Project title	Outdoor Salads consultancy – Investigating potential for engineering solutions for outdoor crop protection
Project number	FV 253
Project leader	Professor Chris Pearson
Report	Final report 2004
Previous reports	None
Project coordinator	David Barney Geest Plc Midgate House Midgate Peterborough PE1 1TN
Date project commenced	1 January 2004
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Key words	salad, outdoor crop, crop protection

GROWER SUMMARY

Growers of Outdoor Salad crops are increasingly concerned at their limited ability to control crop weeds, pests and diseases. Their concern arises as a result of three factors:

a) Restrictions limiting the use and efficacy of chemical crop protection products.
b) An accepted desire to manage crops in such a way that environmental impact is minimised.
c) Ever increasing quality expectation from consumers and the retail trade – particularly with respect to 'Ready-to-eat' products.

Current crop protection techniques rely largely on the application of chemical controls. Most current R&D work has concentrated on optimising these chemical controls and, where legislation has threatened the availability of crop protection products, protecting approvals. It was believed that there may be mechanical / engineering solutions to many of the current problems encountered by Salad growers. Before any project work is commissioned, it was suggested that some form of investigation be carried out to identify areas where engineering can help – and provide a basis for the prioritisation of (scarce) research funding in the future.

This contract was set up to carry out such an investigation ready for discussion at the Salads R&D meeting scheduled for October 2004.

Following an introduction to the Salads R&D committee in January 2004, G's Marketing, Intercrop, Langmead Farms and Huntapac were visited during February and March 2004, to learn about individual work practices growing outdoor salads and concerns about the degree and type of pest infestation, including weeds each experienced. During each visit, ideas were discussed where advances in engineering and sensor technology etc might be relevant. Overall, for the outdoor salad crop, there were 4 customer/retailer complaints of contaminants per 100,000 units. 60% are due to insects, 20% weeds, stones etc and the remaining 20% due to discoloured leaves and other quality defects. The actual number would more likely be 10 times this figure, given that only 10% of customers encountering problems actually complain.

The discussion with the four leading growers highlighted and subjectively ranked the pests they had to deal with into two groups. Top priority was a group containing caterpillars, slugs, aphids, and casual intruders like ladybirds, beetles and grasshoppers etc. Second priority was a group containing thrips, flea beetle and cut worm.
Ideas for potential engineering solutions suggested by this brief study were therefore focussed on dealing with insect contaminants, but opportunities to tackle the other problems like dealing with weeds etc were not ruled out.

Follow-on visits were agreed to SRI, HRI, the Wolfson Institute-University of Greenwich and SAC to discuss ideas concerning how pest infestation might be avoided, how it might be limited during the salad growth period or removed during the harvesting operation and prior to dispatch to the retailer or processor. Telephone

discussions took place concerning applications of ultrasonics and sonics with key researchers at University of Warwick, fluidised bed opportunities at University of Birmingham and advances in microwave and RF technology researched by the Power Faraday, led by the Rutherford Laboratory.
These discussions resulted in an invitation to attend an ideas generation workshop to discuss project opportunities, hosted by HDC, and held on May 25th 2004 in London, attended by the participating growers.

Four specific ideas for research projects were developed by the delegates, and a further 3 ideas generated on related opportunities to improve productivity outside the brief of this particular study. Emphasis was placed on improving non-pesticide options for soil sterilisation, since growers consider this provides a priority opportunity to prevent weed and pest infestation at the outset. Further, some of the ideas developed could be adapted to other crops, so making the commercial case for exploitation stronger, and less of an outdoor salads niche.

They are:

1. Feasibility LINK project for optimal soil sterilisation using pulsed microwaves and an efficient soil handling system built into an existing bed-making machine.
2. Levy-funded investigatory study on “mechanical” removal and collection of pests during growth period or immediately prior to harvest.
3. Levy-funded investigatory study on detection of insect contaminants and removal in bagged whole head lettuce on harvester rigs or prior to vacuum cooling.
4. LINK project to remove insect contaminants on baby-leaf harvesters using latest air classification techniques.

Additional ideas are:

1. Levy-funded investigatory study to improve baby-leaf harvester cutter performance using sonification.
2. Levy-funded desk study to explore mechanisation opportunities for whole head harvesting as a result of recently completed LINK “Caulicut” project.
3. Levy-funded desk study to investigate possibilities of limiting crop infestation during the growth period through the use of sonic pegs.

The ideas for project proposals need to be developed further by HDC and the interested academics, helped by their nominated grower mentors, so that they can be discussed at the next Salads R&D Committee in October 2004. Additional discussions may be necessary with relevant specialists who could not attend the workshop or with those who could help develop ideas and alternatives.

SCIENCE SECTION

Background

Growers of Outdoor Salad crops are increasingly concerned at their limited ability to control crop weeds, pests and diseases. Their concern arises as a result of three factors:

a) Restrictions limiting the use and efficacy of chemical crop protection products.
b) An accepted desire to manage crops in such a way that environmental impact is minimised.
c) Ever increasing quality expectation from consumers and the retail trade – particularly with respect to ‘Ready-to-eat’ products.

The crops included in the ‘Outdoor Salad’ sector are invariably classed as ‘minor crops’ and, as such attract little investment from crop chemical manufacturers. In addition, review within Europe of pesticide legislation and approval is resulting in the removal of many, current crop protection products.

As a result, growers have to resort to more frequent applications of fewer products – or suffer the consequences of reduced control.

The ‘Specific Off-Label Approval’ system (SOLA) allows UK growers to maintain some pesticide approvals. However, this process is costly (with growers having to fund the collection of residue data) and limited, ultimately, by the availability of appropriate chemistry.

In the UK, Salads are grown in largely arable areas. Increasingly, the crops surrounding Salads are produced in ways that actively encourage bio-diversity. For Salad crops destined for minimal or no further processing, the additional pest pressure created by more benign husbandry systems is challenging (already weakened) crop protection techniques.

Salad consumption in the UK continues to grow. Increasingly, this growth occurs in ‘prepared salads’ – mirroring the trend towards convenience seen in other food sectors.
By definition, ‘prepared salads’ are a ‘ready-to-eat’ food and the consumer (quite rightly) has high quality expectations of this type of product. As a result of the challenges to crop protection systems, the ability of manufacturers to meet the expectations of the consumer is limited. This limitation is most often seen in the form of contaminant or quality complaints.

If the UK follows USA trends, the presence of contaminants in ‘prepared salad’ products carries a threat of litigation.

Current crop protection techniques rely largely on the application of chemical controls. Most current R&D work has concentrated on optimising these chemical controls and, where legislation has threatened the availability of crop protection products, protecting approvals.

Little work has, in the past, been applied to the development of alternatives to chemical crop protection - other than that specifically targeted at Organic production.

It is assumed that the availability of chemical controls will continue to decline. This will be as a result of environmental pressure, legislative review, the build up of pest and disease resistance and the lack of new chemistry aimed at Salad crops.

As a result, the Salads Industry needs to review its strategic approach to crop protection and focus on the development of alternatives to chemical control.

It is believed that there may be mechanical / engineering solutions to many of the current problems encountered by Salad growers.

Before any project work is commissioned, it is suggested that some form of investigation be carried out to identify areas where engineering can help – and provide a basis for the prioritisation of (scarce) research funding in the future. This contract was set up to carry out such an investigation ready for discussion at the Salads R&D meeting scheduled for October 2004.

