Project Title	The development of methods to control volunteer potatoes in a range of vegetable crops
Project number:	FV 281
Project leader:	Prof P. C. H. Miller Silsoe Spray Applications Unit (part of The Arable Group)
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Location of project:	Wrest Park, Silsoe, Beds
Project coordinator:	Dr Emma Garrod
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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

Headline

- Computer analysis of video images has been shown to be a viable way of detecting volunteer potatoes in both onion and carrot crops.
- Very low spot doses (< 1 ml) of glyphosate spray were effective at killing potatoes, though larger more vigorous plants may require a separate dose on each stem.
- Overall the study suggests that spot herbicide application could be developed to become a technically feasible and economically viable method of volunteer potato control.

Background and expected deliverables

- The registration of metoxuron (Dosaflo) will not be continued beyond December 2007. This herbicide has been used to give weed control in carrots and other vegetables when applied as an overall spray. Work to identify herbicide products that might replace metoxuron has identified some alternatives that will give control for some species, but the control of volunteer potatoes in a range of vegetable crops continues to be a problem.
- Selective application of total herbicides to weed potatoes is an attractive option in principle providing good control with low cost chemicals. However, the only commercially available technique using weed wipers relies solely on height differential between crop and weed and has often proved unsatisfactory with respect to efficacy, crop damage and pesticide safety.
- Recent developments in image analysis based systems for agriculture provide opportunities to tackle selective application in novel and more precise ways that are economically attractive to growers whilst satisfying pressures to reduce pesticide volumes.
- It is concluded that a very promising approach to the control of weed potatoes in a range of vegetable crops could be based on:

i) the detection of weed potatoes using image analysis techniques with images collected by a camera system mounted on the treatment machine and analysed "on-line";

ii) the control of the weed potatoes by the application of a total herbicide such as Glyphosate targeted to give good control of the weed potato but with the minimum damage to the crop.

- This project set out to confirm the technical feasibility of each of the critical components of the proposed system under field conditions. A follow up project under the Hort LINK scheme will develop and validate identification techniques, spray application methods and validate field performance of a complete system.

Summary of the project and main conclusions

1. This study aimed to assess the feasibility of controlling volunteer potatoes in a range of vegetable crops, particularly carrots and onions, by detecting the position and size of the potato plant and applying a pulse of herbicide spray to kill the potato while minimising the damage to the surrounding crop.

2. The work involved two main components namely:

   (i) the construction of an experimental pulsed spray application system and its use in a series of field trials to explore the likely spatial resolution requirements when making targeted herbicide applications;

   (ii) an assessment of the feasibility of detecting volunteer potatoes using image analysis techniques developed from those being used to guide and control field machinery such as mechanical hoes.

3. An application system based on a narrow-angle flat fan nozzle, solenoid valve, electronic timer and 12 V d.c. supply was assembled and used effectively in field trials to apply 0.5 and 1.0 ml pulses of spray in time periods down to 0.03 s.

4. Results from field trials with potatoes growing on the edge of cropped areas gave lower levels of control than originally anticipated. Scores from three

visual assessments up to 30 days following treatment ranged from 2.23 to 5.10 for the sprayed treatment on a scale that gave a complete kill as 10.0 and no effect as 0. It was noticed that plant stems not directly contacted by the spray did not die as a result of translocation within the plant. The target for pulse treatment of detected volunteer potatoes is therefore to get some herbicide on each plant stem.

5. Images of volunteer potatoes growing in both carrot and onion crops were collected at growth stages equivalent to those that have been used when applying overall sprays. A preliminary analysis of these images suggested that almost 100% of volunteer potatoes could be detected in onion crops whereas in carrots the detection with existing algorithms could be as low as 80%. Approaches to improving the detection algorithms have been identified and further work is now required to develop and validate these approaches.

6. The study suggests that the control of volunteer potatoes by the targeted application of a herbicide is technically and economically viable but that further work is needed to:

   (i) develop the application system;
   (ii) develop and validate identification methods;
   (iii) validate the field performance of a complete unit.

Financial benefits

An initial economic analysis has been conducted:

The cost of treatment based on this technology has been estimated to be £44/ha based on the following assumptions: A 6 m machine operating at 5 kph with a field efficiency of 80% giving a work rate of 2.4 ha/h; Seasonal and weather conditions limit operation to 20 8h days yielding a treatment capacity of 380 ha; Capital cost is estimated at £35,000 which with a write of period of 5 years at 10% interest gives an annual repayment charge of £9,240; Tractor and driver costs are assumed to be

£20/h, the cost of glyphosate £200 pa and maintenance £4,000 pa.

Total costs are therefore £16,640 pa or £44/ha spread over capacity area. Operating at half capacity reduces the total annual cost to £13,940 (assuming maintenance down to £3000 pa), but increase area costs to £73/ha. We understand that these figures are comparable with treatment using Dosaflo and should therefore provide an economic alternative now that this chemical is withdrawn. Economics of operation improve further if utilisation can be extended through the season on multiple crops, e.g. carrots and onions.

Action points for growers

This is a feasibility study and it is too early to produce grower action points.

Exploitation and future applications

The scientific results from this study will provide the starting point for a follow on Hort LINK project jointly funded by HDC and BPC. The objective of this project will be to advance the technology to the point that manufacturers will be able to produce commercial prototype machines. The inclusion of leading agricultural engineering companies within the consortium along with growers and a chemical company greatly improves the chances of these results being exploited in a timely fashion.

The follow on Hort LINK project will focus on the control of volunteer potatoes in carrots and onions. However, much of the technology is generic and it is envisaged that once machines are commercially available it will be possible to apply the technology to other row crops and other weeds especially the larger perennial weeds.

Science Section

1. Introduction

The need to address the control of volunteer potatoes in vegetables has been focussed by the loss of registration for metoxuron (Dosaflo) as a result of the ongoing review of pesticide use within the European Union. This herbicide has been used to give wee control in carrots and other vegetable crops when applied as an overall spray. Work to identify other herbicides or combinations of herbicide products that might replace metoxuron has identified some alternatives that will be effective for some weed/crop combinations but the control of volunteer potatoes in a range of vegetable crops, particularly carrots, continues to be a problem. There is relatively little published information relating to the performance of wiper applicators in terms of herbicide deposit. A study for MAFF examined both wipers and targeted spray systems based on plant height to control injurious weeds in grassland while preserving species richness (Pywell *et al.*, 1997). This work did not use a weed identification system but did generate relevant background information for the work detailed in this report.

The main need to control volunteer potatoes relates to the effects on crop yield and quality. Such effects are difficult to quantify in direct financial terms because of the variability of infestation with area, previous crop management and season. However, many growers recognise that control of volunteer potatoes is a key component in carrot and onion production. Control of volunteers is also important in relation to the carry-over of disease in the potato crop. The study reported by Turley (2001) indicated that volunteers act as a reservoir for infection with up to 74% of volunteer potato virus and up to 11% having leaf roll virus.

The selective application of total herbicides to volunteer potatoes is an attractive option in principle providing good control with low cost and relatively environmentally safe chemicals. However, the only currently commercially available technique for making such applications involves the use of wiper applicators that rely solely on the height difference between weed and crop and that often require multiple applications to achieve high levels of efficacy.

