm below the nozzle.

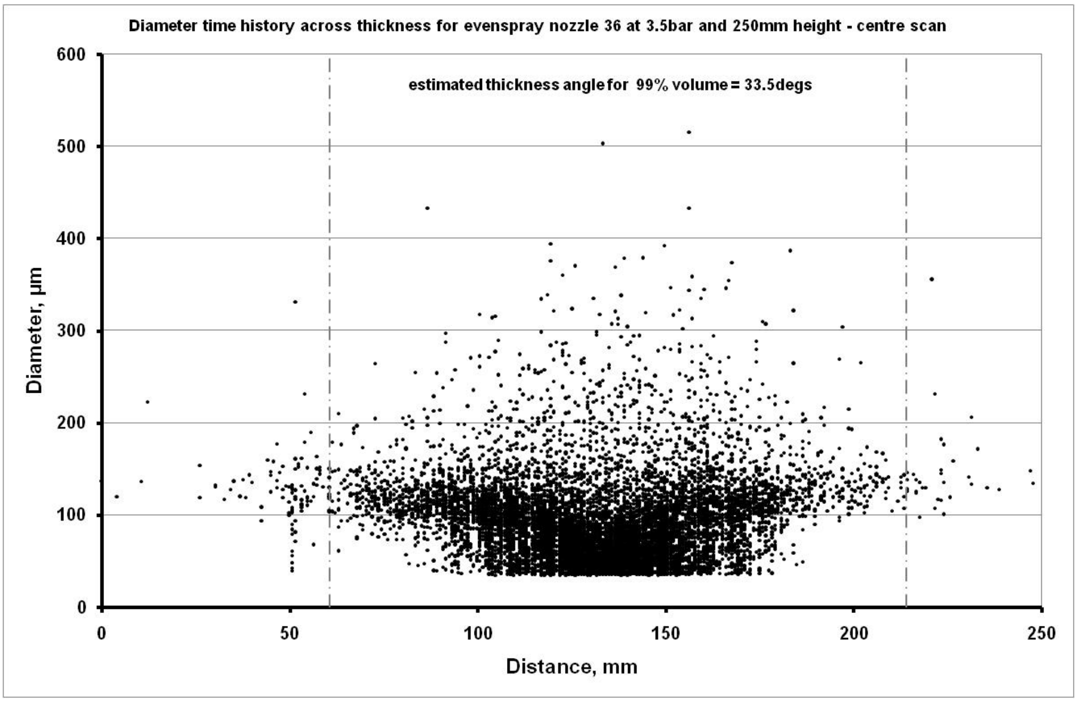

Figure 6. The droplet size distribution measured by scanning across the centre line of the spray pattern of the “Even-spray” nozzle operating at a pressure of 3.5 bar – sampling 250 mm below the nozzle.

The edge of the spray fan pattern from the even-spray nozzle was not as sharply defined as with the “Alternator” design (see also Figs. 1 & 2) but this was regarded as acceptable given that the even-spray nozzle was likely to be used in a patch (rather than spot) spray mode using selective rather than non-selective herbicides. The results also confirmed that the even-spray nozzle was able to generate a fine spray at pressures greater than approximately 3.5 bar (see Fig. 7) and therefore would provide a nozzle suitable for the treatment of small weeds, particularly grass weeds, at an early stage of growth.