Objectives and scope of investigation:

1. To rank key perceived problems, and focus on issues with the greatest commercial potential identified by growers.
2. To briefly review the latest understanding of how the crop grows, the metabolism of common pests and the chemical and physical means they attach themselves to leaves etc.
3. To suggest how relevant advances in engineering science and technology might provide novel solutions to the key commercially sensitive problems identified earlier.
4. To identify a shortlist of experienced researchers in engineering science and technology with ideas and interests likely to result in viable projects which can be progressed through LINK and DEFRA etc.
5. With this background, a one-day workshop will be organized where researchers will be asked to discuss options from their respective technical backgrounds to tackle the prioritized grower problems. The workshop will be attended by 3 leading growers, 3 or 4 researchers and, if useful, equipment suppliers or technology specialists familiar with LINK e.g. INBIS.

Work carried out:

Following an introduction to the Salads R&D committee in January 2004, G's Marketing, Intercrop, Langmead Farms and Huntapac were visited during February and March 2004, to learn about individual work practices growing outdoor salads and concerns about the degree and type of pest infestation, including weeds each experienced. During each visit, ideas were discussed where advances in process engineering, sensor technology etc might be relevant, and notes written and agreed as a record of each visit. These are all attached to this report as appendix 1.

A review meeting was held with Emma Garrod and David Barney, where grower concerns and priorities were discussed, and follow-on visits agreed to SRI, HRI, the Wolfson Institute-University of Greenwich and SAC to discuss ideas concerning how pest infestation might be avoided, how it might be limited during the salad growth period or removed during the harvesting operation and prior to despatch to the retailer or processor. The notes from this meeting are attached as appendix 2.

Each follow-on visit built on the concerns and preferences expressed by the growers, and resulted in an invitation to attend an ideas generation workshop discussing project opportunities, hosted by HDC, held on May 25th 2004 in London, and attended by the participating growers. Agreed visit notes are attached as appendix 3.

In addition, telephone discussions took place concerning applications of ultrasonics and sonics with key researchers at University of Warwick, fluidised bed opportunities at University of Birmingham and advances in microwave and RF technology researched by the Power Faraday, led by the Rutherford Laboratory.

Invitations to the workshop were made following these discussions as a result of ideas etc generated, and a further invitation made to INBIS, a leading engineering consultancy, recently involved with DEFRA sponsored Advanced Food Manufacturing LINK projects, both as partners and as consultants helping DEFRA to scope opportunities with leading UK retailers and food manufacturers.

The final workshop held in London on May 25th aimed to produce a list of project opportunities which could be developed further for consideration by HDC Salads R&D for support through levy or LINK funding as part of their research portfolio. It was attended by three of the participating growers and the interested researchers, notes of which are attached as appendix 4.

Briefing notes for Workshop

The following briefing notes were used as a scene setter for ideas generation and discussion, and are a reasonable summary of the outcome of discussions with growers and specialists as a result of the farm visits etc.

- Overall, for the outdoor salad crop, there were 4 customer/retailer complaints of contaminants per 100,000 units. 60% are due to insects, 20% weeds, stones etc and the remaining 20% due to discoloured leaves and other quality defects. The actual number would more likely be 10 times this figure, given that only 10% of customers encountering problems actually complain. Ideas for potential engineering solutions suggested by this brief study are therefore focussed on dealing with insect contaminants, but opportunities to tackle the other problems like dealing with weeds etc are not ruled out.

The discussion with the four leading growers, G's, Intercrop, Langmead Farms and Huntapac had highlighted and subjectively ranked the pests they had to deal with into two groups. Top priority was a group containing caterpillars, slugs, aphids, and casual intruders like ladybirds, beetles and grasshoppers etc. Second priority was a group containing thrips, flea beetle and cut worm.

- Flying insects attach themselves to leaves by means of a combination of hooks and/or sticky pads on their feet. They can be attracted by smell or colour, and seem to be able to distinguish different growth stages of plants to optimise when eggs should be laid or young deposited. Caterpillars use a similar means to cling on to leaves. It is not clear how they each might react or be disturbed by pulses of ultrasound, RF or microwave radiation.

- One method of studying the insect population of plants is to spread a sheet underneath the infested plant, and strike the foliage to dislodge pests which are duly collected on the sheet. It may be possible to dislodge pests from the salad crop in a similar way with an air blast, mechanical shock through the soil or perhaps even an airborne ultrasonic or electromagnetic pulse which does not harm the lettuce.

  Plants which are subject to insect or caterpillar damage emit an odour which possibly can be detected by a suitable biosensor system.

Briefly, the following ideas have been suggested to minimise crop contaminants through the growth cycle of lettuces, both whole head or baby-leaf:

Prevention:

Rapid soil sterilisation combined with bed-making machine e.g. automated soil pick-up fluidised bed system using air/steam, RF or microwave or in combination.
Deterrents e.g. ultrasound or electrical or EM radiation
Sacrificial side crop or device using controlled release attractants on a suitable acceptable substrate.

Limitation during the growth period:

For sacrificial side crops or devices, given the current status of knowledge and technologies currently available, research projects are unlikely to be successful within the short time frame over which we should be seeking grower and levy funding. What was needed was the means of limiting colonisation by frequently disturbing the population of the pest concerned, thereby keeping the infection at low level.

Removal prior to harvesting:

Ultrasound or electrical stimulus for pest detachment assisted by strong air aspiration ahead of harvester. As stated earlier, this would require some initial research to see how the pests concerned could be disturbed sufficiently to detach themselves and vacate the lettuce, or even killed in situ without affecting the quality of the leaf.

Detection and removal during harvest and processing:

Image analysis and/or suitable biosensor alerting cutting crew/packer to potential contamination, removal by whole head rejection manually or suitable auto-eject on internal conveyor.
Image analysis and/or biosensor fitted to baby-leaf harvester removal via suitable auto-eject on belt conveyors.
Debris/insects removed by spouted fluidised bed and air classifier fitted to lift belt on baby-leaf harvester.

Weed control

Weeds in whole-head crops present a problem in terms of the nutrients they use, the pests they attract and harbour, and the shade they provide for the maturing crop.

The development of a smart self-propelled hoe using machine vision and perhaps water jet or a laser cutting system to recognise and remove weeds would be of interest to growers of salads and other crops. The machine should be small enough to work within a bed, and intelligent enough to leave the crop undamaged, removing cut weeds with a suitable aspiration and collection system. It may be possible to extend this concept to include an air pulse, mechanical shock, ultrasound or RF/microwave which disturbs casual intruders and other pests sufficiently for them to vacate the lettuce and be collected along with the cut weeds.

Workshop outcome - Ideas for research project proposals

Four specific ideas for research projects were developed by the delegates, and a further 3 ideas generated on related opportunities to improve productivity outside the brief of this particular study. Emphasis was placed on improving non-pesticide options for soil sterilisation, since growers consider this provides a priority opportunity to prevent weed and pest infestation at the outset. Further, some of the ideas developed could be adapted to other crops, so making the commercial case for exploitation stronger, and less of an outdoor salads niche. The ideas are listed below, with more details listed in appendix 4.

1. Feasibility LINK project for optimal soil sterilisation using pulsed microwaves and an efficient soil handling system built into an existing bed-making machine.
2. Levy-funded investigatory study on “mechanical” removal and collection of pests during growth period or immediately prior to harvest.

3. Levy-funded investigatory study on detection of insect contaminants and removal in bagged whole head lettuce on harvester rigs or prior to vacuum cooling.
4. LINK project to remove insect contaminants on baby-leaf harvesters using latest air classification techniques.

Additional ideas were:

1. Levy-funded investigatory study to improve baby-leaf harvester cutter performance using sonification.
2. Levy-funded desk study to explore mechanisation opportunities for whole head harvesting as a result of recently completed LINK "Caulicut" project.
3. Levy-funded desk study to investigate possibilities of limiting crop infestation during the growth period through the use of sonic pegs.