Recent developments in image analysis based systems provide opportunities to address selective application in more precise ways that are likely to be economically attractive whilst satisfying pressures to reduce pesticide use. Initial research funded by BBSRC (Tillett *et al*., 1998) demonstrated the feasibility of autonomous operation in widely spaced row crops using images captured by a camera mounted on the front of a tool frame. Images were analysed to provide guidance information by identifying the crop row while the position of crop plants within the row was deduced from spacing information. Spectral analysis enabled plants within the field of view to be identified against a soil background and hence the positions of weeds as well as crop plants were detected. These approaches have also been developed to provide automated steering control for the high speed hoeing of a wide range of crop types and working conditions (Tillett *et al*., 2002). This research has been developed commercially as the Garfords "Robocrop" guided hoe system and to date, more than 100 units of this vision guided hoe have been sold mainly to UK vegetable growers. The guidance principles have also been used to position spray nozzles relative to crop rows in experimental equipment using actively controlled drop legs (Tillett and Hague, 2006). Image analysis techniques are being used in a current LINK project to detect and track individual plants as part of work to mechanically control weeds within transplanted crops such as lettuce and brassicas. Some of the approaches being used in this study are relevant to the project reported here particularly relating to the quality of captured images, improved immunity from shadows, the tracking of variable numbers of discrete features as well as methods to facilitate faster response times. Work at Silsoe Research Institute using image analysis techniques to map weed and crop distributions at a field scale is also relevant to the project reported here since it involved the accurate assessment of plant size, Tillett *et al*., 2001. Plant size is one of the discriminators that has been used in this study (see Section 3) to discriminate volunteer potatoes from vegetable crop plants.

The concept of selectively applying a total herbicide to plants (weed and crop) within a plant row as part of an establishment strategy is not new. The development of selective chemical thinning systems in the 1960/70's involved the spray application of herbicide formulations that were highly viscous from nozzle systems positioned relatively close to the target. Rapid response times for spray establishment and cut-off were achieved by machining valve seats directly into the nozzle body, (Miller and Watt, 1980). This system was used experimentally to control volunteer potatoes in a sugar beet crop with the potatoes detected on the basis of height using a contact sensor. These preliminary experiments demonstrated the feasibility of the approach with the main limitations identified as relating to the sensing system.

The overall aim of the work described in this report was:

> "To establish the feasibility of controlling volunteer potatoes (and other weed species with a very different structure to the surrounding crop) in a range of vegetable crops using an approach based on detection of the weed with image analysis techniques and the targeted application of a total herbicide."

Specific objectives were therefore:

(i) To develop and assess the potential performance of image analysis based techniques that will discriminate volunteer potato plants from surrounding crop;

(ii) An assessment of the appropriate target sites on individual plants (e.g. proportion of foliage covered, position of deposits on treated plants) for controlling volunteer potatoes in a manner that minimises the risk of damage to the surrounding crop;

(iii) To develop a treatment application method and associated control strategy that could be used with a targeted total herbicide system;

(iv) To conduct an outline economic analysis of such an approach considering factors such as capital costs, working life, work rate, workable days, field performance and operating costs.

2. Part A. Determining the target specification for the application of glyphosate to volunteer potatoes

Experiments were conducted to determine the effect of site of application on identified volunteer potato plants.

2.1 Equipment development

It was recognised that a practical system for applying a herbicide to detected volunteer potato plants would probably use an array of nozzles positioned across the width of the machine with nozzles being actuated to deliver a pulse of spray to the detected potato plants. The spacing, treatment pattern, flow rate and operating height of the nozzles would be a function of the required deposit distribution on the foliage of the potato plants. This was to be investigated using a hand-operated nozzle/solenoid valve combination that would be used in a series of field trials examining the effect of deposit distribution on the level of control achieved.

An electronic timer device was designed and built under a sub-contract to the main contractors for the project work (Mr Peter Richards – Solutions for Research Ltd). This operated from a 12 V d.c. power supply and provided an adjustable pulse to operate a solenoid valve. Pulse time was adjustable from 0.01 s to 0.1 s in 0.01 s steps.

A nozzle and solenoid valve assembly used standard commercially available components to give a unit with the minimum of dead volume between the valve seat and nozzle orifice. Preliminary experiments were then conducted with a range of nozzle types and sizes with the object of delivering a well-defined pulse of spray to individual potato plants. It was initially thought that narrow angle cone nozzles would give the required performance but initial experiments with pulse times down to 0.05 s showed that the spray formation and cut-off with this nozzle design were not sufficiently sharp. A flat fan (FF 015-65 = 65^{o} fan angle and flow rate of 0.6 L/min at a pressure of 3.0 bar) was selected for the work operating at a pressure of 4.0 bar. This spray angle ensured that an adequate spray was produced by gave a footprint that was 200 mm wide when operating at a height of 150 mm above the target (footprint dimensions 200 x 80 mm at a height of 150 mm). The spray volume distribution across the footprint was approximately Gaussian. A smaller footprint with more of a square wave distribution would be closer to the requirements for a full-scale system but further research is needed to design or source such a nozzle system.

Measurements of the spray footprint were made by spraying on to absorbent paper. The same technique was used to calibrate the output from the nozzle system by recording the change in weight after pulses of spray of a pre-set duration on the solenoid control box. The results are plotted in Figure 1.

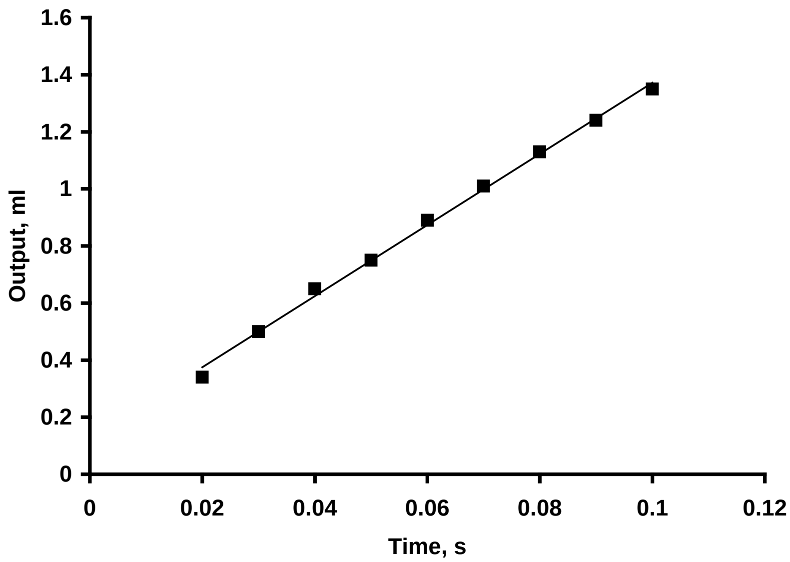

Figure 1 Calibration of the FF 015-65 nozzle operating with a solenoid valve pulse for pre-set time periods and with a liquid supply pressure of 4.0 bar.

2.2 Field experiments

Field experiments were conducted on two sites using potatoes growing on the edge of an established field area. The field sites were at:

- Chicksands – variety Estima (courtesy of Mr Parrish / Mr Cripsey)
- Cardington – variety Maris Piper (courtesy of Mr Findlay)

Applications were made to individual potato plants by directing the nozzle either at the centre of the plan area of the plant, off-setting the nozzle 75 mm from the centre or by directing the spray to the edge of the plan area of the plant. For each plant, the dimensions of the major and minor axis of the plan area and the maximum height of the plant were recorded. On the Cardington site, a formal block experimental design was used with untreated controls and cut plants in each block. At the Chicksands site a single dose rate was used whereas at Cardington two dose levels were used.