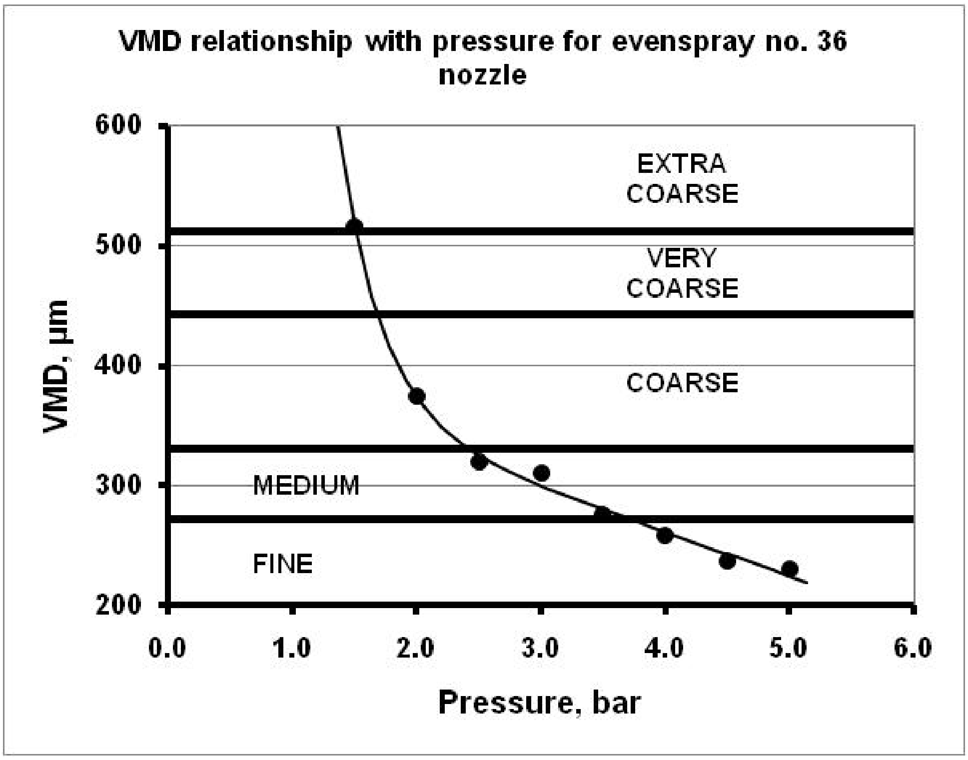

Figure 7. The variation in median droplet size as a function of pressure for the "Even-spray" nozzle.

The performance of the moulded version of the even-spray was in line with expectations based on the initial studies with a prototype design manufactured by Hypro EU Ltd and detailed in the report describing work in the first year of the project (Miller *et al*., 2011).

Development of nozzles for field scale experiments

A total of 60 nozzle and valve assemblies were fabricated and installed on the experimental rig in preparation for field trials in the 2011 harvest season. Initial calibrations and field trials in the onion crop (see 2.5 below) showed that there was some inconsistency in the performance of the nozzles that was due to leakage between the cartridge housing and the nozzle insert with the "Alternator" design. These leakage problems were addressed by investigating the use of alternative plastics in the manufacture of both components. It was thought that use of softer materials would deform sufficiently to fill the small irregularities that are inevitable in the molding process. Experimentation showed that best results were obtained by retaining the relatively rigid material for the cartridge, but replacing the harder material with a softer plastic for the “Alternator” insert. A new batch of nozzles was manufactured for testing, installation and use in the 2012 cropping season.

Conduct nozzle field trials

The calibration of the new nozzle design fitted to the experimental rig showed that a number of the units were not operating as expected and the poor performance was identified as being due to leakage between the “Alternator” insert and the main nozzle body. Initial laboratory experiments had suggested that this characteristic would be transitory and would correct itself as the nozzle bedded in with use. This did not happen quickly with a number of units installed on the booms of the experimental field rig when accumulations of liquid around the nozzle orifice influenced both the spray pattern and stability of the flow rate from the nozzles. The nozzles that were seen to be most troublesome were removed during the initial field trials and the nozzles re-arranged such that two booms used the new design and one boom used the design from the earlier project (Fig. 8.)

Figure 8. The experimental rig as set up for the field trials in the onion crop in the 2011 cropping season. Note the new nozzle/valve assembly design (in orange) fitted to the two booms on the far side of the machine and nozzle/valve assemblies from the previous project (in blue) fitted to the nearside boom.

Refine detection algorithms

Further algorithm development.

Algorithms for the detection of both individual large weeds (Miller *et al*, 2010) and patches of smaller weeds (Hague *et al*., 2006) were developed in previous work. In this period those algorithms have received field testing (see Objective 7 below) and as a result of this experience a number of minor refinements have been implemented.

For example, when spot spraying groups of large broadleaf weeds in leeks it was noticed that rather more of the area was being sprayed than might have been expected. This was due to a smearing effect where the convex polygons placed around plants seen multiple times grew with time. Close inspection showed that there were several reasons for this. The simplest was that the cameras were vibrating sufficiently to cause jitter in plant position in sequences of images. The solution to this was mechanical stiffening of the camera poles. The most significant issue related to the model used to represent radial camera lens distortion. This proved insufficiently accurate at the edges of an image so that there could be a significant error when features were transformed from image into ground coordinates. This in turn caused difficulties in tracking features from one frame to another. An improved model was implemented and performance improved.

Development of a stereo camera system.

