HL0173LFV

Mechanical weed control for integrated and organic salad and brassica production

Annual report
February 2007

Project title:	Mechanical weed control for integrated and organic salad and brassica production
Project number:	HL0173LFV
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Report:	2nd Annual report (1st April 2006 to 31st March 2007)
Previous reports:	6 month report September 2006
Date commenced:	1 April 2005
Date completed:	30 June 2007
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Key words:	brassica, salad, weed management, mechanical weeding, novel cultivation mechanism, two dimensional tracking, crop colour, crop spacing,

CONTENTS:

GROWER SUMMARY

HL0173LFV

Mechanical weed control for integrated and organic salad and Brassica production

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1. HEADLINE

Reliable mechanical weed control, with low levels of crop damage, was demonstrated with an in-row cultivation tool allowing savings on time and energy. The project highlights cost effective savings on cultivation costs with a short pay-back time.

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2. BACKGROUND AND EXPECTED DELIVERABLES

This project aims to produce a cost effective adaptable mechanical control of in-row weeds for a range of integrated and organic salads and brassicas crops.

- The project aim will be achieved through the development of an experimental prototype demonstrating the technology.
- The project will also provide knowledge necessary for post project development of prototype commercial machines

Diminishing herbicide options, fear of ground water contamination and customer pressure to minimise herbicide use are all pushing the industry away from reliance on herbicides. However, product contamination concerns, much of which relate to weeds, necessitate high levels of weed control and have resulted in increasing use of unsustainable hand weeding.

- A major constraint to continued growth of processed bagged salads is contaminants. Major contaminants are weeds and weed seeds, however other pest and disease contaminants are enhanced by poor weed control.
- The majority of salad crops are hand weeded once and some twice at a cost of £400-£1000/ha depending on weed levels. This task is not liked and leads to back problems.

- Brassica production is also affected by weed contamination, but to a lesser extent. Better weed control will reduce these problems. It is estimated that only 5% of brassica crops currently require hand weeding, though that is expected to rise after the loss of herbicides such as Cyanazine in 2007. Most organic brassica crops are hand weeded and costs are typically lower at £100 - £250/ha due to wider plant spacing and a greater tolerance to weeds.
- Typical brassica residual herbicide costs are expensive - between £45 and £60/ha.
- More cost-effective weed control will have the added commercial benefit of reducing potential reliance on imports of certain produce from outside the UK in the future.

Weeds growing within crop rows continue to be the major problem because of

1. gaps in the herbicide control of certain weed species and
2. the close proximity of the weeds to the crop making conventional mechanical weeding difficult without risking crop damage.

THT's imaging and crop row tracking technology has been successfully applied to cultivation equipment for improved inter-row mechanical weed control. There is an opportunity to develop an adaptable, cost-effective technology for mechanically controlling weeds, specifically in-row weeds, for a wide range of brassica and salad crops that would enable machinery to control in-row weeds mechanically. Such a development would increase UK industry competitiveness in a way that is sustainable in a low herbicide environment

The main deliverable of the project will be an experimental prototype demonstrating the technology developed and capable of being taken forward for development by the manufacturing parties.

3. SUMMARY OF THE PROJECT AND MAIN CONCLUSIONS

(REPORTING PERIOD 1 APRIL 2005 TO 31 MARCH 2006)

To develop the mechanical control of in-row weeds, we need to be able to take regular observations of plant positions in the field and then quickly pass this information to a fast tracking algorithm that can then follow plant location from a moving vehicle. Importantly, this tracking algorithm will need to be able to cope with variability in the spatial planting of the crop.

During the first 6 months of the project, extensive measurements were made in both commercial brassica and salad crops to quantify the degree of planting variability (Objective1). We have identified from discussions with growers and the literature the most important time for us to target the mechanical weeding operation will be approximately 3 to 4 weeks after transplanting. The relatively short period of time salads remain in the field and the competitive nature of brassicas, make later weeding less critical.

The project is also addressing the challenge of following a typical range of salad and brassica crop colours, in particular red salad plants (Objective 2). During the first six months, samples of crops of different colours have been supplied by our commercial Partners. We have found that all crops can be tracked with Near Infrared (NIR), unfortunately NIR, red and blue cameras are not yet commercially available. However, an alternative (Red Green Blue - RBG) camera has been identified.

An algorithm based on a two dimensional wavelet approach to crop location (a type of mathematical template) coupled with Kalman filter tracking of individual plants has been developed during the first year. (Objective 3).

A novel shallow cultivation mechanism with a cut out disc has been field tested with encouraging results. (Objective 4).

A phase lock loop control system has been devised to synchronise approaching plants, as tracked by the vision system, with the cultivator. A single row rig using both electrical and hydraulic drives has been successfully tested using artificial plants (green blocks). (Objective 4).

(REPORTING PERIOD 1 APRIL 2006 TO 31 MARCH 2007)

An experimental toolframe based on a commercial steerable front mounted inter-row cultivator has been constructed by Garford Farm Machinery. The single row cultivation mechanism, developed earlier in the project, has been redesigned and two modules have been mounted on the experimental toolframe (Objective 5).

The computing system and microcontroller used in initial trials have been replaced with a new system with the capacity to operate up to five cultivation disc modules as well as provide inter-row guidance for the steerable toolframe. The main computer, a 1.6GHz Pentium M, is mounted on the implement and connects to a cab mounted console to provide a user interface and display live video images (Objective 5).

The complete system has been commissioned and undergone engineering evaluation (Objective 5). Tests indicated that a dish-shaped intra-row cultivation disc gave a finer tilth than a flat disc, that had a tendency to create larger clods under some soil conditions. A dish-shaped disc was therefore used for the agronomic field trials. Results indicated that the control system was maintaining disc angle in the desired position. The system performed well at speeds of up to 3.6 km h^{-1} and was reliable at commercially acceptable weed densities. Even when synchronisation was lost in very high weed densities, it was quickly regained if weed levels dropped. Treatment of larger crop plants (>12cm diameter) resulted in the disc shaft touching the outer leaves. Whilst not quantified, this contact had the potential to cause crop damage. As a result an alternative cranked drive shaft was created to increased clearance between the plant and drive shaft.