Glyphosate was applied using a tank mix equivalent to 4.0 L of glyphosate applied in 100 L of water per hectare – the maximum recommended rate for spray applications. At both sites a 0.03 s pulse was used to apply 0.5 ml of spray solution per pulse to the target site on the volunteer potato. At the Cardington site, an addition 1.0 ml treatment was applied using a 0.07 s pulse duration.

The effects of the treatments were assessed by visual scoring on three separate occasions at each site commencing approximately 10 days after treatment. A scale with a full score equalling 10 and no effect equalling 0 was used. In addition some fresh weight measurements were made of treated and untreated plants at the Cardington site.

Applications were also made to lengths of row on the Cardington site using a commercial wiper system that incorporated a control system to regulate the quantity of herbicide on the wiper element, (Micron Sprayers Ltd). Two concentrations of glyphose were used: a 2:1 mix (0.33 L of glyphosate in 1.0 L of tank mix) and a 5:1 mix (0.20 L of glyphosate in 1.0 L of tank mix). Applications were made with the wiper element set nominally 300 mm above the top of the potato ridge with the ATV on which the unit was mounted travelling outside of the cropped area at a speed of approximately 1.0 m/s. Applications were made in a single pass travelling over the row in one direction only. Results were assessed by scoring a total of 20 plants in the treated row and results from such treatments provided a reference for the targeted spray treatments.

2.3 Results

Full results from the field trials at the two sites are given in Appendix I and are summarised in Tables 1 and 2 below.

Table 1 Mean scores over three assessments for potatoes treated with glyphosate applied to different parts of the plant (standard deviations in brackets)

Site	Dose, ml of spray liquid/ plant	Mean scores		
		Central application	Off-set 75 mm from centre	Edge application
Chicksands	0.5 ml	5.10 (1.69)	5.08 (1.72)	5.09 (1.71)
Cardington	0.5 ml	2.98 (1.21)	2.58 (0.86)	2.23 (0.87)
Cardington	1.0 ml	4.33 (0.84)	4.58 (0.25)	3.00 (0.42)

Table 2 Mean sizes of potato plant at the time of treatment at both sites

Site	Mean surface area, cm2	Mean height, mm
Chicksands	1038	248.4
Cardington	2646	404.8

Levels of control at both sites are lower than might have been expected. It was very noticeable that when assessing treated plants there were stems that had been contacted by the application and that had died or been severely checked. Other stems on the same plant that had not been directly contacted by the herbicide were relatively unaffected. Unaffected stems tended to grow on and hence there was some element of recovery after the initial effects of the treatment. Figures 2 and 3 show examples of treated plants post-treatment where the continued growth of some stems can be clearly seen. Levels of control were higher on the Chicksands site where the plants were smaller at the time of treatment and on the Cardington site when a higher dose level was used. There was evidence that the site of application influenced the level of control achieved only when using the higher dose treatment on the Cardington site.

Figure 2Potato treated with a pulse of spray applied to the centre of the plant 28 days after treatment – note surviving but damaged stems.

Figure 3 As Figure 2 but with treatment applied to the edge of the plant plan area – again note surviving stems and evidence of stems that have completely died.

The lack of translocation between stems of the same potato plant agrees with the findings of Lutman (1979(a)) and Lutman and Richardson (1978). Lutman (1979(a)) reported that there was some damage to stems on a plant that had not been directly contacted and that the level of damage was a function of the proportion of stems that received the direct application of the herbicide. Coupland and Lutman (1982) reported that there was little evidence of root transfer of the herbicide when it was applied at concentrations typical of those used for spray applications but some evidence of root transfer when higher concentrations typical of those used in wiper applications were used. The results of field trials reported by Lutman (1979(b)) showed little response to herbicide dose rate in the range 0.5-3.0 kg/ha when controlling volunteer potatoes in autumn cereal stubbles with glyphosate and aminotriazole.

The findings from the field trials conducted as part of this project work were probably influenced by the following factors.

(i) The potato plants treated were on the edge of cropped area, growing in ridges with irrigation patterns and other management practices aimed at promoting plant growth: volunteer potatoes may be under more severe growing conditions and may be more sensitive to herbicide application.

(ii) The concentration of the herbicide in the sprayed liquid was chosen to be representative of that applied as a spray rather than wiper applicator so that any off-target loss would influence surrounding crop by leaf rather than root uptake: it should be noted that the higher dose sprayed treatment applied to the centre of plants achieved a higher control score than the higher dose treatment applied with a wiper (4.45 vs 4.12) although the results are not statistically significant.

(iii) No attempt was made in the trials to match the treatment to plant size and the data presented by Lutman (1979(a)) indicated that this would increase the level of control achieved: although the treatments were applied at a timing that was directly comparable with; the application of metoxuron (Dosaflo) to vegetable crops, the potato plants were relatively large at the time of treatment particularly at the Cardington site – see Table 2: the work demonstrates that higher levels of control are likely to be achieved by treating plants that are as small as possible and by directly contacting as many of the plant stems as possible.

(iv) There was evidence that the performance of the wiper applicator was influenced by the effective "shading" of adjacent leaves and by the need to accurately control height above the crop: used at the lower dose, the wiper gave very low levels of control (mean score of 1.0) compared with a score of 4.12 at the higher dose.

(v) The fresh weights of plants treated with the higher dose applied to the centre of the plant area was reduced by approximately 70% compared with the untreated controls in each block: this result suggests that there was some influence on plant stems that were not directly contacted by the herbicide even though such effects were not well reflected in the visual scoring system: this observation therefore supports the findings reported by Lutman (1979(a)).

(vi) This study did not directly assess the production of tubers from treated plants although it was noticed that treated plants that were not killed did show tuber-like swelling and distortions at the base of living stems: the results reported by Turley 2001 show that the control of daughter tubers is important with high percentages of volunteer potatoes coming from that source.

2.4 Conclusions from the application target studies and the implications for future work

The key conclusion from the application target studies, supported by previous findings, is the need to achieve some herbicide contact on all of the stems of the plant in order to achieve good control. This is likely to be achievable but requires some further nozzle development so as to:

(i) give a relatively small but sharp well defined footprint that can be well matched with that of adjacent nozzles so that a number of nozzles would be actuated to apply herbicides to potatoes of the size used in this study;

(ii) a small percentage of the output spray volume in small droplets (<100 µm in diameter) such that the risk of drift on to the crop is minimised. The work described in this report did not quantify the potential contamination of surrounding crop resulting from over-spray or drift. Over-spray will be minimised by having a spray volume distribution pattern with a sharp cut-off and relatively small footprint while drift will be reduced by reducing the percentage of spray volume delivered in small droplets.

Treating the relatively large target with a multiple nozzle approach at the same spray liquid concentration as used in this study would effectively increase the dose applied per plant. The results from this and other studies reported in the literature indicate that this level of dose applied to the plant plan area will give good levels of control. Treating volunteer potatoes at an earlier stage of growth, assuming that they could be accurately detected within the growing crop, would give high levels of control with less chemical usage.