Next Steps:

The ideas for project proposals need to be developed further by HDC and the interested academics, helped by their nominated grower mentors, so that they can be discussed at the next Salads R&D Committee in October 2004. Additional discussions may be necessary with relevant specialists who could not attend the workshop or those who could help develop ideas and alternatives.

Appendix 1: Grower visit notes

Notes of introductory meeting with G's Marketing Ltd, Soham, 10th Feb 2004

Present:	Chris Foulds	G's Marketing Ltd
	David Norman	Fresh Produce Consultancy
	Chris Pearson	HDC Consultant

Objective of meeting:

The main objective of these introductory meetings with leading growers is to gain an overview of the problems concerned with outdoor crop protection due to the various pest infestations etc, rank their relative commercial importance from the growers' perspective, and identify where engineering solutions might be beneficial.

Main points:

1. Growing regime

   Lettuce seedlings are raised in peat blocks from seed over 3-4 weeks and delivered in carriers to automated planters, some designed and built by G's. The field is ploughed, harrowed, and where necessary dressed with fertiliser, perhaps with added slug pellets when necessary prior to planting.

   There is a sophisticated pre-planned planting programme designed to bring the crop to harvest to match a projected sales forecast, and crops are frequently inspected by a crop manager and an assigned agronomist. Depending on crop progress, a harvest date is predicted and finalised to match confirmed demand and quality criteria. Iceberg lettuce takes ~ 6 weeks on average to reach maturity after planting, whereas Little Gem takes 4 to 5 weeks.

   Boom irrigation is used as and when necessary.

2. Harvesting

   On-field packaging and despatch – naked iceberg, cos et al

   A mechanised system is used where a crew of 25 perform the operation from cutting the crop to palletising and loading on to a trailer shuttling to a retailer's distribution centre truck field-side. 10 are employed as cutters, who cut and inspect the crop, remove unacceptable foliage, and check for pest damage/presence. They bag the product and pass it via a take-off conveyer to a colleague, who twists and seals each bag and loads it into a customer crate. The rate of working is in the region of 4 to 6 heads per minute, harvesting across typically 6 beds/12m.

   On-field packaging and despatch – naked gem

   This product is cut, de-leafed and checked for pest damage in a similar manner, but transferred into a cup belt take-off conveyor to be flow-wrapped on board the harvester, whence it is transferred to customer crates for palletising etc. There is an additional quality check at the point of loading the flow-wrapper.

Harvesting and processing of prepared products

Crop destined for use as prepared salads are harvested from the field in the same way, but inspected and transferred to crates and palletised at the field side. On arrival at the preparation plant, each load is inspected by QC (2% sampling rate) and stored in a chill store (2° C to 5°C) for between 24 to 48 hours, awaiting final preparation.

The crop is then transferred into a high care operation, where each lettuce is cut in half, cored and fed into a shredding machine. This in turn discharges onto a belt into a washer (or washers), equipped with an insect trap and then transferred by belt conveyor to be packed into FFS bags using a combinatory weigher or similar system. The washers are typically 3x3x3m, contains 6 m^3 of air agitated water, with a product throughput of 3 tonne/hr per line. Typical residence time is 90 seconds.

3. Pests

Crop managers will always inspect the crop frequently for damage/infection, and arrange appropriate treatment pre-harvest if necessary. The harvesting crew are alerted to particular infections, and check the crop as they handle it accordingly.

The pests are highly seasonal. Aphids can be checked by dressed seed with an approved pesticide. Caterpillars are prevalent from typically the silver-y moth, which lays eggs on the underside of leaves, and the caterpillars hatch and crawl inside the lettuce, making damage detection/evaluation difficult. Slugs are not perceived to be a real problem, and infection can be controlled by the use of pellets etc.

There are significant problems from “casual intruders” e.g. earwigs, ladybirds, beetles, flies and sometimes locusts, especially for lettuces destined for prepared salads, since they have proved difficult to detect and remove both in the field and factory.

4. Inspection and removal of pests

Naked products are inspected by the harvesting crew, and also washed prior to consumption, but complaints still occur. Prepared products are much more vulnerable. The wash tanks, equipped with an internal filter system, are effective at removing aphids. Caterpillars stick to leaves and often survive the shredding process, and are not removed effectively by the wash tank filters currently installed. However, increased vigilance loading the shredder by the production crew can reduce complaint levels significantly, triggered by field inspection prior to harvesting to alert crews and processors of any infection.

The real problem is the casual intruder, since these are “unexpected” and difficult to remove by the current design of the washer filter system.

5. Complaint levels

Typically, complaint levels due to insect damage etc are:

Iceberg	0.5 per 100,000 units
Cos	1 to 1.5 per 100,000 units
*Babyleaf	2.5 per 100,000 units

*Babyleaf is a crop which is sown from seed directly by drill, so has a much higher crop density. It is harvested by cutter bar/belt knife equipped machine, run 5 to 15 cm above ground level.

6. Ranking, preferences etc.

G’s consider the detection and removal of casual intruders to be the #1 commercial priority, with prepared salads being the lead product category. If annual complaints could be reduced from 100 to 10, then the benefit could be of the order of £0.5M per annum.

From an engineering viewpoint, there might be a possibility of developing an air-based separation system at the shredder output, prior to transfer to the wash tank belts, given recent developments in air handling systems and associated classifiers made possible by new design methodology based on CFD and sophisticated nozzle arrays, with smart control systems. It might also be possible to upgrade or devise new filter systems in the wash tanks using a similar approach. Capital costs for such a system around £100k were considered acceptable by G’s, if complaint levels could be reduced to 10 per annum or less.

Initial additional ideas ranged from disturbing pests by suitable combinations of RF, microwave or ultrasound just ahead of the harvester, and devising suitable biosensors for the crew to use to detect pest presence. Both require more insight into the biology, modus operandi of attachment and metabolic systems of individual pests before such engineering opportunities can be postulated and checked for feasibility by lead researchers etc.

7. Weeds

The possibility of removing weeds mechanically when they have grown higher than the crop was discussed. The benefits would be yield improvements since weeds like fat hen deprive the crop of nutrients and sunlight, and require extra labour to remove them. G’s suggested an array of parallel pinch belt mechanisms to trap the stems and pull the weeds, linked to a suitable trash removal system to prevent crop contamination. Another idea was to use a motor scythe attachment to a sprayer, for example, with accurate height control and powerful aspiration to remove debris and convey to a suitable collecting box. The latest CFD techniques might be useful to check the feasibility of various designs to ensure the crop is not damaged, and just the weeds are removed without entraining soil etc.

Notes of introductory meeting with Intercrop, Betteshanger, 12th Feb 2004

Present:	Thane Goodrich	Intercrop
	Chris Pearson	HDC Consultant

Objective of meeting:

The main objective of these introductory meetings with leading growers is to gain an overview of the problems concerned with outdoor crop protection due to the various pest infestations etc, rank their relative commercial importance from the growers' perspective, and identify where engineering solutions might be beneficial.

Main points:

Intercrop's operations are concentrated on field-based salad growing activities, and do not involve any high care prepared salad, although lettuce is supplied as a raw material for these products to Geest.

1. Baby-leaf crops – growing regime

   These crops are grown in raised beds 2m wide (growing width 1.6m to allow room to anchor covers with soil). The beds are steam or chemically sterilized to limit weed infestation and to reduce soil borne diseases. The steam system treats 3 beds in parallel using 2m x 2.5m pads, injecting to 8cm depth and judged complete when a soil temperature sensor reads 80°C, which takes 4 to 6 minutes. Chemical decontamination uses methane sodium, and the bed is immediately covered, the seed bed being exposed prior to drilling.

   A specially designed seed drill has been developed to plant 1000 to 1200 seeds per linear metre of each bed, arranged in 18 to 22 lines at an average depth of 4 to 5 mm. Boom irrigation is used during the growing period, but some beds have solid set irrigation pipes and sprinklers laid in the tractor row, spaced 10 to 12 metres apart.

   Crop covers of various types are used to provide the correct microclimate, as well as providing some protection from pests, weather, etc. Ventilated polythene sheet is used in the spring to increase ground temperature for early crops, and removed a day or two before harvest. It is laid semi-automatically, using the soil at the edge of each bed as an anchor and "seal". Subsequent crops in late spring/early summer use non-woven fleece, because this gives better airflow, and installed and removed in the same way as the polythene sheet. Summer to autumn crops use a mesh cover, anchored by bags every 5 metres, mesh pitch being typically 0.8 to 0.5mm, but trials with 0.3mm mesh could offer better pest proofing.

   Each site has an assigned crop manager and a crop walker/agronomist to inspect the plants for pest damage or disease several times per week, and they update their crop growth mathematical models to predict yields and optimal harvest dates. Sticky traps are used to catch insects etc, and the crop manager and walker take a view on the risk of consequential contamination, sending contents of the traps to an entomologist weekly so species can be identified, and a sound prediction made on the likely contamination pattern.

The crop growing period from sowing to harvest typically ranges from 30 to 60 days.

2. Baby-leaf crops – harvesting regime

A specially designed mechanized harvester straddles the bed, cutting the crop and transporting the leaves via inclined belt conveyor to a vibrating mesh table to remove small leaf material, insects and caterpillars etc. The crop is then manually packed into returnable boxes (2 to 3 kg), and vacuum cooled prior to shipment to Geest during the next 24 to 48 hours. The machine is equipped with a vacuum lift system which precedes the belt knife cutter bar to remove debris and insects.

3. Planted crops – growing regime

As with Baby-leaf crops, a crop manager and associated crop walker supervise the crop, checking several times per week for pest and quality problems, and predicting the best time for harvest etc.

Intercrop contracts a nursery man to assemble and deliver germinated seeds in 4cm square peat blocks. These are put under polythene tunnels to grow them into seedlings ready for planting.

They are then mechanically planted into non-sterilised beds, the first 5 batches being covered with fleece to help produce a good microclimate. Subsequent batches are left uncovered for the growing period. Boom irrigation is used throughout the season as required. The growing period ranges from 4 to 8 weeks.

4. Planted crops – harvesting regime

A tractor, equipped with "wing" platforms carry a stock of returnable boxes, covers 5 beds (2 for each wing, and 1 behind the tractor). The crew checks and bags each lettuce after cutting, and is warned to look out for particular pest damage by the crop manager. The boxes are then vacuum cooled, target 8°C within 4 hours of cutting, and shipped to Geest within 24 to 48 hours.

5. Pests

A comprehensive survey has been carried out during recent growing seasons, covering contaminant priorities, crop risk, infection frequency and efficacy of current controls. The following ranking of the relative importance of pest type per crop was given:

Continental lettuce

#1 Caterpillar (e.g. silver-y moth)
#2 Slugs (eggs laid in soil, slug pellets can be used)
#3 Birds (Rooks and pigeons)
#4 Rabbits (can be fenced out)
#5 Thrips (thunder bugs)
#6 Aphids
#7 Cut worm (moth larvae from turnip moth)

Baby-leaf lettuce

#1 Caterpillar
#2 Slugs
#3 Birds
#4 Aphids
#5 Thrips

6. Potential engineering-based opportunities

Initial ideas ranged from disturbing pests by suitable combinations of RF, microwave or ultrasound just ahead of the harvester, and devising suitable biosensors for the crew to use to detect pest presence. Both require more insight into the biology, modus operandi of attachment and metabolic systems of individual pests before such engineering opportunities can be postulated and checked for feasibility by lead researchers etc. It could be a challenge to devise a bird scarer which emulates a peregrine falcon in appearance or odour etc!

Weeds

Intercrop believe that current research undertaken by SRI on precision hoeing etc cover engineering opportunities here.

Notes of introductory meeting with Langmead Farm, Fishbourne, 24th Feb 2004

Present: Shaun Clarkson	Senior Agronomist
Sam Pochecha	Agronomist (trainee)
David Moore	Farm Director

Objective of meeting:

The main objective of these introductory meetings with leading growers is to gain an overview of the problems concerned with outdoor crop protection due to the various pest infestations etc, rank their relative commercial importance from the growers' perspective, and identify where engineering solutions might be beneficial.

Main points:

Langmead Farm operations are concentrated on field based salad growing, and do not involve any high care prepared salad operations, although lettuce is supplied to Nature's Way Foods, an allied business co-packing for retailers e.g. Tesco.

Over the last few years, Langmead have concentrated on salad and spinach crops, extending their operations to southern Spain. They aim to be premier suppliers of salads, and have developed their own field machinery, for example, to retain a quality and margin advantage over their competitors. They use their Spanish operation where appropriate as an R and D test bed for UK crops and vice versa. They therefore have a strong development culture, focused on growing quality crops on their particular soil and weather conditions in the UK and Spain.

A comprehensive spread-sheet based analysis of the source and cause of lost product/reduced yield is undertaken on a continuous basis. It highlights and guides remedial action to improve yields, covering all aspects of the agronomy concerned, including disease, pests and weeds, and provides essential data on seasonal, soil, pest and weed infestation variations, leading to a structured discussion on performance improvement throughout the company.

1. Whole head crops – growing regime

   The crop is grown on raised beds 1.9m to 2.0m wide. Depending on local conditions, the field is ploughed and harrowed at the end of the season, and a 3 plot wide bed-forming machine put through to over-winter. Prior to planting, the bed forming machine is used again, this time equipped with a herbicide spray and slug pellet dispenser.

   The seedlings are delivered by the contracted plant raiser in 42mm peat blocks, packed in trays. Each tray has been checked prior to delivery for pests and disease. The trays are loaded on to an automated planter, which dispenses 70,000 iceberg lettuces or 150,000 little gem lettuces per hectare, in 4 rows per bed, plant spacing according to variety e.g. 25cm pitch for icebergs. The machine is designed to sow 3 beds at a time.

The early planting in March is covered with fleece 12 beds wide, anchored with soil. Subsequent plantings are open to the weather, and a hoe put through after 3 to 4 weeks to improve aeration, add a top dressing, and dispense slug pellets where necessary.

The crop is checked frequently each week, and an insect trap sent to an entomologist at Central Science Labs for aphid analysis. Sticky traps and moth traps are also used.

The crop takes 80 days to mature in the spring and autumn, reducing to 40 days in high summer. Boom irrigation is used as when necessary in the UK, but soil level pipeline irrigation is used in Spain.

2. Whole head crops – harvesting

The harvesting crew work across 7 beds, each cutter harvesting on average 6 heads per minute. They check each head for pest damage, strip the outer leaves, and insert the lettuce into a polythene bag. The bags are passed to packers, who inspect the lettuce, sellotape the bag and place it into a crate. The full crates are pushed down a chute towards the rear of the rig, and loaded onto pallets in a shuttle trailer. The product is then transported to the chill store via a vacuum cooler (20 min residence time), and held for dispatch at ~5°C from 2 to 48 hours, depending on demand.

3. Baby leaf crops – growing regime

The beds are prepared in a similar way as for whole head crops over winter, and prior to planting. A specialized seed drill is used to plant dressed seeds to reach a density of 500 per sq.m, arranged in two linear banks of 12 lines across the 1.9 m bed, at a depth of 25mm. On high risk baby leaf a Thrip 5mm mesh is put over the crop, sealed by ploughing in at the extremities, and removed just prior to harvest, and boom irrigation used as and when necessary.

The crop is checked frequently in a similar way as whole head lettuces, and takes 60 days to mature in the spring, 25 days in mid summer, and 50 days in the autumn.

4. Baby leaf crops – harvesting

A custom-built harvester uses a belt knife to cut the crop, elevating the cut leaves up an inclined belt with agitation and air aspiration to remove debris, insects etc, and then onto a belt conveyor where they are packed into crates, and subsequently palletized onto a trailer following behind. The product is then transferred to a chill store via a vacuum cooler and held for shipment in the same way as whole head crops.

Yield loss from the cutting process was briefly discussed, and perhaps advances in cutting technology from other industries, including new materials of construction, coatings and alternatives e.g. steer-able water jet might provide further R&D opportunities.

5. Pests

The following ranking of pest problems was suggested, based on the historical spread sheet crop loss analysis and latest opinion:

Whole head lettuce
#1 Slugs, aphids and caterpillars
#2 Pigeons
#3 Casual intruders, flies, ladybirds etc

Prepared salads – whole head
#1 Slugs, aphids and caterpillars
#2 Pigeons
#3 Casual intruders, flies, ladybirds etc

Baby leaf (also applies to spinach)
#1 Casual intruders flies, ladybirds, locusts, grasshoppers, crickets (and debris)
#2 Flea beetle (particularly under dry conditions; soil born eggs and from adjacent crops e.g. oilseed rape
#3 Caterpillars, particularly from Silver-Y moths

Engineering-based ideas to tackle these problems ranged from disturbing pests by suitable combinations of RF, microwave or ultrasound just ahead of the harvester, and devising suitable biosensors for the crew to use to detect pest presence. Both require more insight into the biology, modus operandi of attachment and metabolic systems of individual pests before such engineering opportunities can be postulated and checked for feasibility by lead researchers etc.

Given advances in CFD to model turbulent airflow etc, it may be possible to devise a spouted fluidised bed classifier to separate a proportion of entrained pests as an addition to the baby leaf harvester. Machines typically cost £180k to£200k, and an additional capital cost of up to £50k for such a system seems acceptable.

6. Weeds

Weeds in whole head crops can be controlled by hoeing, but in baby leaf crops, including spinach, present an additional problem because of the increased crop density and contamination during harvest. The principal weed types are groundsel, mayweed and dandy-lion.

There have been developments to automate hoeing as a part of "precision agriculture" using cheese wire technology, for example. There might be opportunities to develop appropriate separation technology to fit to baby leaf harvesters to deal with weeds and pests at the same time.

7. Automation opportunities

Langmead suggested that labour costs and crewing problems, particularly when harvesting whole head crops, present an engineering development opportunity if the cutting, inspection and bagging operations could be mechanized.

Notes of introductory meeting with Huntapac Produce, Tarleton 26th Feb 2004

Present:	Andrew Sutton	Field Manager
	Chris Pearson	HDC Consultant

Objective of meeting:

The main objective of these introductory meetings with leading growers is to gain an overview of the problems concerned with outdoor crop protection due to the various pest infestations etc, rank their relative commercial importance from the growers' perspective, and identify where engineering solutions might be beneficial.

Main points:

Huntapac Produce concentrates on growing whole head lettuces, mainly iceberg and little gem. Their main customer is Sainsbury, and, consequently, quality standards are set by them.

1. Growing regime

The crop is grown on rented as well as owned land. A soil sample is taken to specify fertiliser requirements etc. The land is ploughed, and power harrowed and then ridges formed to mark out beds, arranged to make husbandry easy in terms of spraying efficiency and machinery turning circles, avoiding obstacles e.g. telegraph poles etc. A bed maker forms a 1.8m (72") wide growing area, a single row machine used for the early crops which require fleece covering, a triple row machine used afterwards.

Huntapac do not sterilise beds prior to planting at this time. Seedlings are raised in 42mm peat cubes, packed 140 to a tray, and mechanically planted in the beds. For iceberg, 4 rows are planted in each bed, separated 14" centre-to-centre, and at a spacing of 12". The plant density for little gem is greater, 4 rows at the same pitch, but with a 9" spacing. The machine plants is designed to plant a single bed at a time, and manufactured in France by Regero.

The early planting is covered with fleece and polythene 7 beds wide, anchored by bags of soil around the edge, and placed at 9ft intervals. In early April, alternate rows are sheet covered, to ensure a controlled transient growing regime from covered to fully exposed to the weather.

The field manager and agronomist inspect the crop several times a week, and check for weeds, pest infection etc. Boom irrigation, herbicide sprays and slug pellets are used as and when necessary. The crop takes 84 days to mature in the spring, 42 days in high summer and 56 days in the autumn.

2. Harvesting

The harvesting rig is designed to cover 5 beds at a time, even 7 when necessary, machines being single boom or double boom construction. 2 to 3 cutters are assigned to a bed, and harvest at ~6 heads per minute or faster. They check the crop for quality and place the head into a cupped conveyor belt. The belt system is arranged in line with the cutters, and turns through a right angle to present the crop to a manual bagging operation, crewed by up to 12 people, depending on demand. The baggers remove brown leaves, size grade for acceptance to Sainsbury or alternative retailers, load into a polythene bag, reverse and sellotape, and finally place on to a central discharge belt leading to a turntable at the rear of the rig. 2 experienced packers do a further quality check, confirm size etc, and pack into boxes, discharged through a roller table to a shuttle trailer. The trailer takes the product to the packhouse, where it is vacuum cooled, and held on pallets in a chill store at 5°C, awaiting despatch.

3. Pests

The following ranking of pests problems was given:
#1 Mildew – due in the main to the local damp conditions
#2 Aphids – particularly if chemical sprays are no longer acceptable
#3 Sclerotinia – again due to damp local conditions
#4 Slugs (particularly in spring), caterpillars (silver-Y and cabbage white)
#5 Pigeons, crows and rabbits

Engineering-based ideas to tackle these problems ranged from disturbing pests by suitable combinations of RF, microwave or ultrasound just ahead of the harvesting crew, and devising suitable biosensors for them to use to detect pest presence. Both require more insight into the biology, modus operandi of attachment and metabolic systems of individual pests before such engineering opportunities can be postulated and checked for feasibility by lead researchers etc.

An additional idea was to improve the performance and effectiveness of soil sterilizers by integrating a sterilisation system into the bed making machine, perhaps picking the soil up and treating it using steam, RF or microwave or a suitable combination of all three to assure uniformity etc before laying the bed ready for planting.

4. Weeds

Weeds present a problem since they not only take nutrients and shade the crop, but also harbour pests e.g. aphids. Weed control is very labour intensive, and mechanised systems would be attractive, provided they were robust, reliable, easy to trouble-shoot and cost effective. A small smart self-propelled hoe system, which could recognise weeds from crop, and deal with them without inflicting damage, would be an attractive development, of use to many other crops besides lettuces.

Appendix 2

Notes of review of grower requirements and priorities, Harpenden, 2nd March 2004

Present:

Emma Garrod	HDC
David Barney	Geest Procurement
Chris Pearson	Consultant

Objective of meeting:

To discuss the outcome of the visits to Growers, ideas for engineering solutions to address problems encountered in crop protection and determine follow-up discussions with selected academics to take ideas further and seek candidates for concluding HDC workshop.

Main points:

1. Discussion of pest priorities and likely commercial impact

   The collated subjective ranking by the growers of the pest problems they encountered were given a crude individual score (rank#1= 10; rank#2= 9 etc). The result was as follows:

#1	caterpillar	48
#2	slugs	45
#3	aphids	43
#4	birds	40
#5	casual intruders	36
#6	rabbits	13
#7	thrips	11
#8	mildew	10
#9	flea beetle	9
#10	cut worm	4

   Clearly, a much more rigorous analysis involving a calculation of the proportion of the crop affected by each pest etc on an average year, and the resulting economic impact might change the order etc, but it was agreed that the top 5 here represented the required focus needed.

   David Barney described an alternative, complementary approach. Overall, for the salad crop, there were 4 customer/retailer complaints of contaminants per 100,000 units. 60% are due to insects, 20% weeds, stones etc and the remaining 20% due to discoloured leaves and other quality defects. The actual number would more likely be 10 times this figure, given that only 10% of customers encountering problems actually complain. It was agreed that solutions should be sought which address the despatched product ex-grower contaminant problems as the priority, leaving other opportunities for grower productivity increases aside at present.

Thus the agreed priority area for engineering solutions to minimise contaminants leaving the grower's premises covers caterpillars, slugs, aphids and casual intruders (beetles, locusts, ladybirds etc). Prevention of bird damage represents a productivity opportunity.

2. Discussion on initial engineering options for pest control and removal

It was agreed that a discussion with HRI's Prof Tatchell on the modus operandi of attraction of these pests, attachment of their eggs, caterpillars etc would provide insight into the viability of ideas for discouragement and/or removal using e.g. ultrasound or RF/microwave etc.

Briefly, the following ideas were discussed:

Prevention:

Rapid soil sterilisation combined with bed-making machine e.g. automated soil pick-up fluidised bed system using air/steam, RF or microwave or in combination.
Deterrents e.g. ultrasound or electrical or EM radiation
Sacrificial side crop or device using controlled release attractants on a suitable acceptable substrate.

Removal prior to harvesting:

Ultrasound or electrical stimulus for pest detachment assisted by strong air aspiration ahead of harvester.

Detection and removal during harvest and processing:

Image analysis and/or suitable biosensor alerting cutting crew/packer to potential contamination, removal by whole head rejection manually or suitable auto-eject on internal conveyor.
Image analysis and/or biosensor fitted to baby-leaf harvester removal via suitable auto-eject on belt conveyors.
Debris/insects removed by spouted fluidised bed and air classifier fitted to lift belt on baby-leaf harvester.

3. Weed control

Weeds in whole-head crops present a problem in terms of the nutrients they use, the pests they attract and harbour, and the shade they provide for the maturing crop.

The following ideas were discussed:

Smart self-propelled hoe using machine vision and perhaps water jet or a laser cutting system. The machine should be small enough to work within a bed, and intelligent enough to leave the crop undamaged.

Aspirated motor scythe which could cut and top mature weeds higher than the lettuce crop, removing the debris, and therefore minimising shading.

Baby leaf crops are more difficult to weed due to crop density, and controlled release seed dressings, coupled with good bed sterilisation may be beneficial here.

This R&D opportunity has been well researched by Nick Tillett at the SRI, and ideas should be developed further through discussion with him.

4. Ideas for further visits to academia and research establishments

It was agreed that visits should be made to the following:

Dr Mike Bradley, Wolfson Institute, Greenwich for leaf-handling technology etc.
Prof Mark Tatchell, HRI for background bioscience of pests etc.
Dr Nick Tillett, SRI for discussion on weed control etc.
Mr David Ross, SAC for a Scottish grower's perspective and academic comment on ideas generated.

Contacts to determine interest/technical advice will be made with:
Prof Peter Fryer, Birmingham University re: spouted beds/air classifiers etc
Prof Jonathan Seville, Birmingham University re: controlled release coatings etc
Prof Tim Mason, Coventry University re: Ultrasound/sonochemistry
Dr Duncan Billson, Warwick University re: air coupled power ultrasonics
RF/Microwave Faraday re: Power RF/Microwave treatment (could be via Loughborough)
Sensor Faraday re: biosensors etc (via SIRA)
Prof Chris Pearce, Technical Director, INBIS for "engineering entrepreneurs" overview and links with advanced robotics etc at Salford and Bath Universities (AMTRI).

5. Productivity aids

Both Intercrop and Langmead were keen to discuss other engineering opportunities outside the specific "contaminant" brief focussing this study, but of interest as a productivity aid for the salad growing industry. The following initial ideas will also be discussed with academic contacts as appropriate:

Semi automated whole head harvester
Optimised cutter system for baby-leaf harvester improving yield (materials of

construction, coatings, water jet etc)
Reliability improvements/remote predictive maintenance/modular machinery and electronics for horticultural equipment
Grow-bag system or hydroponics for whole head to minimise pests/optimise growth and enable automated harvest possibilities
Hydroponics for baby-leaf production
Optimised logistics using AI tools or Bayesian belief networks or real-time mathematical risk analysis e.g. real-time schedulers etc.

6. Final HDC Workshop

Subsequent to the meeting, it was agreed that Emma Garrod would seek a suitable date, and invite the 4 participating growers and the key academics selected on the basis of their interest and ideas from the proposed visits and contacts. At present, Prof Tatchell, and Dr Tillett are essential, and Prof Pearce has declared an interest. In order to ensure a list of viable project ideas as the desired outcome of the workshop, it would be wise to limit attendance to ~12 people.

Appendix 3 – Notes of follow-up meetings with specialists

Notes of introductory meeting with Wolfson Centre for Bulk Solids Handling Technology, 8th March 2004

Present:	Dr Mike Bradley	Manager, Wolfson Centre
	Chris Pearson	Consultant, HDC

Objective of meeting:

- To discuss the opportunities and ideas which arose from the recent Growers' survey concerning potential engineering approaches to improve crop protection and reduce contaminants in harvested products ready for dispatch.

- To confirm interest in attending a one-day workshop with growers and fellow academics to develop ideas and arrive at a list of research project opportunities for the HDC to consider and progress.

Main points:

1. Dr Bradley confirmed that that the expertise the Wolfson had on leaf handling, and design of specialist air conveying systems and separators would be relevant to the ideas generated by the survey with the Growers. He therefore would be interested in taking part in the proposed workshop.

2. The specific areas of interest concerning pest control and removal are:

   Prevention:
   Rapid soil sterilisation combined with bed-making machine e.g. automated soil pick-up fluidised bed system using air/steam, RF or microwave or in combination. The Wolfson have experience in specifying the handling systems and fluidised bed designs to help assure uniform heat treatment of the bulk soil, and a range of techniques to provide the essential design data.

   Removal prior to harvesting:
   Ultrasound or electrical stimulus for pest detachment assisted by strong air aspiration ahead of harvester. The Wolfson could help in the concepts and design of the aspiration and collection systems required.

   Detection and removal during harvest and processing:
   Debris/insects removed by spouted fluidised bed and air classifier fitted to lift belt on baby-leaf harvester. Wolfson experience and design skills again of relevance here.

3. Weed control

   Weeds in whole-head crops present a problem in terms of the nutrients they use, the pests they attract and harbour, and the shade they provide for the maturing crop.

If an in intelligent self propelled hoe was developed, then removal and collection of the cut weeds may be possible using an appropriate aspiration system. A further idea was to use an aspirated motor scythe which could cut and top mature weeds higher than the lettuce crop, removing the debris, and therefore minimising shading. In both cases the Wolfson expertise was relevant.

Notes of introductory meeting with Silsoe Research Institute 9th March 2004

Present: Nick Tillett	Silsoe Research Institute
Chris Pearson	Consultant, HDC

Objective of meeting:

- To discuss the opportunities and ideas which arose from the recent Growers' survey concerning potential engineering approaches to improve crop protection and reduce contaminants in harvested products ready for dispatch.

- To confirm interest in attending a one-day workshop with growers and fellow academics to develop ideas and arrive at a list of research project opportunities for the HDC to consider and progress.

Main points:

Briefly, the following ideas were discussed:

Prevention:
Rapid soil sterilisation combined with bed-making machine e.g. automated soil pick-up fluidised bed system using air/steam, RF or microwave or in combination.

Removal prior to harvesting:

Ultrasound or electrical stimulus for pest detachment assisted by strong air aspiration ahead of harvester.

Detection and removal during harvest and processing:

Image analysis and/or suitable biosensor alerting cutting crew/packer to potential contamination, removal by whole head rejection manually or suitable auto-eject on internal conveyor.
Image analysis and/or biosensor fitted to baby-leaf harvester removal via suitable auto-eject on belt conveyors.
Debris/insects removed by spouted fluidised bed and air classifier fitted to lift belt on baby-leaf harvester.

It was clear that Nick Tillett's expertise in anticipating and tackling the problems of developing and retrofitting horticultural machinery to use alternative/advanced technology would be invaluable at the workshop.

Weed control

Weeds in whole-head crops present a problem in terms of the nutrients they use, the pests they attract and harbour, and the shade they provide for the maturing crop.

Nick Tillet has carried out a great deal of work developing a computer vision guidance system for tractor drawn hoes with Garford Farm Machinery and Robydome Electronics.

The brief discussion with growers emphasised the need to develop a small smart self-propelled hoe using machine vision and perhaps water jet or a laser cutting system as an alternative to a mechanical knife or wire to avoid disturbing the crop. The machine should be small enough to work within a bed. Nick Tillet's experience here would be invaluable at the workshop to take this idea further. Clearly, such a machine could be used for many other crops e.g. carrots and onions, and so might prove an attractive investment for growers and equipment makers to consider.

Notes of introductory meeting with Prof Mark Tatchell 11th March 2004

Present: Prof Mark Tatchell Research Director, Horticultural Research Institute
Chris Pearson Consultant, HDC

Objective of meeting:

- To briefly review how selected pests are attracted to the crop, attach themselves to the leaves, and how they may be disturbed and/or removed during the growing period or prior to harvest by physical, rather than chemical, means.

- To discuss the opportunities and ideas which arose from the recent Growers' survey concerning potential engineering approaches to improve crop protection and reduce contaminants in harvested products ready for dispatch.

- To confirm interest in attending a one-day workshop with growers and fellow academics to develop ideas and arrive at a list of research project opportunities for the HDC to consider and progress.

Main points:

1. Overall, for the outdoor salad crop, there were 4 customer/retailer complaints of contaminants per 100,000 units. 60% are due to insects, 20% weeds, stones etc and the remaining 20% due to discoloured leaves and other quality defects. The actual number would more likely be 10 times this figure, given that only 10% of customers encountering problems actually complain. Ideas for potential engineering solutions suggested by this brief study are therefore focussed on dealing with insect contaminants, but opportunities to tackle the

other problems like dealing with weeds etc are not ruled out.

The discussion with the four leading growers, G's, Intercrop, Langmead Farms and Huntapac had highlighted and subjectively ranked the pests they had to deal with into two groups. Top priority was a group containing caterpillars, slugs, aphids, and casual intruders like ladybirds, beetles and grasshoppers etc. Second priority was a group containing thrips, flea beetle and cut worm.

2. Flying insects attach themselves to leaves by means of a combination of hooks and/or sticky pads on their feet. They can be attracted by smell or colour, and seem to be able to distinguish different growth stages of plants to optimise when eggs should be laid or young deposited. Caterpillars use a similar means to cling on to leaves. It is not clear how they each might react or be disturbed by pulses of ultrasound, RF or microwave radiation.

3. One method of studying the insect population of plants is to spread a sheet underneath the infested plant, and strike the foliage to dislodge pests which are duly collected on the sheet. It may be possible to dislodge pests from the salad crop in a similar way with an air blast, mechanical shock through the soil or perhaps even an airborne ultrasonic or electromagnetic pulse which does not harm the lettuce.

4. Plants which are subject to insect or caterpillar damage emit an odour which possibly can be detected by a suitable biosensor system. Prof John Pickett FRS at Rothamsted Research may have some useful suggestions here.

5. Briefly, the following ideas were discussed:

   Prevention:

   Rapid soil sterilisation combined with bed-making machine e.g. automated soil pick-up fluidised bed system using air/steam, RF or microwave or in combination.
   Deterrents e.g. ultrasound or electrical or EM radiation
   Sacrificial side crop or device using controlled release attractants on a suitable acceptable substrate.

6. *Limitation during the growth period*

   Prof Tatchell remarked that for sacrificial side crops or devices, given the current status of knowledge and technologies currently available, research projects are unlikely to be successful within the short time frame over which we should be seeking grower and levy funding. However, he would not rule out this approach in the longer term (1 to 2 decades). What was needed was the means of limiting colonisation by frequently disturbing the population of the pest concerned, thereby keeping the infection at low level.

Removal prior to harvesting:

Ultrasound or electrical stimulus for pest detachment assisted by strong air aspiration ahead of harvester. As stated earlier, this would require some initial research to see how the pests concerned could be disturbed sufficiently to detach themselves and vacate the lettuce, or even killed in situ without affecting the quality of the leaf.

Detection and removal during harvest and processing:

Image analysis and/or suitable biosensor alerting cutting crew/packer to potential contamination, removal by whole head rejection manually or suitable auto-eject on internal conveyor.
Image analysis and/or biosensor fitted to baby-leaf harvester removal via suitable auto-eject on belt conveyors.
Debris/insects removed by spouted fluidised bed and air classifier fitted to lift belt on baby-leaf harvester.

7. Weed control

Weeds in whole-head crops present a problem in terms of the nutrients they use, the pests they attract and harbour, and the shade they provide for the maturing crop.

The development of a smart self-propelled hoe using machine vision and perhaps water jet or a laser cutting system to recognise and remove weeds would be of interest to growers of salads and other crops. The machine should be small enough to work within a bed, and intelligent enough to leave the crop undamaged, removing cut weeds with a suitable aspiration and collection system. It may be possible to extend this concept to include an air pulse, mechanical shock , ultrasound or RF/microwave which disturbs casual intruders and other pests sufficiently for them to vacate the lettuce and be collected along with the cut weeds.

Notes of introductory meeting with Scottish Agricultural College, Edinburgh
7th April 2004

Present:	David Ross	Crop Systems Department
	Fraser Milne	Crop Systems Department
	Chris Pearson	Consultant, HDC

Objective of meeting:

- To discuss the opportunities and ideas which arose from the recent Growers' survey concerning potential engineering approaches to improve crop protection and reduce contaminants in harvested products ready for dispatch.
- To confirm interest in attending a one-day workshop with growers and fellow academics to develop ideas and arrive at a list of research project opportunities for the HDC to consider and progress.

Main points:

1. SAC has considerable experience in developing multi-spectral imaging to distinguish weeds from crops, and in-line inspection of vegetables e.g. potatoes. Trials had also been carried out on detecting insects behind lettuce leaves, with interesting results. He therefore could contribute to ideas for contaminant detection in growing crops or inspection possibilities during harvest using this approach.

2. David Ross has been involved in LINK sponsored research concerning potato inspection, for example, and is very well aware of the need to define a robust exploitation route when developing instrumentation and control equipment for niche applications like outdoor salad growing. His colleague, Fraser Milne, also emphasized the need to make the technology robust from the outset, and stressed the need to ensure there was adequate attention to design-for-reliability in the transition from proof-of-principle rigs to production prototype, if grower confidence in using the technology was not to be compromised.