A preliminary agronomic assessment was also undertaken (Objective 6). Whilst the crop (cabbage Elisa) was grown at an atypical time of year (transplanted out in early September 2006), the trial has provided an early opportunity to evaluate performance. Weed pressure on the trial site was judged to be high and with a reasonably representative sample of weed species. Three weeding treatments were conducted at 16 days, 23 days and 33 days after transplanting. All treatments were conducted at 1.8 km h^{-1} using a toolframe equipped with both inter-row and intra-row cultivators. Weed numbers were counted in three annular areas (radii of 0-80mm, 80-160mm and 160-240mm) centred on crop plants. Weed counts were performed immediately before and after each treatment, and again two weeks after treatment.

The efficacy of weed control was at its best during treatments one and two, with initial weed numbers immediately after treatment reduced by 77% and 87% respectively. Subsequent re-growth and new germination in the two weeks after treatment reduced those figures to 74% and 66% of the original weed numbers. By the third treatment overall weed numbers pre treatment were lower, but those that remained had grown to be larger and more robust. This, combined with the difficulty in tracking where ground cover was almost complete, reduced the initial reduction in weed numbers to only 65%. However, there was no significant recovery in weed numbers over the subsequent two weeks possibly due to the late stage in the season not being suitable for further weed germination. Some crop plants were damaged in the final treatment due to the difficulty of tracking in a weed infestation judged to be worse than a commercially acceptable level.

A further field trial on lettuce on a commercial holding is planned for May 2007 (Objective 6).

The demonstration of the technology under commercial conditions is planned for June 2007 (Objective 7).

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4. EXPECTED FINANCIAL BENEFITS:

An analysis based on field performance and projected capital cost suggests that the operating cost per pass of a 4m machine controlling weeds in Brassicas would be £43/ha. The equivalent figure for a 2m machine working in Salads would be £109/ha. A full breakdown of this analysis are given as an Appendix to the science section of this report.

Organic production
It is assumed that two passes of the machine are required and that these replace two inter-row cultivation operations. If we assume that a typical organic brassica crop requires £300/ha of hand weeding labour and that use of the machine halves this need for hand weeding, then payback would be achieved in 0.8 years.
If we assume an organic salad crop requires £500/ha of hand weeding labour and that this is also halved then the payback period would be 1.4 years.

Conventional production
Conventional Brassica producers do not generally use hand weeding labour. If weed control measures fail the cost is more likely to be experienced as a loss of quality and yield with the worst areas being abandoned completely. For the purposes of this analysis it has been assumed that one pass of the weeder replaces one pass of an inter-row cultivator and results in a 2% higher yield. It is further assumed that herbicide applications costing £45/ha are reduced from three to two applications. The payback period in this situation has been calculated as 1.3 years.
Conventional salad growers do frequently employ hand weeding labour at an estimated average of £400/ha. It has been assumed that two passes of the machine halves this figure and replaces two inter-row cultivation operations as well as one herbicide application. On this basis the payback period is 1.4 years.

In addition to the direct financial benefits indicated above there should be a number of other benefits which are less easy to quantify in financial terms:

- Environmental benefits resulting from reduced herbicide use
- Improved product quality

- The potential for reducing the number of weeding operations through better targeting may help minimise problems caused by frequent soil disturbance.
- Plant location techniques developed to track individual widely plants may improve existing inter-row guidance, further reducing herbicide use.
- Lower weeding costs outlined above would increase potential for organic production especially where manual labour is scarce

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5. ACTION POINTS FOR GROWERS:

As the first agronomic field trials are of a preliminary nature it is premature to draw definite conclusions. We would however make the following observations:

- The competitive nature of brassica plants means that it is not necessary to get as close with the weeder as previously anticipated. Observations from the preliminary field trial in autumn 2006 demonstrated that the immediate under-story of the cabbages used in the trial had very few weeds.
- Crop damage was low, but the hooked stems of some brassica plants might require a larger (50mm radius) uncultivated zone to avoid root damage. The competitive nature of the brassica plants described above would facilitate using a larger radius without compromising the level of weed control achieved.
- Early weeding was most successful in the autumn conditions. However, this may change in spring as the soil heats up and weed emergence and weed species may differ in vigour and composition.
- The machine operated reliably in the typical to heavy commercial weed infestation levels experienced on the experimental site.
- The machine can be fitted with inter as well as the intra row cultivation tool being developed in this project. This would enable a single pass with the new weeder to replace a pass with a conventional inter-row hoe – thus saving time and energy use.

SCIENCE SECTION

HL0173LFV

Mechanical weed control for integrated and organic salad and brassica production

1. INTRODUCTION:

The scientific approach of the project has been to develop fast, two dimensional mathematical template matching techniques, (exploiting periodicity within the planting grid), which enable individual crop plants to be located and can cope with crop spacing variability. Regular observations of plant position are passed to a tracking algorithm that can follow plant location from a moving vehicle. We have ensured that this can be made to work for a typical range of salad and brassica crop colours, in particular red salad plants. A novel shallow cultivation mechanism has also been developed. This has been synchronised with the plant tracking algorithm enabling weeds to be removed from between crop plants within the row leaving the crop undisturbed. The final phase of the study will allow the performance of the resulting experimental apparatus to be assessed for both physical accuracy and horticultural value in terms of reliability, weed kill and any crop damage.

2. PROGRESS, RESULTS AND DISCUSSION

(REPORTING PERIOD 1 APRIL 2006 TO 31 MARCH 2007):

The primary and secondary milestones for the project are shown in Appendix 1. Objectives 1, 2, 3, 4 and 5 are now fully completed, whilst progress with objectives 6 and 7 are in progress and on target. Objectives 1, 2, 3 and 4 have been fully reported on in the 1st project annual report and therefore will not be repeated here. This report will therefore focus on project activities during the reporting year specifically in Objectives 3, 5, 6 and 7.

Objective 1: Quantify variability in plant spacing

A full description of the progress made in achieving this objective is given in the previous annual report.

Objective 2: Establish crop colours that can be tracked

A full description of the progress made in achieving this objective is given in the previous annual report.

Objective 3: Development of two dimensional tracking

A full description of the progress made in achieving this objective is given in the previous annual report.

Objective 4: **Develop a novel cultivation mechanism**

A full description of the progress made in achieving this objective is given in the previous annual report.