It is concluded that the pulsed application of a total herbicide appropriately targeted is an effective way of controlling volunteer potatoes in vegetable crops although further work is required to develop a nozzle system with the appropriate characteristics.

3. Part B. Detecting volunteer potatoes in carrot and onion crops

3.1 Specific objectives

The development and assessment of performance of image analysis based techniques that will discriminate weed potato plants from surrounding crop and locate treatment sites on individual plants.

3.2 Approaches

3.2.1 Selection of discriminating features

A variety of features could be considered in order to detect the occurrence of volunteer potatoes in vegetable row crops in general and onion and carrot crops in particular. The ones that were felt to offer most promise for a practical implementation were:

1. Colour.
2. Feature size.
3. Feature position with respect to crop rows.
4. Feature height.

Other characteristics such as leaf texture and leaf shape have not been considered in this study as they are dependant on higher quality, higher resolution images (pixel size <1 mm in ground coordinates) than those employed in this study (5 mm). Maintaining adequate image quality under field conditions due to effects such as saturation, noise and motion blur introduces significant technical challenges. In our judgment the cameras and the very powerful computing necessary to perform such detailed analysis would not be economically practical. We will however, continue to keep this under review as technology advances.

3.2.2 Colour

It has been shown (Marchant *et al.*, 2004) that analysis of colour can be used to discriminate between vegetation and a soil background with a good degree of reliability under a wide range of natural lighting conditions.

There have been some reports (e.g. Vrindts and Baerdemaeker, 1997; Lieberman, 2006) of successful discrimination between species of plant on the basis of colour, but with a small set of species, and not under natural lighting conditions. A method is needed which will distinguish potato volunteers from a range of crops. Moreover, the method should work even when the potatoes have been already received a previous herbicide application - which can have a significant effect on leaf colour.

Accordingly, green colour can be reliably used to distinguish all types of plant matter from the background, but not between crop and potato volunteers.

3.2.3 Feature size

In general potatoes will be larger than the crop plants, so size is a useful source of evidence for classification. However, implicit in the use of size is the need to find the boundary of the plant. This is straightforward only where the volunteers are non-overlapping with the crop rows.

We have considered a simpler measure based upon the width of a feature (i.e. size in a direction perpendicular to the crop rows). If a feature is abnormally wide relative to the width of ground covered by a single crop row, it is judged most likely to be potato.

3.2.4 Feature position with respect to crop rows

A robust method of crop row location has been developed in previous work for the purpose of guiding inter-row cultivation machinery (Hague and Tillett, 2001). By application of this approach, a known pattern of crop rows can be located in video images. Given knowledge (provided by the operator) of the approximate width of the crop plants within a row line, it is possible to identify vegetation outside of the crop rows as weed (Hague *et al.*, 2006).

3.2.5 Feature height

Once volunteer potatoes have become well established they often grow to be significantly taller than the crop. This height difference could be used as a distinguishing feature. Height might be detected using an array of laser scanners, ultrasonic range finders, stereo vision or optical flow. Optical flow is a stereo vision technique that analyses disparity between successive images from a single camera displaced due to movement over time, rather than two images taken simultaneously from two spatially displaced cameras. Optical flow is preferred to the other options because of its potential to use the same hardware required for measurement of the other discriminating features. However, there are a number of problems; in order to obtain the best differentiation of height a low camera position is preferred - but this viewpoint is undesirable for most other methods of vision based crop/weed discrimination, which are best suited to a plan view from a relatively high viewpoint to limit occlusion. Only volunteers significantly taller than the crop can be distinguished by this approach - but potatoes of this size are usually more easily distinguished by the area they cover in a single image. In order to avoid the need for accurate calibration, the height of the soil background need also be determined as a reference. Finally, in the absence of clearly discernable features, it is necessary to track features by cross-correlation of image patches, which is computationally time consuming.

3.3 Combining measurements of characteristic features to obtain a classification

Note that individual features don't fully resolve the classification - for example green material can be crop or volunteer; locations far from a crop row may be weed or soil. In order to get the most accurate and reliable discrimination between crop, weed and soil it is desirable to combine the information gleaned using some, or all, of the characteristic features described above. This should provide the best possible result.

There are a number of possible mathematical frameworks under which this merging of information might be performed. We have chosen a Dempster-Shafer approach. A Dempster-Shafer (DS) approach to classification has an advantage over Bayesian methods here as the later must assign a prior probability to each outcome as a starting point which can bias the result in a situation where information is sparse.

For the reasons given above, features 1-3 (colour, size, position) have been selected in this initial trial to provide the evidence for classification of scenes into crop, weed or soil. We have undertaken some preliminary work on optical flow as an independent measure of height as reported in the experimental results, but its possible inclusion within the Dempster-Shafer classifier has been left for future work.

Considering the classification of a scene into three components plant, weed and soil background. The DS approach distributes a unit mass of belief across an exhaustive set of all possible classification outcomes {Plant, Weed, Soil} and all its possible subsets. Initially the mass of 1 is assigned to the set {Plant, Weed, Soil} denoting that a location may be any member of that set, but without indication any relative likelihood of a particular classification outcome.

To combine the evidence offered by a pixel's colour, a form of vegetative index is first computed:

$$y = \ln g - a \ln r - (1\text{-}a) \ln b$$

Here ln *x* is the natural logarithm of *x, r, g, b* are the red, green and blue pixel intensities, and *a* is a constant dependent only on the properties of the camera.

The index *y* is then transformed into a *basic probability assignment* as shown in Figure 4. Low indices assign the full unit mass to the belief that the pixel represents the soil background. Higher indices assign the unit mass to the set of classifications {Crop, Weed} - since the colour appears to indicate some form of vegetation, but does not reliably indicate which.

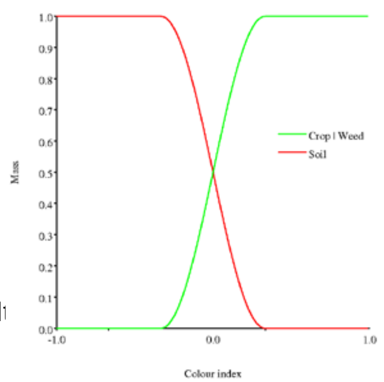

Figure 4 Probability assignment based on colour index.

The location of a pixel also provides evidence; for each pixel in the image, the distance is determined from that pixel to the mid line of the nearest row. This is divided by a (user supplied) estimate of the width of ground covered by the crop row. The graph of Figure 5 illustrates how this is used to generate a basic probability assignment; pixels near to the crop row are most likely crop or soil, so most mass is assigned to the set {Crop, Soil}; some mass is assigned to {Crop, Weed, Soil} too since it is possible for weeds to occur in the row. Pixels far from the crop row have the unit mass assigned to {Weed, Soil} since crop should not occur in this position. At around the nominal row width, any of {Crop, Weed, Soil} could occur, so the mass of belief is assigned accordingly.

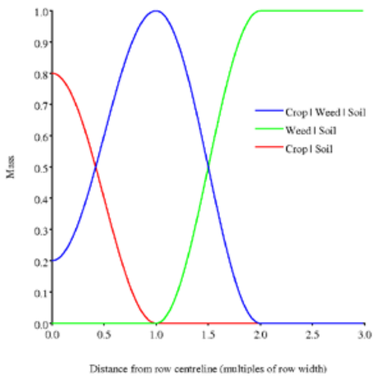

Figure 5 Probability assignment based on distance row centreline.