We also completed construction of a stereo camera comprising two imagers placed 12cm apart that could be synchronized under control of a PC. This was used to take static stereo pair images of weed beet and bolters in a crop of sugar beet with a view to investigating the feasibility of detecting these types of weeds by height differential. A preliminary analysis of these image pairs have given promising results, but the stereo analysis algorithms will require further refinement if the technique is to progress to a practical sensing technique. In Fig. 10 the stereo image illustrates the general reduction in brightness from bottom to top of the image due to camera poise. The brighter patch in the center of the image is due to a tall weed beet plant.

Figure 9. Stereo camera specially constructed to take stereo images of tall weeds such as weed beet

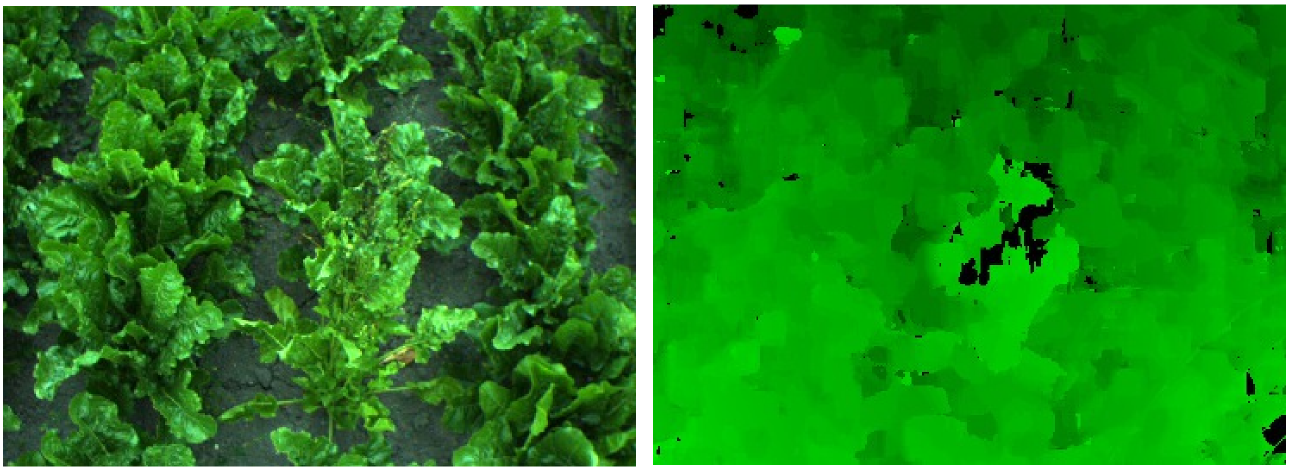

Figure 10. Single frame from a pair of stereo images (left) and a stereo image (right) where brightness decreases with increasing range

Field trials in a range of crop conditions

Field trials were conducted with the experimental rig operating at a forward speed of 4.0 km/h and crops of sugar beet, onion and leeks. Some experiments were also conducted at a single plant scale examining the application of herbicide to tall weeds such as weed beet.

Trials in the sugar beet crop.

These had the objectives of testing the new nozzle systems, refining the detection algorithms and examining inter-row spray applications of a non-selective herbicide. Some problems with nozzle leakage and the switching of nozzles were experienced. These were initially thought to relate to aspects of water quality used in the preparation of the total herbicide mixture but were subsequently traced to leakage in the nozzle components and features of the control algorithm. Weed pressures were very low and although useful rig performance assessments were completed, no agronomic assessments were made.

Experiments were also conducted in which sprays from a hand-held pulsed nozzle system were directed at the base of weed beet simulating the application of spray to the weed beet that had been detected and pushed forward by a rubbing bar at a height of 350 mm. Spray pulses of 0.02 seconds were used to drive a 12 V d.c. solenoid positioned immediately up-stream of an “015” 25^{o} even-spray nozzle that was operated at a pressure of 2.0 bar. The spray liquid was a 2.0% solution of glyphosate (as Roundup Flex) and the number of pulses applied to each plant was varied between one and six depending on the size (maximum plant diameter above the ground) of the weed beet. The nozzle was positioned approximately 250 mm above the base of the weed. The size and leaf characteristics of each treated weed beet were also recorded. Assessments of the effects of the spray application were made 7 days after treatment by visual scoring and taking photographic records. Results from these experiments were inconsistent. Some of the weed beet showed significant effects due to the spray application and it was likely that these would die. Other plants showed small and in some cases insignificant effects. There was no correlation between the level of control and weed size or the quantity of leaf at the base of the plant. Some plants were bent over by the simulated rubbing bar action and in some cases these plants remained mainly horizontal but continued to grow.