Objective 5: **System integration & validation**

- *The speed of the system*

    - Fast deployment and retraction are necessary to achieve economic work rates. The target maximum forward speed is 1m/s, which for an in-row plant spacing of 0.5m leads to nominal rotational speed of 2 Hz.
    - Where nominal plant spacing is less than 0.5m we would expect to operate at lower forward speeds maintaining a similar rotational speed.
    - However, variability in plant spacing within the row will require acceleration to higher speeds momentarily to maintain synchronisation. The maximum rotational speed therefore needs to be approximately 3 Hz.

- *Identifying the best choice of drive*

    - Two forms of drive have been considered; electric and hydraulic.
    - Geared electric drive has the advantage of being relatively easy to control using pulse width modulation techniques combined with solid state electronic components.
    - However, the torque that can be delivered, particularly at the 12V commonly available on tractors, is limited. Soil bin studies and practical experience suggest that the torque available electrically (typically 2.5 Nm) will be insufficient under normal field conditions.
    - Initially, an electrically driven rig was built (Figure 1), as it gave us the opportunity to conveniently develop various system components with the blade operating above ground and therefore under no load.

Figure 1: Electrically driven test rig for experimental development above ground

- *Identifying the optimal trajectory profile for the disc*

    - To maximise the area cultivated, the cut out disc is closely engaged around each plant for the majority of a cycle. There is a relatively short period (typically 17% of cycle time) between disengaging with one plant and engaging with the next. During this period the disc can be at any orientation with no risk of crop damage. This period is even shorter if an individual plant spacing is smaller than the nominal value. This fully disengaged period is not normally long enough to accelerate the disc to compensate for variable plant spacing. A compromise is therefore sought in which a smooth trajectory profile is defined with the largest angular correction taking place mid cycle.
    - That trajectory is based on a cubic spline in which the gradient at both ends (the plant positions) is defined as the angular velocity appropriate to the actual forward speed and nominal plant spacing. This ensures that phase errors are at a minimum at the point it matters most.
    - The smooth profile avoids rapid accelerations that require large power inputs and lead to increased component wear.
    - The profile is recalculated for every plant according to its position relative to the previous plant and defines the demanded velocity that the motor controller attempts to match. Figure 2 illustrates typical trajectory profiles showing that the velocity (slope) is always the same at the moment a plant is encountered.

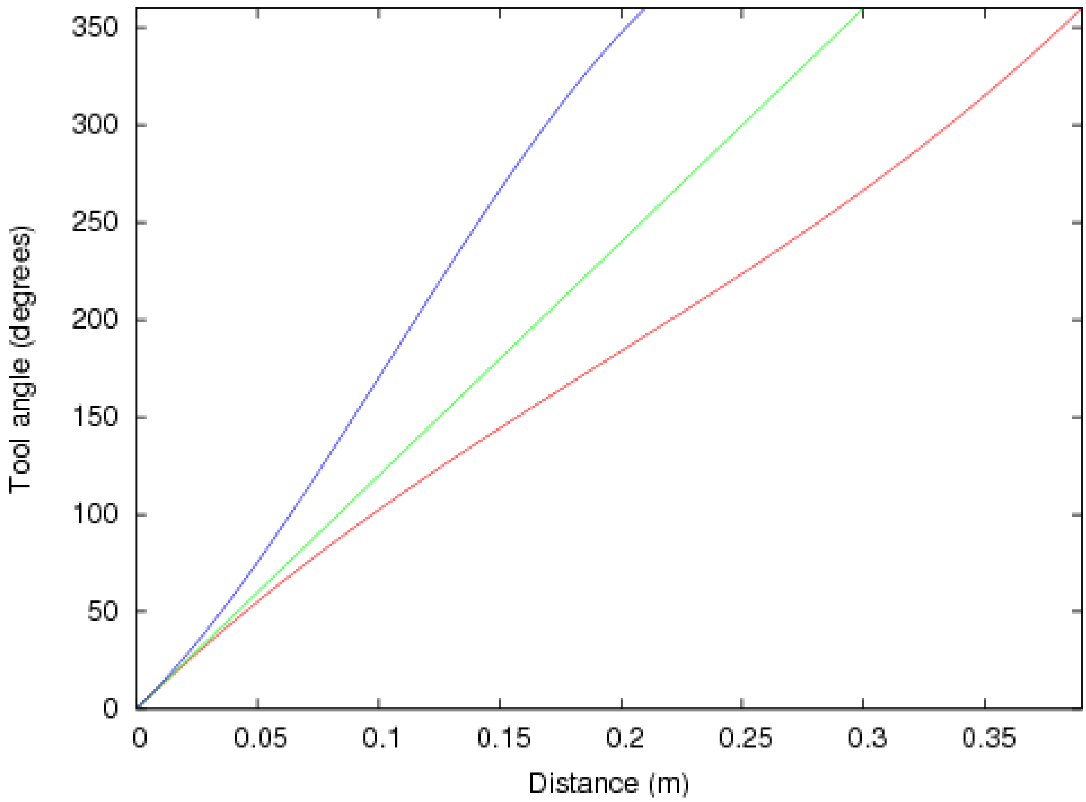


Figure 2 Disc trajectory profiles for a nominal plant spacing of 30 cm, given actual plant spacings of 21 cm (Blue), 30 cm (Green) and 39 cm (Red).

- *Constructing the hydraulically driven rig*

  - Following successful development of control and tracking strategies using electrical drive, a hydraulically driven rig was constructed with accurate depth wheel control. This has allowed field testing on a single row with artificial plants (Figure 3).
  - Initial tests gave satisfactory results (Figure 4) and so a hydraulically driven module was designed based on this rig and described in more detail below.

Figure 3 A single row field test rig with depth control and hydraulic drive shown operating on artificial plants above the soil surface.

Figure 4 Cultivation between artificial plants at a 30 cm pitch using the rig illustrated in Figure 3

- *Design and construction of a guided toolframe*

    - An experimental toolframe has been constructed by Garford Farm Machinery (Figure 5). The toolframe is based on a commercial disc steered front mounted inter-row cultivator.

- The 2m wide toolframe has the capacity to accommodate up to five rotary cultivation units and will be used in all further trials and demonstration work.

Figure 5 A 2m wide experimental toolframe designed and constructed by Garford Farm Machinery that will be used for all future trails and demonstration work.

- *Design and construction of selective disc cultivation modules*

  - The hydraulically driven single row experimental rotary disc cultivation mechanism described above, has been redesigned by Garfords (Figure 6).
  - The new units encapsulate the toothed belt driven encoder and an index sensor within a machined block. The machined block incorporates the shaft bearings and thus provides increased robustness.
  - Each of the disc cultivation modules are fitted to a depth wheel unit. This provides accurate depth control, though their parallelogram linkage mounting provides some compliance in the event of hitting an obstruction.

- For the trials conducted in September 2006 two disc cultivation modules were mounted on the experimental toolframe and fitted with discs to suit a 0.5m in-row-plant spacing.
- The depth wheel units also provide the mounting point for inter-row cultivation blades.

Figure 6 A hydraulically driven selective disc cultivation module fitted with a flat disc

- *Design and construction of a PC based computer system with a microcontroller machine interface*

    - As anticipated the computing system provided by Robydome based on their inter-row hoe guidance system was unable to cope with the computational load imposed by operation on multiple rows.
    - A new computing system has been developed based on a 1.6 GHz Pentium M processor on a standard commercial single card computer.
    - A custom designed machine interface card has been specially developed to provide low level control of the hydraulic motors and means of reading encoders, proximity detectors and a potentiometer.
    - Both the single card computer and the interface card have been mounted in a metal enclosure on the implement (Figure 7).
    - A user interface is provided by a separate Robydome cab mounted console connected to the main computer via Ethernet.
    - It has been decided not to attempt to provide user information on

the tractor console or to integrate with tractor steering as a suitable tractor has not been available.

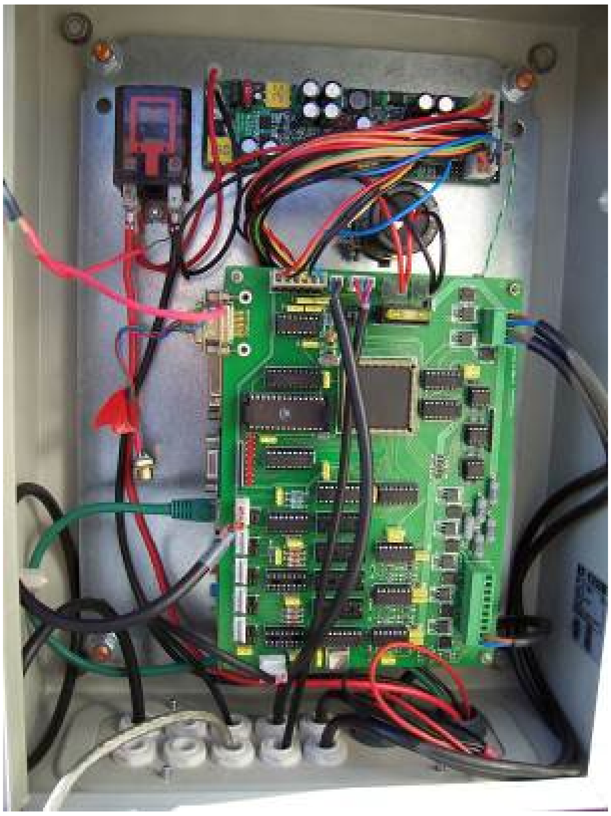


Figure 7 The computing enclosure containing a single card PC (hidden behind) and a custom designed machine interface card (in front)

- *Initial trials of the integrated system*

    - The integrated system has been commissioned and field tested on both artificial plants and cabbage transplants (Figure 8).

Figure 8 The integrated system undergoing initial field trials on two rows of cabbages

- The toolframe depth wheel serving as a temporary odometry measuring wheel proved insufficiently accurate on rough ground. It was replaced by a lightly loaded 0.5m diameter wheel running immediately behind a cultivator depth wheel.
- A vision derived measure of forward motion has been combined with odometric information to further reduce the adverse effects of rough ground.
- Tests indicated that a dished intra-row cultivation disc gave a finer tilth than a flat disc that had a tendency to create larger clods under some soil conditions. A dished disc was therefore selected for the agronomic trials.
- Results indicated that the control system was maintaining disc angle to within 10° of the desired position which is within the margin for error built into the disc profile.
- The system performed well at speeds of up to 3.6 km h^{-1} and was reliable at commercially acceptable weed densities. Even when synchronisation was lost in very high weed densities it was quickly regained if weed levels dropped.
- Treatment of larger crop plants (>12cm diameter) resulted in the disc shaft touching the outer leaves. Whilst not quantified, this contact had the potential to cause crop damage, and so an alternative cranked drive shaft was created (Figure 9).

Figure 9 Cranked disc shaft modification to increase plant to shaft clearance

<u>Objective 6</u>: <u>Quantify weeding performance</u>

- *Experimental design for initial agronomic trials September/October 2006*

- This preliminary assessment was designed to take advantage of a version of the experimental prototype being available in the autumn. As the cabbage crop was grown at a non-typical time of year it was not grown through to harvest – only to assess weeding efficacy at typical weeding times relative to crop and weed growth stages in the early weeks after transplanting
- Field trial plots were established at Silsoe (Figure 10). The seedbed was power harrowed approximately three weeks prior to transplanting with no pre-emergence herbicides in order to maximise the potential for the autumn flush of weed emergence to properly test the system.
- The crop was a fast growing cabbage (Elisa) grown at Kirton in "floppy 50s" to produce a large plant quickly (sown 26/7/06)
- Planting was by hand with an inter-row spacing of 0.5m and a nominal intra-row spacing of 0.5m that was made deliberately variable to correspond a commercially planted brassica crop whose variability was measured under objective 1 (SD 34mm).
- The crop was netted to protect from pest damage.

Figure 10 Netted plots of transplanted cabbage at Silsoe for the September/October agronomic field trial.

- The experimental plan was designed in consultation with a statistician and included the following planned treatments with 3 replications of each treatment:

    1. weedy control (to assess level of background weed infestation)
    2. weed free control (regularly hand weeded) to compare crop for any hoe damage
    3. "early" treatment weeding at approx. 3 weeks after transplanting
    4. "optimum" treatment i.e. weeding at approx. 4 weeks after transplanting

5. “late” treatment i.e. weeding at approx. 5 weeks after transplanting.

- Crop and weed assessments were made in the trial plots:

1. shortly after trial establishment as a baseline assessment of emerging weed flora, weed density and potential patchiness over the experimental area
2. immediately prior to treatment to asses baseline weed infestation at time of treatment
3. immediately after treatment to assess whether there are any remaining rooted weeds
4. approximately two weeks after treatment (to assess regrowth and any new weed emergence stimulated by the soil disturbance)

- Assessments of the weed flora on each occasion included:

1. weed species present, to identify whether certain species are more sensitive or able to recover from the treatment.
2. growth stage typical of the weed flora
3. the proximity of weeds to the crop and their density was recorded by using a series of concentric rings centred on the crop plant to provide spatial information on weed removal
4. the growth stage of surviving weeds was be recorded

Figure 11 Concentric rings used as an aid to spatial weed counting laid over a plant prior to treatment timing 1

- Assessment of the crop included:

:

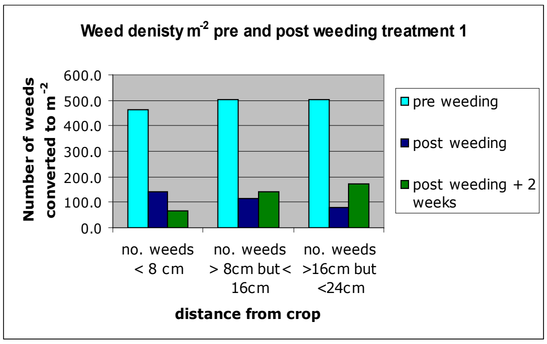
1. any noticeable crop damage immediately after treatment using a simple grading system.

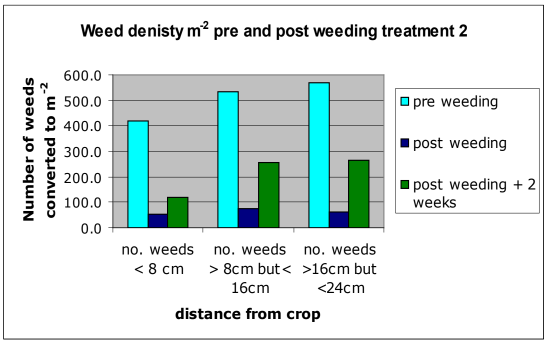
2. crop growth stage at time of treatment

- *Experimental results for initial agronomic trials September/October 2006*

    - The efficacy of weed control was at its best during treatments one and two with initial weed numbers immediately after treatment reduced by 77% and 87% respectively. The first weeding treatment coincided with the very early seedling 1 to 2 true leaf stage, with many pre-emerging seedlings were still at the "white-thread" stage (Figure 12). The second weeding was at the 4 to 5 true leaf stage

Figure 12 Weed seedlings at treatment 1 were typically at the 1 to 2 true leaf stage or even the "white thread" stage indicating that the flush of weed emergence was still occurring.





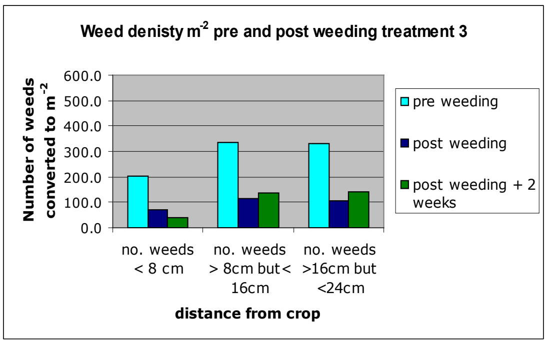


Figure 13 Weed density immediately prior to weeding, immediately after weeding and two weeks after weeding for treatment times one, two and three (the 27 September, 4 October and 17 October respectively).

- Subsequent re-growth and new germination in the two weeks after treatment reduced those figures to 74% and 66% of the original weed numbers (Figure 13). However, even two weeks after weeding, the weed control efficacy compared with the untreated plots was significant (Figure 14)

Figure 14 The bed on the right had been cultivated by the machine two weeks earlier at timing 2. The bed on the left is untreated.

- Whilst rainfall was marginally higher in the two weeks after the second treatment (13mm) than in the two weeks after the first (9mm), this is unlikely to have accounted for the higher recovery in weed numbers seen after the second treatment. It is thought that the greater susceptibility of weeds to mechanical damage at the earlier treatment was a more significant factor.

Figure 15 Typical weed levels experienced during treatments one, two and three on the 27 September, 4 October and 17 October respectively.

- By the time the third treatment was conducted weed infestation had reached the point in many places that coverage was complete (Figure 15) and the weeds had themselves started to compete with the crop and indeed themselves as can be seen in the lower weed densities at weeding time 3 (Figure 13). However, despite the lower weed densities at this later treatment time, the weeds themselves were much larger and robust. As the vision system relies on identifying plant material from a soil background, it is not surprising that in some cases tracking was poor or not possible. This combined with the larger better-rooted weeds, reduced the initial reduction in weed numbers to only 65%. However, there was no significant recovery in weed numbers over the subsequent two weeks possibly due to the late stage in the season not being suitable for further weed germination.

- The weeds present on the experimental site were typical of brassica production including Mayweed (*Tripleurospermum inodorum*), Shepherd's purse (*Capsella bursa-pastoris*) (Figure 16)

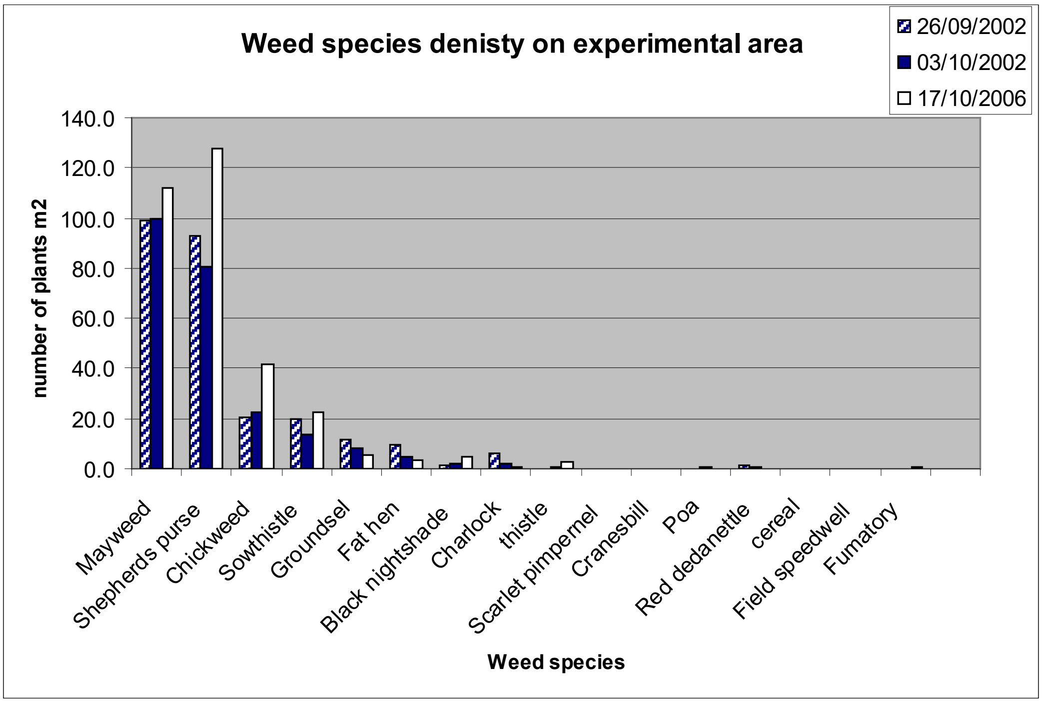


Figure 16 Weed species recorded on unweeded plots during the course of the agronomic assessment at Silsoe.

- Some crop plants were killed in the final treatment due to the difficulty of tracking in a weed infestation judged to worse than a commercially acceptable level. However, the greatest tracking challenge presented by the brassica crop, was the crooked stem observed on many of the plants which meant that the above-ground foliage and below ground root system were slightly offset and could cause problems with possible root damage (Figure 17). In a few cases (only one or two plants on a couple of the plots) this resulted in root damage and temporary wilting. However the crops quickly recovered in the early weeding treatments with no obvious long-term consequences.

- Possible damage to the crop root could easily be avoided by increasing the radius of the non-weeded zone around the crop and hence allowing a greater margin for clearance of any below ground damage. Increasing the radius of the un-cultivated zone should not present a problem with such a competitive crop. This is because weeds emerging directly under the crop foliage (within an annular radius of 80mm) were severely suppressed by the crop itself. A commercially and acceptable and practically achievable trade off between weeding proximity and crop competitiveness should be feasible.

Figure 17 The crooked stem growth habit of the brassica crop presented a challenge to the tracking system at later weeding times.

- *Economic analysis*

    - An analysis (Appendix 2) based on field performance and projected capital cost suggests that the operating cost per pass of a 4m machine controlling weeds in Brassicas would be **£43/ha**. The equivalent figure for a 2m machine working in Salads would be **£109/ha**.

- Organic production

    1. It is assumed that two passes of the new weeder would be required and that these replace two inter-row cultivation operations. If a typical organic brassica crop requires £300/ha of hand weeding labour and that use of the machine halves this, then payback would be achieved in **0.8 years**.
    2. If an organic salad crop is assumed to require £500/ha of hand weeding labour and that this would also be halved then the payback period would be **1.4 years**.

- Conventional production

    1. Typically conventional Brassica producers do not use hand weeding labour. If weed control measures fail the cost is more likely to be experienced as a loss of quality and yield with the worst areas being abandoned completely. For the purposes of this analysis it has been assumed that one pass of the weeder replaces one pass of an inter-row cultivator and results in a 2% higher yield. It has also been assumed that the number of herbicide applications costing £45/ha each are reduced from three to two. The payback period in this situation has been calculated as **1.3 years**.
    2. Conventional salad growers do frequently employ hand weeding labour at an estimated average of £400/ha. It has been assumed that two passes of the machine halves this figure and replaces two inter-row cultivation operations as well as one herbicide application. On this basis the payback period is **1.4 years**.

- In addition to the direct financial benefits indicated above there should be a number of other benefits which are less easy to quantify in financial terms

    1. Environmental benefits resulting from reduced herbicide use
    2. Improved product quality
    3. The potential for reducing the number of weeding operations through better targeting may help minimise problems caused by frequent soil disturbance.
    4. Plant location techniques developed to track individual widely plants may improve existing inter-row guidance, further reducing herbicide use.
    5. Lower weeding costs outlined above would increase

potential for organic production especially where manual labour is scarce

- *Agronomic trials for May 2007 on a commercial lettuce crop*

    - The plans for this trial will be discussed and finalised at the next project meeting on 6th February 2007.
    - The main aim of the commercial trial will be to increase our experience with
        1. a closer spacing of crop
        2. different coloured foliage
        3. contrasting season
        4. a more sensitive crop to damage and weed competition.

    - We aim to gain further information on potential weed species selectivity, which will be compared with known gaps in current chemical control and problematic weeds that have been identified for the salad crops.
    - Preliminary specification (i.e. efficacy at crop and weed growth stages) will be determined.
    - Treatments will include
        1. weeding according to current best practice on the commercial site (i.e. interow with existing equipment plus hand weeding)
        2. weeding of just the interow (with existing equipment) as this will allow us to assess the impact of the in-row weeds)
        3. weeding using the new prototype experimental weeder.

    - All treatments will be carried out at the same time, but on crops of different growth stage at the same commercial site.
    - Assessments will be based on those reported for the preliminary experiment carried out at the Cranfield/Silsoe site in Autumn 2006, however some modification of the diameter of the concentric rings may be necessary to match the different crop planting geometry.

Objective 7: Demonstration

- The integrated system will be demonstrated in a commercial lettuce crop during or just after the agronomic trail planned for spring 2007. The format, venue and dates for this will be discussed and agreed with the project partners at the next project meeting on 6th February 2006.

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3. TECHNOLOGY TRANSFER:

- Presentation made on project aims at HDC roadshow (Stockbridge House, February 2005)
- Presentation made at HDC Open Day (Kirton, June 2005)
- Presentation made at the Soil Association Horticulture Symposium (HDRA, June 2005)
- Project webpage
  http://www2.warwick.ac.uk/fac/sci/hri2/research/weedecologyandmanagement/hl0173lfv/
- A4 project summary sheet produced for all Partners
- Presentation made at the East Malling Members Day (East Malling Research 26 January 2006).
- Presentation made at the Horticulture LINK event held in London on 23 February 2006
- A. P. Dedousis, R. J. Godwin, M. J. O’Dogherty , , J.L. Brighton, N.D. Tillett (2005) An investigation into the design and performance of a novel mechanical system for intra-row weed control. British Crop Protection Council Conference, Glasgow
- A. P. Dedousis, M. J. O’Dogherty, R. J. Godwin, N.D. Tillett, J.L. Brighton (2006) A novel approach to precision mechanical weed control with a rotating disc for inter and intra-row weed hoeing. 17th Triennial Conference of the International Soil Tillage Research Organisation Kiel, Germany.
- A. P. Dedousis, R. J. Godwin, M. J. O’Dogherty, N.D. Tillett, J.L. Brighton (2006) Effect of implement geometry and inclination angle on soil failure and forces acting on a shallow rotating disc for inter and intra-row hoeing. 17th Triennial Conference of the International Soil Tillage Research Organisation Kiel, Germany
- Article on the project appeared in the Grower 16 July 2006 (page 16)
- Presentation on the project made to a group of Norwegian and Danish researchers and advisers visiting Warwick HRI on 23 August 2006.
- O'Dogherty, M. J., Godwin, R. J., Dedousis A. P., Brighton, J.L., Tillett N. D. (2006) A mathematical model of the kinematics of a rotating disc for inter and intra-row hoeing. Biosystems Engineering (In Press)
- A. P. Dedousis, R. J. Godwin, M. J. O’Dogherty, N. D. Tillett, A. C. Grundy (2007) Inter and intra-row mechanical weed control with rotating discs. Proceedings of the 6th European Conference in Precision Agriculture, Skiathos, Greece.
- N. D. Tillett, T Hague, A. C. Grundy, A. P. Dedousis (2007) A vision guided system using rotating discs for within-row mechanical weed control. Proceedings of the 6th European Conference in Precision Agriculture, Skiathos, Greece.
- Tillett, N. D., T Hague, T., Grundy, A. C., Dedousis, A. P. (submitted 2007) Mechanical within-row weed control for transplanted crops using computer vision. Biosystems Engineering.
- Presentation on the HortLINK project made as part of the University Department Seminar Series. October 2006.
- Production of official project information leaflet (proof attached)

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APPENDIX 1. Project milestones ■= completed tasks

Activity	Milestone no	Partners (lead first)	Year 1 (April 05-Mar 06)				Year 2 (April 06-Mar 07)				Year 3 (April07-June07)
	Bold = primary		Q1 April-June 05	Q2 July-Sept 05	Q3 Oct-Dec 05	Q4 Jan-Mar 06	Q1 April-June 06	Q2 July-Sept 06	Q3 Oct-Dec 06	Q4 Jan-Mar 07	Q1 April-June 07
Objective 1 Spacing variability		HRI lead									
Quantify planting accuracy within-the-row	1.2	SRI/RM/Edwards	May-05								
Identify appropriate safety margins around crop	1.3	HRI	Jun-05								
Grab image sequences for off line development	1.4	SRI/RM/Edwards	Jun-05								
Identify ideal timings for weed removal	1.5	HRI	Jun-05								
Design specification produced	**1.1**	All		**Jul-05**							
Objective 2 Crop colours		SRI lead									
Establish limitations of existing RGB ratio	2.2	SRI	Apr-05								
Establish limitations of NIR images	2.3	SRI	Apr-05								
Quantify reflectance spectra	2.4	SRI	May-05								
Multi-variate anaysis to select filter combinations	2.5	SRI	Jun-05								
Recommendations completed	**2.1**	SRI	**Jun-05**								
Objective 3 Two dimentional tracking		THT lead									
Develop mathematical templet (wavelet approach)	3.2	THT			Dec-05						
Develop Kalman filter tracking algorithm	3.3	THT			Dec-05						
Test complete tracking on stored image sequences	**3.1**	THT					**Apr-06**				
Objective 4 Cultivation and control		THT lead									
4a) Develop selective cultivation device	**4.1**	THT/Garford			**Oct-05**						
4b) Select actuator and develop phase lock loop control	**4.2**	THT/Garford/Robydome				**Jan-06**					
Objective 5 Systems integration and validation		THT lead									
Design and construct guided toolframe	5.2	Garford/THT					Apr-06				
Construct and fit at least two selective cultivation modules	5.3	Garford/THT					May-06				
Construct PC based console and microcontroller system	5.4	Robydome/THT					May-06				
Integrate vision guidance with tractor steering	5.5	THT/AGCO/Robydome						Jul-06			
Provide some user information on tractor conole	5.6	THT/AGCO/Robydome						Aug-06			
Conduct initial trails	**5.1**	THT/Garford/Robydome/AGCO							**Oct-06**		
Objective 6 Quantify weed control performance		HRI lead									
Assessment in commercial crop	**6.1**	HRI/THT/RM/Edwards									**May-07**
Objective 7 Demonstration		HRI lead									
Field demonstration to interested parties	**7.1**	HRI/All									**May-07**

Appendix 2 Economic analysis

	Intra-row hoe cost benefit	**Organic Brassicas**		**Conventional Brassicas**		**Organic Salads**		**Conventional Salads**	
		Existing strategy	Proposed strategy	Existing strategy	Proposed strategy	Existing strategy	Proposed strategy	Existing strategy	Proposed strategy
	Intra-row weeder								
1	Field efficiency (0-1)		0.75		0.75		0.75		0.75
2	Working width (m)		4		4		2		2
3	Forward speed (km/hr)		3		3		2		2
4	Spot work rate [**2*****3**/10] (ha/hr)		1.2		1.2		0.4		0.4
5	Actual work rate [**1*****4**] (ha/hr)		0.9		0.9		0.3		0.3
6	Workable days per season		50		50		60		60
7	Capacity based on 8h days [**5*****6*****8**] (ha/yr)		360		360		144		144
8	Capital cost (£)		34000		34000		30000		30000
9	Depreciation at 15% of cap cost(£/yr)		5100		5100		4500		4500
10	Running cost at 10% of cap cost (£/yr)		3400		3400		3000		3000
11	Annual cost of ownership [**9+10**] (£/yr)		8500		8500		7500		7500
12	Annual cost of ownership spread over capacity [**11**/**7**] (£/ha)		23.61		23.61		52.08		52.08
13	Variable cost, tractor +driver (£/hr)		17		17		17		17
14	Variable tractor+driver cost [**13**/**5**] (£/ha)		18.89		18.89		56.67		56.67
15	Cost of Intra-row weeding [**12**+**14**] (£/ha)		42.50		42.50		108.75		108.75
16	Number of intra-row treatments		2		1		2		2
17	Total cost of intra-row weeding [**15*****16**] (£/ha)		85.00		42.50		217.50		217.50
	Inter-row hoeing								
18	Inter-row hoeing cost (£/ha)	25	25	25	25	60	60	60	60
19	No of inter-row hoe passes	2	0	2	1	2	0	2	0
20	Total cost of inter-row cultivation [**18*****19**] (£/ha)	50	0	50	25	120	0	120	0
	Conventional spraying								
21	Number of conventional sprayer passes for herbicide			3	2			2	1
22	Contract/Farm sprayer charge/cost (£/ha)			10	10			10	10
23	Variable cost of herbicide per treatment (£/ha)			35	35			35	35
24	Total cost of herbicide spraying [(**22**+**23**)***21**] (£/ha)	0	0	135	90	0	0	90	45
	Hand weeding								
25	Variable average cost hand weeding (£/ha)	300	150	0	0	500	250	400	200
	Abandoned crop due to weed infestation								
26	Av % of crop expected to be abandoned due to weed	0	0	2	0				
27	Establishment cost (£/ha)	2200	2200	2200	2200				
28	Total average loss due to abandoned crop (**26*****27**/100)	0	0	44	0				
27	**Total weed control costs** [**17+20**+**24+25+28**](£/ha)	**350.00**	**235.00**	**229.00**	**157.50**	**620.00**	**467.50**	**610.00**	**462.50**
28	**Benefit of proposed strategy over existing practice (£/ha)**	**115.00**		**71.50**		**152.50**		**147.50**	
	Pay back period if used to capacity [8/(28*7)] (years)	**0.821256**		**1.320901**		**1.36612**		**1.412429**	

Developing mechanical weeding for salad and brassica production

The UK field vegetables industry would save £750K a year if efficient mechanical weeding systems could be developed for in-row weeding

Good weed control is essential in modern salad and brassica production. For bagged salads, contamination with weeds is not tolerated by retailers or consumers. Poor weed control can also lead to other pest and disease contaminants. In brassica crops weed contamination may not be such a problem, but weed competition can have a dramatic effect on crop yields.

However, the range of herbicides available for salad and brassica growers has diminished over recent years as a result of EU and UK pesticides reviews, and the more frequent use of those that remain is leading to increasing problems of tolerance in formerly susceptible weeds.

Added to this, there is growing concern about groundwater contamination from the use of herbicides and customers are pressing for the use of herbicides to be minimised. All this is pushing growers towards greater reliance on hand weeding, but this is costly and a very unattractive job.

Imaging technology has been developed to a point where it can improve inter-row mechanical weed control. Further development to enable machinery to control in-row weeds mechanically would be an enormous benefit to the industry and make a substantial contribution to the competitiveness and profitability of field vegetable growers.

Research aims

The aim is to develop adaptable, cost-effective technology for mechanically controlling weeds, particularly in-row weeds, for a wide range of brassica and salad crops. It is expected that a prototype machine will be developed which can be taken forward by the manufacturing partners.

Research methods

The variability of plant spacing in rows will be quantified on a range of grower holdings to cope with the trade off between acceptable crop damage and weed control for common cropping situations. A mathematical template will be developed that will allow plants to be tracked in a two-dimensional, multiple-row planting pattern.

As the imaging technology uses illumination variant colour segmentation based on the red/green ratio to differentiate between the colour of crop and weed plants, the demand for red foliaged salad crops creates an additional challenge. Using a spectroradiometer, the key discriminating points of the spectrum will be identified.

Manufacturing partners in the consortium will be developing a new cultivation mechanism and synchronised control system to enable the fast deployment and retraction of a shallow undercutting blade to provide in-row mechanical weeding.

Using the technology developed, a steerable toolframe will be constructed equipped with a PC-based computing platform and camera to validate the system. Initially trials will use artificial crops and weeds followed by final field evaluation on commercial holdings.

Weeds very close to lettuce, likely to cause yield loss and quality problems (above left). Close, early and accurate weeding is essential for these crops. (Below) Shepherd's Purse between rows of cabbage, unlikely to reduce yield but could cause crop contamination

"This project has the potential to greatly reduce the expensive and monotonous task of hand weeding"

David Edwards
Edwards Brothers

Benefits for industry

The majority of salad crops are hand weeded once and sometimes twice at a cost of £400 - £1000/ha depending on weed levels. Hand weeding in brassica crops is less common but is expected to increase as further herbicides become unavailable. Costs here are £100 - £250/ha.

Brassica herbicides are expensive – between £45 and £60/ha. One pass of a combined in-row and inter-row weeder will cost £25/ha.

Putting these financial benefits together, the new weeding technology could save the UK industry £750K pa. In addition, there would be environmental benefits from the reduced use of herbicides.

Top: the novel shallow cultivator has been successfully synchronised with a computer programme for the tracking of individual crop plants. Above: An experimental prototype rig in the field

"We aim to develop an experimental prototype for mechanical weeding salad and brassica crops"

Andrea Grundy
Warwick HRI

What is HortLINK?

LINK is the UK Government's principal mechanism for supporting collaborative research partnership between UK industry and the research base.

The aims of the HortLINK programme are:

- To improve the sustainability of the horticultural industry
- To improve knowledge and understanding of processes and factors which determine the performance of the horticultural industry
- To enable access by the horticultural industry to innovative ideas and technology by involving a wide range of research institutes and university departments
- To promote wider industry awareness of the benefits of advanced horticultural techniques/methods.

Further information from the programme co-ordinator.
E-mail:
david.cole@defra.gsi.gov.uk

LINK collaborative research

HortLink

defra
Department for Environment Food and Rural Affairs

Project details
Mechanical weeding for sustainable salad and brassica production in a zero or limited herbicide environment

Reference number
HL0173

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Government sponsor
Defra

Proof of official project leaflet