Feature size is used similarly; features very much wider than the row width are considered to be unlikely to be crop (Figure 6). In this implementation size is based on a width perpendicular to the crop row using a threshold of gray level.

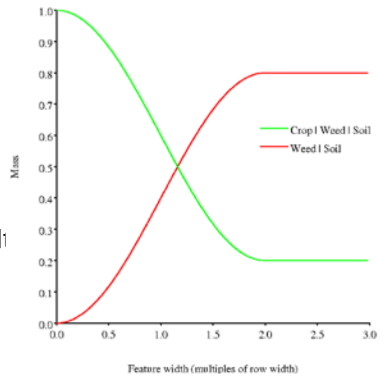

Figure 6 Probability assignment based on feature size.

The three items of evidence are then combined using Dempster's rule to provide an overlay of belief for each classification. The images given as examples in the results section below have been automatically highlighted red in areas where the classification of {Weed} is most plausible.

We have at this stage made no attempt to create a treatment map from which the sprayer would be controlled. It is likely that the process of creating this map will have a positive effect of the accuracy of classification as it will provide an opportunity to merge classification information from a succession of images.

3.4 Acquisition of image sequences for algorithm development and evaluation

Image sequences were obtained from two different commercial crops using the same equipment on both occasions. The experimental apparatus consisted of a digital camera mounted on the front of a tractor (Figure 7) connected via an IEEE 1394 serial connection to a laptop computer kept in the cab. The camera was mounted centrally at a height of 1.4 m looking ahead and down such that the bottom of the field of view was substantially vertically below the camera and the full width of the bed was visible over approximately 2.5 m. The resolution of the images was 320 by 240 pixels leading to a resolution of approximately 6 mm in ground coordinates. This resolution limits the ability of the system to detect small weeds, but is not thought to be a problem of volunteer potatoes which rapidly grow beyond this size after emerging. Higher resolutions e.g. 640 by 480 pixels could be achieved using the same camera if necessary, though with an increase in computational burden.

Figure 7 Camera mounting used to obtain image sequences.

The camera settings (e.g. white balance, gain, integration time and frame rate) were controlled from the computer using custom software developed for the purpose. Experience has shown that it is important to control the camera specifically for the application as standard settings designed to obtain aesthetically pleasing results often loose information due to saturation, or invalidate the assumptions made in derivation of the illumination invariant colour transformation. The software also enabled sequences of images to be stored onto the computers hard disc for subsequent analysis.

The first crop to be viewed was carrots grown on a peat soil at Home Fen. The crop had followed potatoes and had a severe infestation. It had been treated with a general herbicide some two weeks earlier which had severely checked most non-potato weeds and had caused some yellowing and distortion of the potato leaves. An application of Dosaflo was planned, but had not yet been applied to this crop when these images were obtained on 25 May 2006. The lighting was generally direct sun with a predominately blue sky. These lighting conditions are generally the most difficult due to the large variations in illumination between shadow (low levels biased to blue by sky colour) and direct sun (high levels biased to red by the sun's colour).

Figure 8A carrot crop at Home Fen with a weed potato infestation from which image sequences were obtained.

The second crop to be viewed was onions grown on a light soil at Caldecote. This crop had been treated with a conventional general herbicide program and there were few weeds other than a moderate weed potato infestation. On this occasion the potatoes did not seem to have been greatly affected by earlier herbicide treatments. An application of Dosaflo was planned, but had not yet been applied to this crop when the image sequences were obtained on 30 May 2006. The lighting conditions were similar to those experienced in the carrots, though some development of the image acquisition software had taken place and so the two sets of images have a slightly different white balance.

Figure 9 An onion crop at Caldecote near Shefford, Beds, with a weed potato infestation from which image sequences were obtained.

3.5 Algorithm performance

The following images have been chosen from the sequences of images to illustrate the strengths and weaknesses of the approaches implemented off line in the laboratory. The blue crosses represent raw observations of crop row location and the green lines reflect the position of the crop rows as tracked by the Kalman filter. Those parts of the images coloured red have been identified as being more likely to be weed that either crop or soil. This identification has been made on the basis of a combination of colour, feature size and position relative to crop row. Height information has not been used in these examples.

We have performed an analysis of performance based on a manual assessment of individual images taken out of the sequences. This approach is likely to understate the performance ultimately achievable, as it does not take advantage of the opportunity to merge characterisation information over sequences of images. In a final practical system this merging process will take place as a treatment map is created. This treatment map will be used to control the sprayer using an approach broadly similar to that described by Tillett *et al.*, 1998. Merging data in this way should provide a more robust and accurate result as it is based on more information. Furthermore, we are now aware of significant opportunities to improve the quality of the basic images through improved camera control techniques and better techniques for creating RGB images from the raw Bayer pattern produced by the camera. Overall we feel that the initial results presented here are capable of improvement.

3.5.1 Carrots

Of the two crops carrots proved to be the more challenging as at the time the images were acquired the size of the smaller potato plants was similar to that of the carrots. Therefore where small potatoes grew within the row, but did not extend significantly beyond, some potatoes were missed. An analysis based on manual inspection of 19 images taken from the sequences suggested that 53% of potatoes were detected to an extent that greater than 50% of their area was correctly classified. A further 27% had greater than 20% of their area correctly classified. It therefore seems likely that this 80% of volunteer potatoes would have been treated successfully. The remaining 20% of the potatoes, all of which were growing close to or within the row, were either missed completely of were judged to have less than 20% of their area correctly classified and therefore unlikely to receive an adequate dose of herbicide. There were four occurrences of crop being wrongly identified as weed though these were only very small and probably affected only one plant in each case. This represents a negligible (approximately 0.1%) proportion of the crop inspected in this assessment. There were also 21 occurrences of other non-potato features been identified for treatment. These were generally small weeds situated between crop rows.

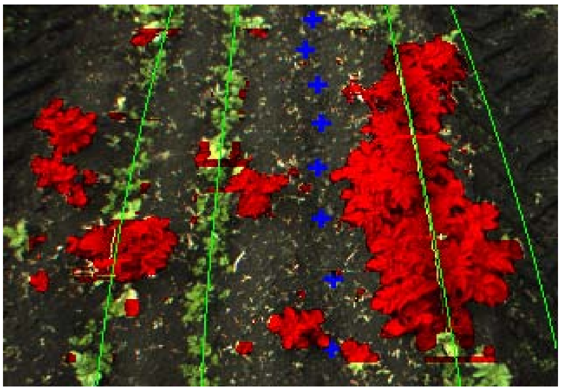

Figure 10 Large block of weed potatoes extending within and between rows have been correctly discriminated from the carrot crop.

Figure 11 Small weed potatoes and some other weeds between rows of carrots have been correctly identified (note outer right row is missing due to wheeling damage).

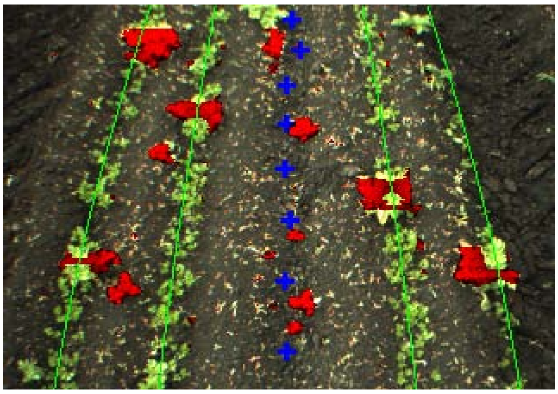

Figure 12 This example shows how relatively small weed potatoes within carrot rows can be either missed completely or only part of their extent identified for treatment.