Trials in the onion crop.

In addition to work to refine the detection algorithms, assessments were made of the levels of control achieved by the system when using both selective (Flumioxazin as Digital at 100 mL/ha) and non-selective (glyphosate at 4.0 L/ha) herbicides. Levels of crop contamination around treated volunteer potatoes were also quantified. Treated crops were assessed visually 6 days after treatment. The results showed detection levels of 95.4% of volunteer potatoes and much higher levels of kill (circa 95%) with a total herbicide than with a selective herbicide (see Figs. 11 & 12). The response to the selective herbicide was noticeably less pronounced than in the previous year and this may have related to the dry growing conditions leading to higher levels of leaf wax.

Figure 11. A typical volunteer potato in an onion crop spot treated with glyphosate and assessed after 13 days

Figure 12. A typical volunteer potato in an onion crop spot treated with flumioxazin (as Digital) and assessed after 13 days

Measurements of crop contamination were made by placing a 300 mm diameter stainless steel ring around volunteer potato plants that had been spot sprayed with a tracer dye solution (nominally 1.0% “Green S”). All plants (volunteer potatoes and onions) within the ring were then carefully cut and sorted into bags containing either potato or onion foliage. Bags were then returned to the laboratory, weighed and the quantity of original spray liquid retained on the plants determined by washing in a known volume of de-ionised water and using spectrophotometric techniques calibrated with a reference dye sample taken from the spray nozzles at the time of treatment. A total of 25 potato plants were sampled. Results from this work showed that deposits on crop plants within 150 mm of a treated volunteer potato were, on average, an order of magnitude less than on the target weed (Fig. 13) at 0.56 +/- 0.36 µL/g compared with 10.56 +/- 3.23 µL/g plant weight on the volunteer potatoes.

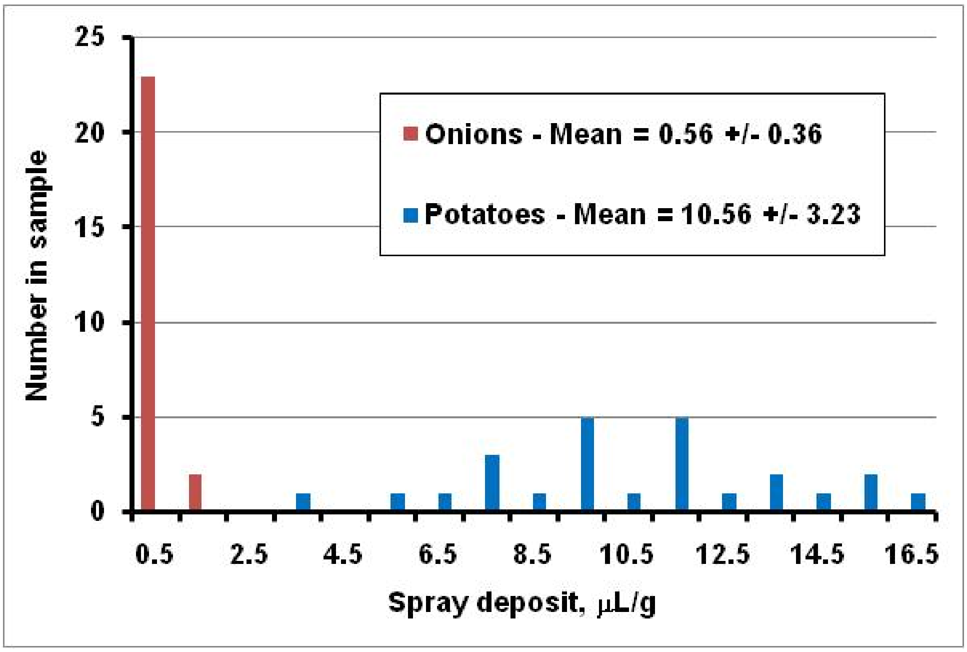

Figure 13. The distribution of measured deposits on spot treated volunteer potatoes and surrounding onion plants

Trials in the leek crop.

Treatments were applied based on an aggressive tank mix of selective herbicides (Starane at 0.5 L/ha + Shield at 1.0 L/ha + Linuron at 1.0 L/ha) and a non-selective herbicide (glyphosate at 4.0 L/ha) to a crop having a moderate to heavy weed infestation (Fig. 14.). The weeds were volunteer potatoes with some redshank and thistle. Treated crops were assessed visually at both 8 and 15 days after treatment. The results with the selective tank mix gave levels of control that were comparable with overall spraying (Fig. 15.) and with no evidence of crop damage. Weed kill was more rapid with glyphosate (Fig. 16.). Control was estimated at circa 90% and there was very little evidence of crop damage.

Figure 14. Spot spraying of volunteer potatoes in a leek crop - June 2011

Fig.15. Control of volunteer potatoes achieved by spot spraying a selective herbicide mixture and assessed at 15 days

Figure 16. Control of volunteer potatoes achieved by spot spraying a non-selective herbicide (glyphosate) and assessed at 15 days

Other trials conducted in 2011.

The patch spraying technique received initial field testing in autumn 2011 in a crop of rape drilled using strip tillage techniques at a 50cm row spacing. The “Alternator” nozzles sprayed glyphosate between rows when weeds were detected inter-row. Whilst limited in extent due to intense weed pressure, the algorithms performed as expected and weed kill was effective.

Evaluate economic performance

An important factor influencing the commercial viability of the technology is the role that regulation and chemical registration might play. During this reporting period, two meetings were held with representatives of the Chemicals Regulation Directorate as follows:

1) An initial meeting where the project concepts were explained and the recommendation from the Chemicals Regulation Directorate was that specific proposals regarding weed targets, crop and chemical formulations needed to be made;

2) A second meeting arranged in conjunction with representatives from AHDB Horticulture (HDC) where it was agreed in principle that spot applications of a non-selective herbicide could be made to crops that were already covered by a SOLA (now an EAMU) relating to the inter-row application of glyphosate.

Work to complete a complete an economic analysis of performance will be completed in the final year of the project.

Overall conclusions

i. Field trials continue to demonstrate that computer vision based detection and spot spraying can control (>90%) large broadleaf weeds.
ii. Targeting accuracy is sufficiently high that in practice spot application of non-selective herbicides results in only very minor localized crop damage.
iii. Glyphosate has again proved to be the most effective herbicide, though spot application of selective herbicides has been shown to be capable of similar levels of control to overall application with the advantage of reduced inputs and reduced crop stress.
iv. It has been shown that it is feasible to produce “Alternator” nozzles in volume with a satisfactory performance.
v. Stereo imaging has been shown to have promise in detecting weeds that exhibit substantial height differential with the crop

Technology transfer

Papers

Miller, P.C.H.; Tillett, N.D.; Hague, T.; Lane, A.G. (2012). The development and field evaluation of a system for the spot treatment of volunteer potatoes in vegetable crops. Aspects of Applied Biology, 114, International Advances in Pesticide Application, pp113 – 120.

Miller, P.C.H.; Tillett, N.D.; Swan, T.; Tuck, C.R.; Lane, A.G. (2012). The development and evaluation of nozzle systems for use in targeted spot spraying applications. Aspects of Applied Biology, 114, International Advances in Pesticide Application, pp159 – 166.

Presentations

- To "Food Research Partnership" on engineering in agriculture that included spot spraying as an example. 16th June 2011, Westminster
- On precision weed control at HDC open afternoon at Stockbridge house, 30th June 2011
- To Cambridge Farm Machinery Club November 2011
- To the BCPC Weeds Review, 9th November 2011, and reported in Farmers Weekly
- At Beijing Agricultural University, China, December 2011
- To Vegetable Agronomists Association meeting at PGRO January 2012
- At farmer meetings organized by Bayer CropScience – Winter 2011/12

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Hague T, Tillett ND, Wheeler H. (2006) Automated crop and weed monitoring in widely spaced cereals. *Precision Agriculture*, **7,** 21-32.

Lund, I; Jensen, P K (2002). Application technology for band spraying. Correlation between liquid band distribution and biological efficacy. *Aspects of Applied Biology,* **66***, International advances in pesticide application*, 107-114.

Miller, P C H; Tillett, N D; Hague, T; Lane, A G (2011).Reducing herbicide use in row crops with new application methods treating detected weeds in bands or spots.HDC Annual Project Report. Project Ref: FV 307a.

Miller, P C H; Tillett, N D; Hague, T; Lane, A G (2010). Minimising the impact of weed control in vegetables by weed detection and spot herbicide application. HDC Project Report. Project Ref: FV 307.

Miller, P C H; Tillett, N D; Hague, T; Lane, A G (2006). The development of methods to control volunteer potatoes in a range of vegetable crops. Report to HDC for Project Ref: FV 281.

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