3. David Ross suggested that contact should be made with Jim Lewis, an agronomist recently retired from Intercrop, who was the inspiration behind much of the engineering development for salad growing, and who might be a valuable contributor to the workshop. David suggested Jim Lewis was well known to David Barney.

Appendix 4

Notes on Outdoor Salads Workshop NFU Headquarters, London, 25th May 2004
Engineering solutions for outdoor crop protection (Commercial – in confidence)

Present:	Emma Garrod,	HDC
	David Barney,	Geest Procurement
	Chris Foulds,	G's Marketing
	Thane Goodrich,	Intercrop Ltd.
	Andrew Sutton,	Coe House Farms Ltd.
	Prof Mark Tatchell	Consultant
	Dr Nick Tillett	SRI
	David Ross	SAC
	Dr Mike Bradley	Wolfson Centre, Greenwich University
	Prof Nick Christofi	Napier University
	Roy Barton	INBIS
	Prof Chris Pearson	Consultant

Background and objective of Workshop:

This workshop sought to brainstorm ideas for HDC supported projects resulting from discussions on engineering based approaches to reduce outdoor crop contamination by pests. These discussions focussed on grower experience and requirements, with follow-on meetings suggested by HDC with selected scientists and engineers involved in horticultural research, familiar with outdoor salad crops and growing regimes. Additional discussions were held with selected researchers working with other industries outside horticulture in LINK or related research e.g. in food manufacture etc, and interested parties invited to the workshop.

The workshop aimed to produce a list of project opportunities which could be developed further for consideration by HDC Salads R&D for support through levy or LINK funding as part of their research portfolio.

Main points:

1. The workshop started with a brief overview of the general opportunities for engineering solutions for outdoor crop protection from the earlier discussions with growers, scientists and engineers. It focussed discussion and ideas on limiting infestation and removal of the principal contaminants of concern to growers, particularly caterpillars, slugs, aphids and casual intruders, like ladybirds etc. throughout the whole-head and baby-leaf salad growth cycle from bed preparation to harvest and despatch from the grower.

   This overview had been circulated beforehand to help stimulate discussion, and the text is given in the main body of this report.

2. The ensuing discussion and generation of ideas resulted in an initial list of project opportunities, and some general observations. Emphasis was placed on improving non-pesticide options for soil sterilisation, since growers consider this provides a priority opportunity to prevent weed and pest infestation at the

outset. Further, some of the ideas developed equally could be adapted to other crops, so making the commercial case for exploitation stronger, and less of an outdoor salads niche.

List of project ideas for engineering solutions for outdoor crop protection

1. Soil sterilisation

Idea:

1. To improve efficiency and uniformity of heat treatment by using pulsed microwaves to minimise power required on appliance and energy used; bed soil could be loaded with carbon to improve absorption; could be combined with steam to further optimise microwave absorption by optimising soil moisture content.

2. To incorporate an appropriate and efficient soil handling system to assure uniform treatment within an existing bed-making machine, without affecting desired bed soil structure.

3. To determine the benefits of an optimal, uniform heat treatment made possible by pulsed microwave, steam injection or a combination of the two in terms of desired weed kill without affecting subsequent salad yield or quality.

Suggested work-plan and involvement:

- Candidate for 1 year Feasibility LINK leading to full LINK or industrial sponsorship, HDC levy funded
- Academic involvement: Greenwich (Mike Bradley), Powerfaraday (Nick Christofi (Napier) and Steve Bowater (Rutherford Labs))
- Grower mentor: Andrew Sutton, Coe House Farms Ltd.

Benefit:

Labour saving; environmental impact (no chemicals, less fuel/pollution); improved crop yield and quality

2. Infestation limitation during growth and insect removal immediately prior to harvest
Investigatory study on "mechanical" removal and collection of pests

Idea:

1. To study the different effects of a range of mechanical, ultrasonic and sonic shocks to lettuce plants, including air pulses, on insect/pest disturbance leading to a release from the leaf.

2. To investigate the optimal means of collection of disturbed pests without sustaining crop damage or contamination with soil.

3. To generate options to include successful technique on appropriate grower machinery suitable for use during the growing period and immediately prior to harvest.

Suggested work-plan and involvement:

- Levy funded study leading to a LINK or directly sponsored industry project

- Academic involvement: Greenwich (Mike Bradley); SRI (Nick Tillett); Consultant entomologist (Mark Tatchell)
- Grower mentor: David Barney (Geest)

Benefit:

Labour saving; environmental impact of pesticide-free treatment; yield improvement and reduced contaminant risk.

3. Detection of insect contaminants and removal in bagged whole head lettuce
Initial investigatory study on non-invasive inspection through bagged product on harvester rig or immediately prior to vacuum cooling

Idea:

1. To investigate X ray, NIR, pulsed laser, microwave or sonics inspection and related analysis techniques (shape or pattern recognition, attenuation etc) to determine limit of detection of insect contaminants after harvest.

2. To study crop handling options which could dislodge pests to a point where one or more of the above techniques becomes viable.

3. To generate options to include successful technique into a whole-head harvesting rig or handling machinery in pack house prior to vacuum cooler.

Suggested work-plan and involvement:

- Levy funded study leading to a LINK or industry fully sponsored project proposal
- Academic involvement: Greenwich (Mike Bradley); Warwick (Duncan Billson); SAC (David Ross)
- Grower mentor: Chris Foulds (G's) and/or David Norman (Consultant agronomist).

Benefits: reduced contaminant risk

4. Removal of insect contaminants on Baby Leaf Harvester

Idea:

1. Devise and build a proof-of-principle rig to demonstrate the effectiveness of an air classification system which will separate insects and debris from cut baby leaf without damaging the product.

2. Produce a design specification and exploitation plan with Growers and equipment manufacturer to make available viable commercial retrofit attachments for current baby leaf harvesting machinery.

Suggested work-plan and involvement:

- Full Horti-LINK project proposal to be submitted to DEFRA
- Academic involvement: Greenwich (Mike Bradley)
- Industrial involvement: Air classification equipment manufacturer (to be advised by Greenwich)
- Grower involvement: Thane Goodrich (Intercrop)

Benefits: reduced contaminant risk

5. Additional studies suggested during the Workshop discussion

5.1 Initial investigatory study to improve baby-leaf harvester cutter knife performance using sonification. Ultrasonic knife manufacturer will be contacted to carry out a small trial to scope technical challenges and benefits.

Levy funded activity; leading to a follow-on LINK or related proposal if successful.
Lead academic: SAC (David Ross) (could benefit from discussion with Warwick (Duncan Billson)).
Grower involvement: David Barney (Geest)

Benefits: improved yield and post harvest quality

5.2 Initial desk study of whole head mechanisation opportunities – lessons from recently completed LINK "Caulicut" project in terms of crop measurement and handling techniques.

HDC (Emma Garrod) to investigate with SRI (Nick Tillett).

Benefits: labour saving; improved crop quality; potential productivity advantage.

5.3 Limitation of infestation during crop growing period using "sonic" pegs to discourage entry/settling through crop or soil agitation. Initial desk study, levy funded.

SAC (David Ross) and consultant entomologist (Mark Tatchell)
Grower mentor: Andrew Sutton (Coe House Farms Ltd.)

Benefits: labour saving; environmental benefits through pesticide free treatment; yield improvements.

Next steps:

HDC will contact the nominated individuals to develop ideas for projects further for discussion with HortiLINK and for the Salads R&D meeting in October 2004.