3.5.2 Onions

In the 30 images used to evaluate performance we could not identify any cases where clearly discernable weed potatoes were not detected, though there were two occurrences of small weeds situated within crop rows that may have been potatoes that were missed. Of the potatoes that were detected all were judged to have greater than 50% of their leaf area correctly classified.

There were five instances of very small areas of crop being misidentified as weed. These might have been filtered out by any future treatment map generation process, but would in any case have affected only one or two plants at each site. These misclassifications occurred mostly at the tip of prostrate onion leaves and were mostly evident at the outer edges of the image. The latter suggests that this effect is made worse due to perspective, a factor that could be reduced by raising the camera and operating with a narrow angle lens (though this would conflict with the requirements of optical flow). Whilst it might not be possible to totally eliminate the possibility of prostrate crop laying in the inter-row area it might be possible to mechanically move the offending leaves to one side prior to the passage of inter-row spray nozzles. This would not prevent spurious spraying but it would reduce crop damage.

There were also 16 apparently spurious detections of very small features some of which may have been small weeds. If required the majority of these occurrences could be filtered out, probably without significant effect of the control of weed potatoes.

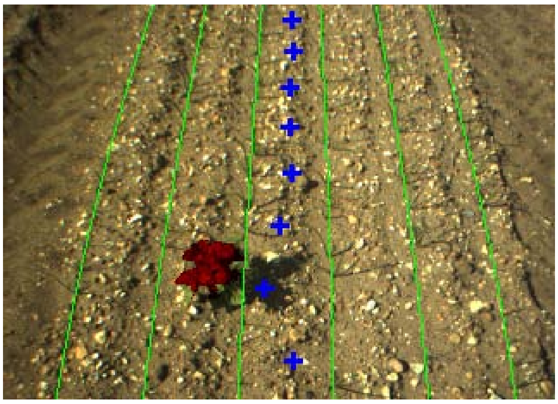

Figure 13 The detection of weed potatoes at the early stages of onion growth is relatively straight forward as there is a large size differential.

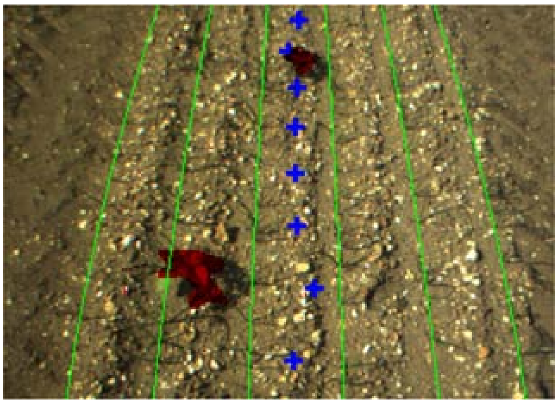

Figure 14 In this example the discrimination is almost certainly adequate for practical purposes, though a small area of the lower potato has been lost as it coincides with the crop row and is not connected (horizontally) with the rest of the plant.

3.5.3 Height from optical flow

Figure 15b shows a plot of relative motion between pixels in consecutive images versus lateral position in the image. Optical flow techniques can be used to translate this relative motion into a direct measure of feature height. This example is taken across a central horizontal band in Figure 15a and clearly shows the large potato on the right.

This result shows promise in detecting larger potatoes, though as the results above have shown the same potatoes can also be reliably detected on the basis of size alone in plan view. The technique appears to be less effective with lower weeds as noise levels are high relative to the small differences between carrots and weed height. This could be improved by lowering the camera, but this would conflict with the requirements of other techniques.

Figure 15a Sample image of large and small volunteer potatoes in carrots.

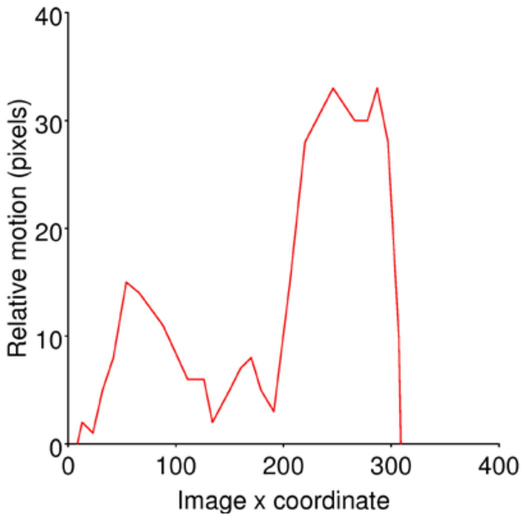

Figure 15b Plot of relative motion of pixels as features traverse from top to bottom of the image (indicative of feature height) taken across a central horizontal band in Figure 15a.

3.6 Discussion

As position relative to crop rows is an important contributing factor in weed discrimination, performance will be at its best when drilling is accurate and care is taken when conducting post emergence operations such as spraying to avoid running over rows. The precautions taken by growers who practice inter-row cultivation should be adequate in this respect. Similarly some planting geometries are better than others with respect to both ease of detection and treatment e.g. onions grown on twin rather than single rows generally provide more clearly defined rows. In these respects the commercial crops used in this trail represented more challenging situations than is sometimes the case.

It will be useful in future field work to investigate a wider range of crop situations especially earlier growth stages. These earlier growth stages may make discrimination easier as size may be a better discriminator especially in carrots.

Future work will pursue some of the technical opportunities identified above for performance enhancement. It will also be necessary in the next phase to develop techniques for transferring the information associated with individual images into a rolling treatment map based on ground coordinates that can be used to control a sprayer. It is anticipated that this could also be done within a Dempster-Schafer framework with successive frames contributing to the belief assigned to a particular area. The software used in this study will be required to be rewritten for implementation in real time (i.e. high speed) for a specific computer system.

There are substantial opportunities for improving the system as a whole by integrating all the technical aspects from the vision based detection, the creation of a treatment map, control of an array of nozzles, through to the choice of chemical formulation and the strategic agronomic decisions as to what to spray and when. For example, use of a side shifting mechanism would allow different spray techniques and materials to be applied on the row to those applied between rows.

3.7 Conclusions relating to the volunteer potato detection component of the work

- A computer vision based approach based on combining information on feature colour, size and position relative crop rows has been developed using a Dempster-Schafer framework.

- Height derived from optical flow has been shown to be capable of detecting larger weed potatoes, though it has not yet been used in combination with the other discriminators.
- Performance was best on onion crops due to the large size differential between crop and weed leaves.
- Performance was satisfactory on carrots, though small weed potatoes within crop rows were sometimes missed.
- A number of technical opportunities for improved performance have been identified during this study.
- Overall the results of this study indicate that it will be possible to detect volunteer potatoes in both carrots and onions without significant misclassification of crop.
- The techniques may also be applicable to other row crops and the detection of other large broadleaf weeds.

4. Overall conclusions and future work

The results of the feasibility study described in this report suggest that the assumptions made in this initial analysis are broadly valid although further work is required to:

(a) develop the application system;

(b) develop and verify the performance of the volunteer potato weed detection system;

(c) validate the performance of a complete machine operating on the principles described in the work reported here.

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APPENDIX I
FIELD DATA RELATING TO TREATED POTATAOES

Chicksands, Parishes farm

Row	Potato ID	Dose	Tillers	Long side, mm	Short side, mm	Surface area, m^2	Height, mm	Treatment	Score 09/06/06	Score 12/06/06	Score 16/06/06
1	1	0.5ml	4	320	290	928	240	Centre	6	5	5
1	2	0.5ml	4	430	320	1376	330	Centre	7	7	7
1	3	0.5ml	2	420	300	1260	340	Centre	5	6	4
1	4	0.5ml	3	300	290	870	220	75mm off centre	2	5	4
1	5	0.5ml	4	370	260	962	310	75mm off centre	2	5	4
1	6	0.5ml	4	380	270	1026	300	75mm off centre	2	5	5
1	7	0.5ml	3	380	240	912	270	75mm off centre	3	4	5
1	8	0.5ml	3	270	270	729	190	75mm off centre	4	6	6
1	9	0.5ml	5	490	380	1862	320	Centre	5	7	6
2	10	0.5ml	1	290	240	696	180	Centre	6	4	3
2	11	0.5ml	4	420	330	1386	260	75mm off centre	3	5	5
2	12	0.5ml	4	320	320	1024	310	Centre	6	6	6
2	13	0.5ml	4	520	340	1768	380	Centre	6	5	6
2	14	0.5ml	2	270	190	513	130	75mm off centre	2	2	2
2	15	0.5ml	1	250	190	475	130	Centre	10	10	9
2	16	0.5ml	1	180	160	288	170	75mm off centre	9	9	9
2	17	0.5ml	4	360	210	756	210	Centre	4	5	5
2	18	0.5ml	3	230	220	506	170	75mm off centre	3	8	7
2	19	0.5ml	4	340	170	578	180	Centre	3	7	7
2	20	0.5ml	4	270	170	459	120	Centre	3	2	2
3	21	0.5ml	3	360	280	1008	280	75mm off centre	3	5	4

Chicksands, Parishes farm

Row	Potato ID	Dose	Tillers	Long side, mm	Short side, mm	Surface area, m²	Height, mm	Treatment	Score		
									09/06/06	12/06/06	16/06/06
3	22	0.5ml	2	330	260	858	270	75mm off centre	4	8	7
3	23	0.5ml	3	300	250	750	230	75mm off centre	3	9	7
3	24	0.5ml	5	420	320	1344	410	Centre	2	6	5
3	25	0.5ml	2	360	320	1152	230	Centre	5	7	7
3	26	0.5ml	2	350	350	1225	250	75mm off centre	5	7	6
3	27	0.5ml	3	400	320	1280	280	75mm off centre	8	7	6
3	28	0.5ml	1	300	300	900	270	Centre	9	9	8
3	29	0.5ml	1	340	340	1156	220	75mm off centre	4	4	5
3	30	0.5ml	1	350	250	875	220	Centre	8	8	8
3	31	0.5ml	4	360	340	1224	340	Edge	7	7	7
3	32	0.5ml	4	480	320	1536	270	Edge	2	4	3
3	33	0.5ml	1	340	270	918	250	Edge	3	7	4
3	34	0.5ml	2	350	270	945	260	Edge	5	7	5
3	35	0.5ml	6	400	400	1600	240	Edge	0	3	1
3	36	0.5ml	1	290	290	841	180	Edge	2	4	1
3	37	0.5ml	3	350	250	875	190	Edge	1	3	2
3	38	0.5ml	3	360	290	1044	280	Edge	0	2	1
3	39	0.5ml	4	360	280	1008	190	Edge	3	4	4
3	40	0.5ml	3	420	320	1344	250	Edge	4	6	5
3	41	0.5ml	3	500	390	1950	380	Edge	0	1	1
3	42	0.5ml	2	230	210	483	130	Edge	10	10	10
3	43	0.5ml	2	310	310	961	260	Edge	7	6	5
3	44	0.5ml	5	420	380	1596	260	Edge	3	5	3
3	45	0.5ml	4	380	380	1444	280	Edge	2	5	5

Cardington

Block	Potato ID	Dose	Tillers	Long side, mm	Short side, mm	Surface area, cm²	Height, mm	Treatment	Weight, gr	Score			Weight, gr
										19/06/06	27/06/06	10/07/06	
1	1A	0.5ml	7	590	420	2478	420	Control		0	0	0	1208
1	1B	0.5ml	3	390	340	1326	220	Control		0	0	0	1446
1	2A	0.5ml	6	630	390	2457	370	Centre		4	3	3	494
1	2B	0.5ml	5	520	320	1664	370	Centre		5	4	4	329
1	3A	0.5ml	9	560	430	2408	390	75mm off centre		4	3	3	
1	3B	0.5ml	5	560	360	2016	390	75mm off centre		4	3	2	
1	4A	0.5ml	5	540	420	2268	370	Edge		2	2	1	
1	4B	0.5ml	5	590	450	2655	330	Edge		4	1	0	
1	5A	0.5ml	7	650	470	3055	430	Cut	542	**	**	**	
1	5B	0.5ml	7	560	440	2464	410	Cut	536.5	**	**	**	
2	1A	0.5ml	7	550	440	2420	470	Control		0	0	0	
2	1B	0.5ml	7	620	390	2418	400	Control		0	0	0	
2	2A	0.5ml	8	550	360	1980	410	Centre		4	4	5	514
2	2B	0.5ml	9	540	440	2376	420	Centre		3	4	4	410
2	3A	0.5ml	6	580	530	3074	430	75mm off centre		3	3	3	
2	3B	0.5ml	7	530	350	1855	370	75mm off centre		3	4	3	
2	4A	0.5ml	5	650	380	2470	380	Edge		2	1	1	
2	4B	0.5ml	6	660	540	3564	390	Edge		3	2	2	
2	5A	0.5ml	8	520	450	2340	430	Cut	496.5	**	**	**	
2	5B	0.5ml	7	560	460	2576	390	Cut	465	**	**	**	
3	1A	0.5ml	5	550	450	2475	420	Control		0	0	0	
3	1B	0.5ml	6	570	530	3021	400	Control		0	0	0	1458
3	2A	0.5ml	6	630	460	2898	440	Centre		3	3	3	
3	2B	0.5ml	7	570	570	3249	420	Centre		3	3	2	713
3	3A	0.5ml	7	570	490	2793	430	75mm off centre		4	3	2	
3	3B	0.5ml	5	600	560	3360	410	75mm off centre		5	4	3	

Cardington

Block	Potato ID	Dose	Tillers	Long side, mm	Short side, mm	Surface area, cm²	Height, mm	Treatment	Weight, gr	Score			Weight, gr
										19/06/06	27/06/06	10/07/06	
3	4A	0.5ml	8	570	570	3249	490	Edge		2	2	1	
3	4B	0.5ml	8	590	430	2537	440	Edge		2	2	1	
3	5A	0.5ml	4	330	260	858	180	Cut	82.7	**	**	**	
3	5B	0.5ml	8	630	400	2520	450	Cut	466.5	**	**	**	
4	1A	0.5ml	7	610	520	3172	390	Control		0	0	0	1851
4	1B	0.5ml	9	580	560	3248	420	Control		0	0	0	
4	2A	0.5ml	7	660	390	2574	430	Centre		3	4	2	546
4	2B	0.5ml	5	550	420	2310	450	Centre		4	3	3	389
4	3A	0.5ml	8	520	510	2652	400	75mm off centre		4	3	2	
4	3B	0.5ml	10	570	510	2907	390	75mm off centre		4	3	2	
4	4A	0.5ml	7	570	470	2679	390	Edge		3	3	2	
4	4B	0.5ml	7	520	460	2392	380	Edge		3	2	1	
4	5A	0.5ml	5	480	390	1872	330	Cut	275	**	**	**	
4	5B	0.5ml	8	580	450	2610	420	Cut	462.7	**	**	**	
5	1A	0.5ml	4	580	360	2088	420	Control		0	0	0	1191
5	1B	0.5ml	6	570	440	2508	460	Control		0	0	0	
5	2A	0.5ml	8	490	470	2303	460	Centre		4	4	2	411
5	2B	0.5ml	5	490	470	2303	380	Centre		4	3	3	415
5	3A	0.5ml	6	630	540	3402	430	75mm off centre		4	2	1	
5	3B	0.5ml	9	610	560	3416	390	75mm off centre		4	3	2	
5	4A	0.5ml	9	570	400	2280	460	Edge		1	2	1	
5	4B	0.5ml	4	590	460	2714	440	Edge		3	1	1	
5	5A	0.5ml	6	520	520	2704	480	Cut	506.6	**	**	**	
5	5B	0.5ml	8	640	440	2816	460	Cut	569	**	**	**	
6	1A	1.0ml	7	570	550	3135	420	Control		0	0	0	910
6	1B	1.0ml	4	510	510	2601	460	Control		0	0	0	
6	2A	1.0ml	8	570	470	2679	450	Centre		5	6	5	387
6	2B	1.0ml	3	560	560	3136	360	Centre		4	6	5	280

Cardington

Block	Potato ID	Dose	Tillers	Long side, mm	Short side, mm	Surface area, cm²	Height, mm	Treatment	Weight, gr	Score 19/06/06	Score 27/06/06	Score 10/07/06	Weight, gr
6	3A	1.0ml	5	620	490	3038	440	75mm off centre		4	5	4	
6	3B	1.0ml	4	590	520	3068	460	75mm off centre		5	5	4	
6	4A	1.0ml	6	570	490	2793	340	Edge		4	4	3	
6	4B	1.0ml	2	510	430	2193	380	Edge		3	4	3	
6	5A	1.0ml	6	600	520	3120	380	Cut	408.8	**	**	**	
6	5B	1.0ml	6	520	520	2704	390	Cut	408.5	**	**	**	
7	1A	1.0ml	7	340	340	1156	290	Control		0	0	0	2508
7	1B	1.0ml	7	570	570	3249	430	Control		0	0	0	
7	2A	1.0ml	5	460	420	1932	340	Centre		5	5	3	
7	2B	1.0ml	6	570	390	2223	390	Centre		5	5	4	337
7	3A	1.0ml	7	620	520	3224	420	75mm off centre		5	5	4	333
7	3B	1.0ml	6	590	430	2537	410	75mm off centre		5	5	4	
7	4A	1.0ml	6	720	560	4032	410	Edge		3	3	2	
7	4B	1.0ml	5	570	530	3021	410	Edge		2	3	3	563
7	5A	1.0ml	7	600	530	3180	450	Cut	541	**	**	**	
7	5B	1.0ml	8	570	430	2451	370	Cut	390	**	**	**	
8	1A	1.0ml	6	570	530	3021	440	Control		0	0	0	1082
8	1B	1.0ml	6	570	520	2964	380	Control		0	0	0	
8	2A	1.0ml	3	560	450	2520	390	Centre		3	4	3	286
8	2B	1.0ml	9	640	470	3008	420	Centre		3	4	3	
8	3A	1.0ml	8	520	520	2704	460	75mm off centre		5	4	4	
8	3B	1.0ml	5	510	510	2601	420	75mm off centre		5	5	5	
8	4A	1.0ml	7	610	590	3599	430	Edge		3	3	2	
8	4B	1.0ml	7	530	530	2809	350	Edge		3	3	3	
8	5A	1.0ml	6	650	370	2405	440	Cut	557.6	**	**	**	
8	5B	1.0ml	8	580	490	2842	410	Cut	413	**	**	**	

Cardington

Block	Potato ID	Dose	Tillers	Long side, mm	Short side, mm	Surface area, cm²	Height, mm	Treatment	Weight, gr	Score			Weight, gr
										19/06/06	27/06/06	10/07/06	
						2646.49	404.88		445.09				

HDC Project Self Assessment and Report Form

This form should be completed by the Project Leader and returned to the Technical Administrator hdc@hdc.org.uk by the contracted report due date.

HDC Project No	FV 281	or	Annual/Interim report for year(s)	
			Final report	☐
Project Leader	Prof Paul Miller		Contractor	TAG

Title	The development of methods to control volunteer potatoes in a range of vegetable crops

Start date	1/03/06	End date	31/8/06	Total cost	£29,532	HDC cost	£29,532

Scientific and Technical Objectives

Please indicate progress made in completing the technical and scientific objectives listed below, with reference to the associated milestones in the contract schedule.

		on schedule		complete
		yes	no	
1)	Develop and assess image analysis based weed discrimination	yes		yes
2)	Assess appropriate target sites for Glyphosate treatment	yes		yes
3)	Development of treatment application method	yes		yes
4)	Outline economic analysis	yes		yes
5)				
6)				
7)				
8)				

(If you have answered 'no' please give a brief explanation on a separate sheet)

Annual/Interim Reports Only

	yes	no
Are the remaining objectives and work plan appropriate for successful completion of the project? (If you have answered 'no', please give a brief explanation on a separate sheet)		

Commercial Benefits and Technical Deliverables

Using bullet points, describe briefly key technical findings and results likely to be of value to the industry.

- Computer analysis of video images has been shown to be a viable way of detecting volunteer potatoes in both onion and carrot crops.
- Very low spot doses (< 1 ml) of glyphosate spray were effective at killing potatoes, though larger more vigorous plants may require a separate dose on each stem.
- Overall the study suggests that spot herbicide application could be developed to become a technically feasible and economically viable method of volunteer potato control.
- The findings of this study provide a good foundation for the follow on Link project.

Communications/Information Dissemination

Please list all HDC and other publications, presentations, posters or other activities in which this project was featured, for the time period covered by this report.

Short reports in HDC News:

- New project news/ final report availability and month/year

Feature articles in HDC News:

- Month/year

Presentations at grower events:

- Event title, location and day/month/year

Signature of project leader	**Date**

HDC use only		
Assessment of Completed Projects		
	Yes	**No**
Was it the right project ?		
Was the work done well ?		
Was the work delivered on time ?		
Were the results communicated and in the right format ?		
Did the work provide value for money to the industry (= profit enhanced or at least defended if results adopted at project completion stage)?		
Did the project deliver usable results?		
Comments		

Recommended action for the HDC		
Annual/Interim report		**Final report**
☐	Review project	☐
☐	SOLA application required	☐
☐	Further communication work needed	☐
	Technology transfer work needed to put into commercial practice	☐
	Further research and development work needed	☐
	Project suitable for independent economic review after a few years	☐

Date to Panel:	Date to Council: