Final Report

Evaluation, and demonstration of degradable polyethylene film on Tasmanian processing potato crops

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PT09005

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Media summary

This project was undertaken to examine the potential benefits of using degradable polyethylene films in horticultural crops.

Trials were conducted using degradable film on potato crops in North West Tasmania during the 2009-10 (year one), 2010-11 (year two) and 2011-12 (year three) seasons.

The original project proposal aimed to evaluate potential water savings, nitrogen fertiliser savings and yield benefits with use of the film on early planted potato crops (particularly processing potatoes).

During the project it became apparent that the potential benefit from use of the film may, in fact, be in early harvest and access to early season markets. In Tasmanian processing crops, there are currently no benefits in earlier harvest and for the film to be economic in processing crops, a yield advantage is required.

In year two and, particularly, year three, project focus changed to fresh market potatoes and aimed to examine the advantage of earlier emergence and earlier crop development to access early season markets.

Crop emergence was about one to two weeks earlier with use of the film. Crops examined were planted in August and September and there may be greater benefits with use of films in earlier planted crops.

Trials were conducted on ferrosol soils, and results indicated that there are potential water savings early in the season (1-2 irrigations). Further work may be warranted on different soil types. It is likely that adequate soil moisture at the time of laying film is important.

Further development of this technology will require development of weed management strategies, film laying machinery and degradation of buried film by harvest time. Further evaluation using other potato varieties, in different soil types, and earlier planting times, may also be warranted.

Further consultation to investigate potential for development of the technology in mainland growing districts (e.g. in Victoria and South Australia) may be warranted, as there is a limited market for use of the technology in Tasmania.

Technical summary

Previous work completed in project HG06152: *Evaluation of degradable polyethylene film for potato production* in the 2007-08 and 2008-09 seasons, demonstrated potential benefits with use of degradable film on Tasmanian potato crops. In the 2007-08 season, extreme soil temperatures resulted in damage to emerging stems. However, the crop recovered once holes were made in the film.

In the 2008-09 season, film use contributed to earlier crop emergence, irrigation savings (early in the season) and a reduction in nitrate leaching. Films remained intact at the time of crop emergence and it was necessary to make holes in the film to facilitate emergence.

During the present project (PT09005: *Evaluation, and demonstration of degradable polyethylene film on Tasmanian potato crops*), films were further developed and designed to degrade at around the time of crop emergence. Trials were conducted over three seasons 2009-10, 2010-11 and 2011-12 at Forthside Vegetable Research Station, Devonport, Tasmania.

Year one: 2009-10

Year one included a nitrogen trial and an irrigation demonstration using film on a processing variety, 'Russet Burbank'.

Preliminary data from previous Tasmanian work indicated that there may be fertiliser savings with use of the film. In the nitrogen trial three rates of basal nitrogen were applied (120, 200 and 300kg/ha) with and without film (3 x 2 factorial design). There was no significant film effect on crop petiole nitrate levels. As expected however, there was a significant basal nitrogen treatment effect on petiole nitrate levels.

Crop emergence was 10 days earlier in film treatments compared to the control, and this translated into earlier crop development. However, at final harvest (at crop maturity) there was no yield advantage with use of the film. Film degradation was slower than desired - it was unclear if this may have limited final yield by limiting entry of water into the mold and/or through the effect of increased soil temperatures.

An irrigation demonstration (single plots) was established to examine the effect of film on a potato crop under three irrigation regimes: 60%, 80% and 100% of evapotranspiration. Different irrigation treatments were applied to examine, in particular, the benefits of film (esp. with regard to water savings) under low irrigation conditions.

The film maintained soil moisture for the first week or two after planting. Later in the season, as crop water use increased, film limited entry of water into the mold.

However there was evidence of some lateral movement of water into the mold and under the film. This demonstration further highlighted the need for film to degrade at around the time of emergence, to allow entry of irrigation water into the mold.

Year two: 2010-11

The year two trial included a processing variety, 'Russet Burbank', and a fresh market variety, 'Dutch Cream'.

Films used were a result of the ongoing development and improvement of the film degradation properties both above and below the ground. Two different film constructions were used with both films designed to degrade and allow easy plant penetration around the time of emergence. "Film 1" was engineered to whiten during the degradation process and reduce any risk of crop damage from extreme soil temperatures. At final harvest the buried edge of both films remained relatively intact. However, the remaining film had lost its physical property strength and therefore did not interfere with harvesting machinery. It was also promising that the above ground film degraded at around the time of emergence.

The effect of film on crop yield depended on harvest time. At final harvest there was no significant difference in total yield. However, earlier in the season the crop in the film treatments was more advanced. Use of the film reduced the length of the early growth phase (i.e. sprout development and vegetative growth), brought forward the next phase, and (most likely) shortened the growing season.

Year three: 2011-12

The year three trial included two fresh market varieties: 'Dutch Cream' and 'Nicola'. Results were consistent with the Dutch Cream results from the year two trial.

Early emergence with use of the film translated to more advanced development early in the season. The effect on yield depended on harvest time. At final harvest there was no statistically significant difference in tuber yield. However nitrogen fertiliser was applied later than planned, and this may have limited the yield in the film treatments (film treatments were more advanced at the time of fertilising, and this application of fertiliser may have been too late for film treatments but just in time for the control).

Conclusion

Trials indicated potential benefits with use of the film in fresh market potatoes to bring forward harvest and access early season markets.

Crops examined were planted in August and September: there may be greater benefits with use of films in earlier planted crops.

Further development of the technology will require development of weed management strategies, film laying machinery and degradation of buried film by harvest time. Further evaluation using other potato varieties, in different soil types, and earlier planting times, may also be warranted.

Further consultation to investigate potential for development of the technology in mainland growing districts (e.g. in Victoria and South Australia) may be warranted, as there is a limited market for use of the technology in Tasmania.

Introduction

The purpose of this section is to provide historical background to the project, why it was undertaken, its significance for industry and the aims of the project.

Historical background to project

In 2005 Integrated Packaging Pty Ltd (the Voluntary Contributor for this project) became a participant in the CRC for Polymers project *Degradable polyolefin films for agricultural production*. The CRC's project objective was to develop polyolefin films for use in agriculture that will degrade in a controlled way to enhance production and crop outcomes.

In 2005, RDS Partners (then Rural Development Services) was approached by Integrated Packaging Pty Ltd to undertake preliminary research on the use of degradable polyethylene film on Tasmanian potato crops.

This initial work in 2005 and 2006 focused on processing potato crops, as a majority of Tasmanian production - about 80% - is for the processing industry. Research included a preliminary examination on sandy soils in the North East and red ferrosol soils in the North West.

Following the preliminary demonstrations, a two-year project (HAL project code HG06152) was established to further examine use of the film on processing crops.

Trials were undertaken in the 2007-08 and 2008-09 seasons on 'Ranger Russett' crops in North West Tasmania. In the 2007-08 trial, potato sprouts were damaged by extreme soil temperatures and it was necessary to make holes in the film to reduce the temperature and allow the plants to emerge. This indicated that film use should be restricted to early plantings when there is less risk of damage from extreme temperatures.

Findings also indicated that earlier emergence could be achieved if films were designed to degrade at the optimal time. Results from the 2008-09 trial, during which film design for degradation timing was still under development, were inconclusive, as the only significant differences between treatments were observed where differences in weed control (not an intended factor) occurred.

Why was this project undertaken?

Previous work completed in project HG06152: *Evaluation of degradable polyethylene film for potato production* in the 2007-08 and 2008-09 seasons, demonstrated potential benefits with use of degradable film on Tasmanian potato crops. Use of film contributed to earlier crop emergence, irrigation savings (early in the season) and a reduction in nitrate leaching.

There were no yield advantages with use of the film. However, it was unclear if timing of film degradation may have affected final yield. Films were still under development and film degradation timing was being refined.

The present project was undertaken to build on the findings from project HG06152 and to examine further potential benefits with use of film technology. In particular the present project examined potential benefits using films designed to degrade at critical times.

Significance for industry

Based on preliminary results it was anticipated that industry benefits would include

- **Early harvest.** In Tasmania, early planted crops are planted into cooler soil which limits emergence rate.
- **Water efficiency.** Use of film on potato crops can reduce evaporative water losses early in the season, and earlier work indicated potential water savings of 1-2 irrigations early in the season. However, potential water savings may vary in different soil types, and crop performance with use of the film may depend on soil moisture at the time of laying the film.
- **Nitrogen efficiency.** Nitrogen fertiliser is a major input in potato crops. Nitrate leaching is also known to be a source of environmental pollution. Film may reduce leaching by protecting fertiliser from being washed through the soil profile.
- **Increased yields.** It was unclear from earlier work if yield benefits were possible with use of the film. In particular, the present trial examined tuber yield, using film designed to degrade at around the time of crop emergence. (A small percentage increase in yield can substantially increase grower returns.)

A literature review was undertaken in the previous project HG06152 and used as a resource for the current project..

Project aims

The project initially aimed to provide:

- An estimation of water savings;
- An estimation of fertiliser savings; and
- An examination of effect on yield and yield structure (tuber sizes).

The project aimed to use films designed to:

- Become brittle at around the time of emergence;
- Provide loss of structural integrity at canopy closure (to allow water to enter the mold); and
- Provide complete or near-to complete degradation of below-ground (buried edge) of film at final harvest.

Initially, the project focused on processing potatoes. It became apparent from the year one results and consultation with industry, that there may be benefits for the fresh market industry and that the benefits would be limited in processing potatoes. As such, trials in years two and three included fresh market varieties.

The year three trial aimed to examine the advantage of earlier emergence and earlier crop development to access early season markets. Films had been designed and developed for improved degradation time for potatoes.

Materials and Methods

Trials were conducted at Forthside Vegetable Research Station, Devonport (North West Tasmania) over three seasons. The research station site was chosen to ensure that the site could be closely monitored and allow management of different treatments more easily than in a commercial crop.

An irrigation demonstration was established in year one, also at Forthside Research Station, to examine the effect of film on a potato crop under different irrigation regimes. In year three a demonstration site was established in a commercial crop at Penguin (also in the North West region).

Trial methods and data collected for the three years are summarised in Table 1. The report then describes trial materials and methods for each year in more detail.

Table 1: summary of trial data collection and methods

	Year one: 2009-10	**Year two: 2010-11**	**Year three: 2011-12**
Field trials			
Potato variety	Russet Burbank	Russet Burbank; Dutch Cream	Dutch Cream; Nicola
Planting date	30/09/2009 (main trial) 20/10/2009 (irrigation demo)	01/09/2010	13/09/2010
Film application date	01/10/2009 21/10/2009	02/09/2010	14/09/2010
Film degradation	One film was evaluated. It was necessary to make holes in film at emergence, and to cut film from the mold during crop growth. (NB film was not removed from irrigation demo.)	Two new films were evaluated (inc. one whitening film); degradation occurred at around emergence time.	Two films evaluated (both non-whitening). Degradation occurred at around emergence time.
Crop emergence	Estimated	Estimated	Percentage emergence recorded
Soil temperature	Disc loggers 6 plots x headspace, 10mm, 50mm, & 200mm	Disc loggers 6 plots x headspace, 10mm, 50mm, & 250mm	Disc loggers 6 plots x 10mm, & 50mm
Soil moisture	Main trial: Microgopher (manual	Microgopher (manual capacitance	-

	Year one: 2009-10	Year two: 2010-11	Year three: 2011-12
	capacitance instrument) for each plot: 36 plots x depths of 100, 200, 300, 400 & 500mm x 8 visits Irrigation demo: Microgopher (manual capacitance instrument) for each plot: 6 plots x depths of 100, 200, 300, 400 & 500mm x 8 visits; GLRL loggers; Hansen loggers.	instrument) tubes were placed in the centre of the mold, the side of the mold and the furrow (three tubes in each plot. Measurements were recorded at depths of 200, 300, 400 & 500mm from the top of the tubes.	
Crop development	Destructive sampling to evaluate length of king tuber and tuber yield.	Destructive sampling to evaluate length of king tuber and tuber yield.	Destructive sampling to evaluate length of king tuber sequential harvest to evaluate tuber yield.
CO_2	-	On 11/09/10 five replicate samples were taken from headspace and four from ambient sources.	-
Incident radiation	-	One film plot and one control plot, using a single point pyronometer.	-
Petiole nitrate	Petioles sampled on 08/12/09 and 19/01/10.	Petioles sampled on 06/11/10 and 23/11/10	-
Soil nitrate	-	Composite samples.	-
Tuber analysis	-	Composite sample from each treatment on 11/11/2010 and at final harvest date	-
Final harvest	30/03/2010	02/03/2011	19/01/2012

	Year one: 2009-10	Year two: 2010-11	Year three: 2011-12
		Russet Burbank 14/02/2011 Dutch Cream	
Demonstrations			
Demonstration and site	Irrigation demonstration – single plots at Forthside Vegetable Research Station	-	Demonstration of film in commercial paddock at Penguin

Year one: 2009-10

Main trial

A "main trial" was established to quantify water and nitrogen savings, and provide an evaluation of yield and quality benefits with use degradable polyethylene film on processing potato crops. Statistical design was a complete randomised block. Treatments design was a 2 x 3 factorial (+/- film and three rates of basal Nitrogen) (**Table 2**). There were six replicates in each treatment.

Table 2: Main trial treatments

Main trial - treatments	120 kg N at planting	200 kg N at planting	300 kg N at planting
Film	Film 120N	Film 200N	Film 300N
No film (control)	No film 120N	No film 200N	No film 300N

Plots were 11m x 2 rows, with one buffer row between plots. At final harvest, 5m x 2 rows were harvested from each plot using a twin row harvester.

Soil moisture was recorded in each plot with a microgopher (manual capacitance instrument), during eight site visits (from 2nd October to 8th December). The microgopher tubes were calibrated with a standard calibration across all tubes. There were some differences in soil across the paddock; and the soil moisture may also have influenced by position of the plots in relation to sprinkler position.

These soil moisture measurements were recorded from depths of 100, 200, 300, 400 and 500mm. Where practicable, readings were taken just prior to, and then after irrigation applications (e.g. 25mm irrigation applied 11th November; 25mm irrigation 19th November). A repeated measures, analysis of variance was performed using the statistical program SPSS®.

- In December, two plants per plot (from two blocks) were sampled.
- In January, two plants per plot (from three blocks) were sampled.

Sap nitrate levels were measured on the 8th December and the 19th January. Petioles were taken from the youngest fully expanded leaves, from randomly selected plants within each plot. Samples were taken early in the morning. Based on results from the 8th of December, 120 kg/ha of Urea was applied to all plots. A repeated measures analysis of variance was performed using the statistical program SPSS®.

Harvest

At harvest, plant counts and stem counts were taken in each of the harvest plots (2 x 5 metre rows). The main trial and the irrigation demonstration were harvested with a small plot harvester and then collected and bagged by hand. All samples were weighed and sorted.

The following data was collected for each plot

- Total weight of the sample;
- Total number of tubers in the sample;
- Weight of tubers < 75 grams;
- Number of tubers < 75 grams;
- Weight of tubers 75 to 250 grams;
- Number of tubers 75 to 250 grams;
- Weight of tubers 250 to 850 grams;
- Number of tubers 250 to 850 grams;
- Total weight of tubers with external defects;
    - Second growth / poor shape includes growth cracks;
    - Soft rot;
    - Green tubers;
    - Common scab;
    - Other including insect damage etc;
- Total number of tubers with external defects;
    - Second growth / poor shape includes growth cracks;
    - Soft rot;
    - Green tubers;
    - Common scab;
    - Other including insect damage etc;
- Total weight of useable tubers; and
- Total number of useable tubers.

Sub-samples from each plot harvest were taken for measurement of tuber specific gravity (SG). From each sub-sample, five tubers were randomly selected and examined for internal defects (brown centre and hollow heart) - the number of defect tubers was recorded.

- Standard tuber size categories for processing potatoes were chosen.
- An analysis of variance was performed using the statistical program SPSS®.

Irrigation demonstration

A demonstration was established to evaluate film-related water savings. This was planted on 20th October – three weeks later than the main trial. There were six single plots (Table 3)

Table 3: Irrigation demonstration treatments

Irrigation demonstration	60% of evapotranspiration	80% of evapotranspiration	100% of evapotranspiration
Film	Film 60%	Film 80%	Film 100%
No film	No film 60%	No film 80%	No film 100%

Irrigation was applied when accumulated deficit for Block C approached 25mm. For each irrigation application, the required volume of water was applied to block C. Block B received 80% of this rate and block A received 60%. This approach was used from the beginning of irrigation until the crop had matured.

Prior to emergence, soil temperatures were higher under the film treatments (as expected) and warm weather was forecast. Therefore it became necessary to apply whitewash to the film treatments to limit the risk of crop damage from high soil temperatures. Applying a solution with a hand held sprayer proved difficult as nozzles became blocked. Therefore a thicker solution was prepared and painted onto the film. This was applied on 5th November 2009. A small length of row was left without whitewash, to provide a comparison of emergence with and without whitewash.

The film remained intact at around the time of emergence, and it was therefore necessary to facilitate emergence by making holes in the film (this also occurred in the main trial). In the irrigation demonstration, the film was left in place for the duration of the growing season (note that in the main trial the film was removed/rolled back during the season).

Temperature loggers (EC Disklog) were installed and set to record soil temperature at two hourly intervals in the 100% irrigation treatment. These loggers were set at depths of 30mm and 200mm.

Soil moisture was recorded in the 6 plots with a microgopher (manual capacitance instrument). Measurements were recorded from depths of 100, 200, 300, 400 and 500mm.

Green-light red-light (GLRL) Odyssey capacitance loggers were installed in the centre of the mold in each of the 6 plots. The loggers were set to record two hourly, at depths of 100, 200, 300 and 500 mm.

Hansen loggers (gypsum blocks) were installed in the 60 % and 100 % irrigation treatments. The sensors were placed in the top of the potato mold, at set depth and in the furrow between the rows for film and non film treatments. These loggers were positioned in order to assess soil moisture dynamics and, in particular, to assess if water moved laterally under the film and whether the film excluded water from the mold.

At harvest, plant counts and stem counts were taken in each of the harvest plots (2 x 5 metre rows). The main trial and the irrigation demonstration were harvested with a small plot harvester and then collected and bagged by hand. All samples were weighed and sorted. Total yield and tuber size distribution (yield structure) were measured for each of the six plots. Rejects were counted and recorded and tuber specific gravity (SG) was measured for each of the six plots.

Year two: 2010-11

Results from the 2009-10 season confirmed that use of the film should be restricted to early planted crops, and that the film should be designed to degrade by 30 days after planting so that soil temperature extremes are minimised and to take advantage of early growth benefits.

The 2010-11 trials aimed to

1. Evaluate crop performance using films that
    a. become brittle at around the time of emergence, to allow plants to emerge through the film with little resistance;
    b. provide complete loss of structural integrity of the film by the time of full canopy closure (to allow adequate moisture to enter the mold, preventing any possibility of moisture stress due to the film);
    c. provide near to complete deterioration of the film, both above and under-ground, by the end of crop growth (to reduce plastic in the environment; and to reduce the effect of plastic on mechanical harvesting equipment).
2. Include evaluation of fresh market potato variety
    a. examine use of the film on a fresh market variety to evaluate benefits from early emergence and potentially early maturity, and the potential to take advantage of early season production and market premiums; and
    b. a ‘last ditch’ effort using the processing variety Russet Burbank.
3. Further evaluate potential nitrogen fertiliser savings in potatoes.
4. Further evaluate early season irrigation water savings in potatoes.

Two trials were established at Forthside Vegetable Research Station, one with a processing variety (Russet Burbank) and one with a fresh market variety (Dutch Cream). For both trials statistical design was a complete randomised block. There were two different films (film treatments) plus a control with no film. There were six replicates and there were an equal number of replicates in each treatment.

Two new films were evaluated. “Film 1” was designed to whiten during the degradation process and reduce any risk of crop damage from extreme soil temperatures. For both films, it was promising that the above ground film degraded at around the time of emergence, and there was no need to make holes in the film for emerging plants.

Plots were 10m x 2 rows, with a 1m buffer between plots within each row.

There were twin buffer rows between plots. Spray runs were planted but not used for trial plots, and a single buffer row was included adjacent to each spray run.

CO2

Samples were collected on 11th September, using syringes, from film headspace and also soil surface (ambient). Analysis based on gas chromatography was undertaken by the Central Science Laboratories, University of Tasmania. Five replicate samples were taken from headspace and four from ambient sources. CO_2 data was recorded for use in the development of a potato crop model with use of the film (a CSIRO project).

Incident radiation

Incident radiation was measured in one film plot and one control plot, using a single point pyronometer. Incident radiation data was recorded for the development of a crop model (CSIRO).

Soil moisture

Soil moisture was recorded in each plot with a microgopher (manual capacitance instrument), during 10 site visits from 3rd September (one day after film was laid) to 26th October 2010. The microgopher tubes were calibrated with a standard calibration across all tubes. There were some differences in soil across the paddock; and the soil moisture may also have been influenced by position of the plots in relation to sprinkler position. In each of the six plots examined, tubes were placed in the centre of the mold, the side of the mold and the furrow (three tubes in each plot i.e. a total of 27 tubes). The tops of the tubes were aligned. Soil moisture measurements were recorded from depths of 200mm, 300mm, 400mm and 500mm from the top of the tubes. A repeated measures analysis of variance was performed using the statistical program Minitab®. The aim of placing tubes in different positions within the mold, was to examine soil moisture dynamics including lateral movement of water under the film early in the season.

Petiole nitrate

Sap nitrate levels were measured on the 6th November and 23rd November 2010). Petioles were taken from the youngest fully expanded leaves, from randomly selected plants within each plot (all plots were sampled on 6th November; plots from 3 out of 6 blocks sampled on 23rd November). Samples were taken early in the morning.

Soil nitrate

Soil samples were taken on 3rd September and 2nd November for analysis of soil nitrate. Samples were taken from each of the following positions: 0-30cm in the mold; 30-60cm in/below the mold; and 0-30cm in the furrow.

Destructive sampling

Several plots were sampled on 3rd November, 9th November, 15th December and 18th January. A repeated measures Analysis of Variance for tuber weight was performed using the statistical program Minitab®.

Tuber analysis

Samples were collected from each treatment for tuber analysis. Each was a composite sample and were analysed by Phosyn Analytical (Queensland). Both cultivars were sampled on 11th November and then again at Harvest, 24th February for Dutch Cream and 2nd March for Russet Burbank.

Final harvest

At harvest, plant counts and stem counts were recorded for each of the harvest plots (2 x 5 metre rows). The trials were harvested with a small plot harvester and then collected and bagged by hand. All samples were weighed and sorted. The Dutch Cream trial was harvested on 14th February 2011 and the Russet Burbanks on 2nd March 2011.

Total yield and tuber size distribution (yield structure) were measured. Standard size measurements for processing potatoes were used for both Russet Burbank and Dutch Creams.

Reject tubers were counted and weighed. Tuber specific gravity (SG) was measured by weighing a sub-sample from each plot in air and in water, to calculate SG.

An analysis of variance was performed using the statistical program Minitab® to compare treatments. A repeated measures analysis of variance was also performed for those plots sampled during the season.

Year three 2011-12

Design was a complete randomised block. There were two different films (film treatments) plus a control with no film. There were six Dutch Cream replicates, four Nicola replicates and there were an equal number of replicates in each treatment.

Plots were 6m x 2 rows, with a 1m buffer between plots within each row.

There were twin buffer rows between plots. Spray runs were planted but not used for trial plots, and a single buffer row was included adjacent to each spray run.

Trial plots were smaller than the previous two years, due to budget constraints, but were considered adequate and allowed enough material for a total of 5m for final harvest (5m being standard for potatoes).

The trial was planted on 13th September 2011 and the film was laid by hand on 14th September. Film was laid by hand rather than machine, due to small length of plots. Planting was planned for August and was delayed due to wet weather.

Crop emergence

The crop was closely monitored around the time of emergence, and percentage emergence recorded.

Destructive sampling

On 25th October, one plant was sampled from 11 plots to determine if tuber initiation had commenced. Tubers were observed in only one out of 11 plants sampled.

On 10th November, one plant was sampled from each plot (i.e. 30 plots), and the length of the king tuber was recorded.

On 7th December, four plants were sampled from 8 blocks (i.e. 24 plots) and length of the king tuber recorded.

On 7th December 2011 and on 22nd December, 4 plants were harvested from eight blocks (4 Dutch Cream and 4 Nicola i.e. a total of 24 plots).

Harvest

5m was harvested from each plot on 19th January 2011. Tops were slashed a couple of days prior to harvest for ease of harvest and to allow skins to set. Tubers were graded into size categories for fresh market potatoes (Woolworths produce specifications).

Tuber SG was not measured in year three. Tuber SG is particularly important for processing potatoes for French fries, as SG affects frying quality.

Results

Film degradation

In year one, the crop was closely monitored around the time of emergence, and it was necessary to make holes in the film to facilitate emergence of the stems through the film.

In year two, two new films were evaluated (Figure 1). One film was designed to whiten during the degradation process to reduce the risk of crop damage from extreme soil temperatures. Both films degraded at around emergence time or soon after and there was no need to make holes in the film. The buried edge of film remained at harvest.

Figure 1: Emergence and film degradation, year two trial, "film 1" left and "film 2 right (12th October 2010, 6 weeks after planting)

For the film that was designed to whiten, whitening occurred 15 days after planting (Table 4). For both films embrittlement was approximately 40 days after planting.

In year three, two films were evaluated, and embrittlement occurred at approximately 30 days after planting.

Table 4: Time to film whitening and time to embrittlement.

Film Code	Date trial started	Whitening days	Embrittle days	
			date	days
524	1/09/2010	15	12/10/2010	40
525		Did not whiten		40
557	14/09/2011	Did not whiten	11/10/2011	30
552		Did not whiten		30

Soil temperature

For several weeks after planting and while the film remained intact, daily maximum soil temperature at 10mm below the surface was typically 15 to 20 degrees warmer in film treatments compared to the control. On some individual days soil temperatures reached 40^{o}C or greater. At 50mm below the surface temperature was typically 10 to 15 degrees warmer.

In year two, one of the films evaluated (“film 1”) was designed to whiten. For the first week, soil temperatures were similar to “film 2”, and then as “film 1” whitened soil temperatures were similar to the control. Whitening was effective in reducing risk of damage from extreme soil temperatures.

Data for year three is presented in Figure 2, Figure 3 and Figure 4.

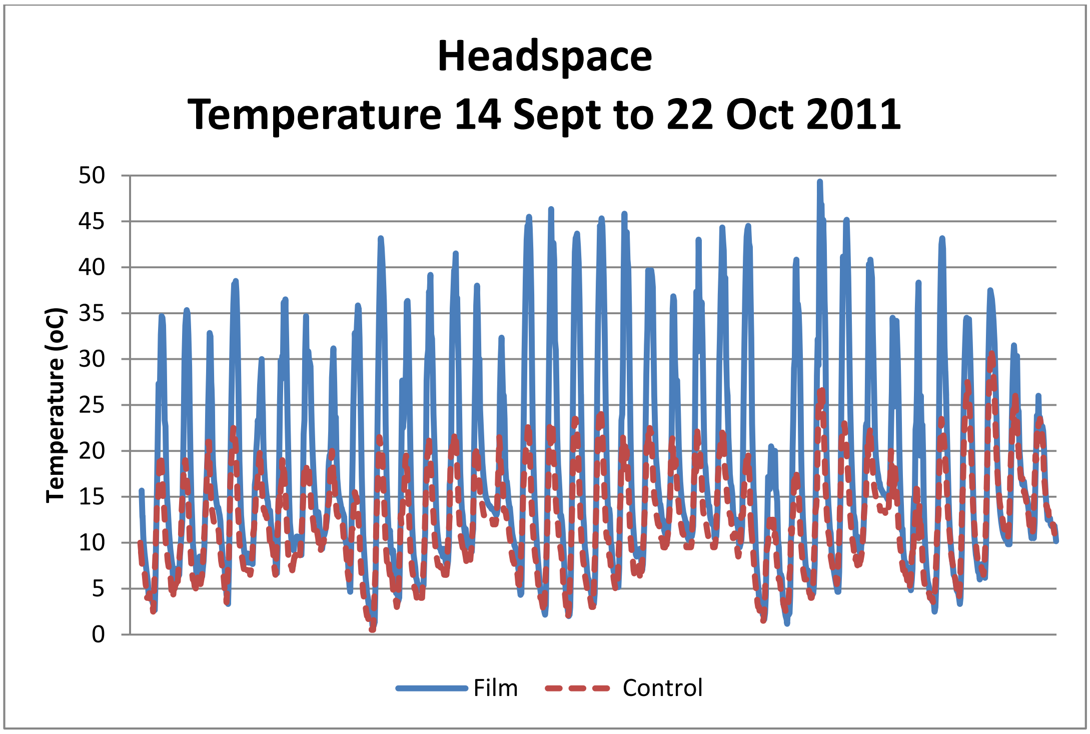

Figure 2: Headspace temperature 14 Sept to 22 Oct 2011

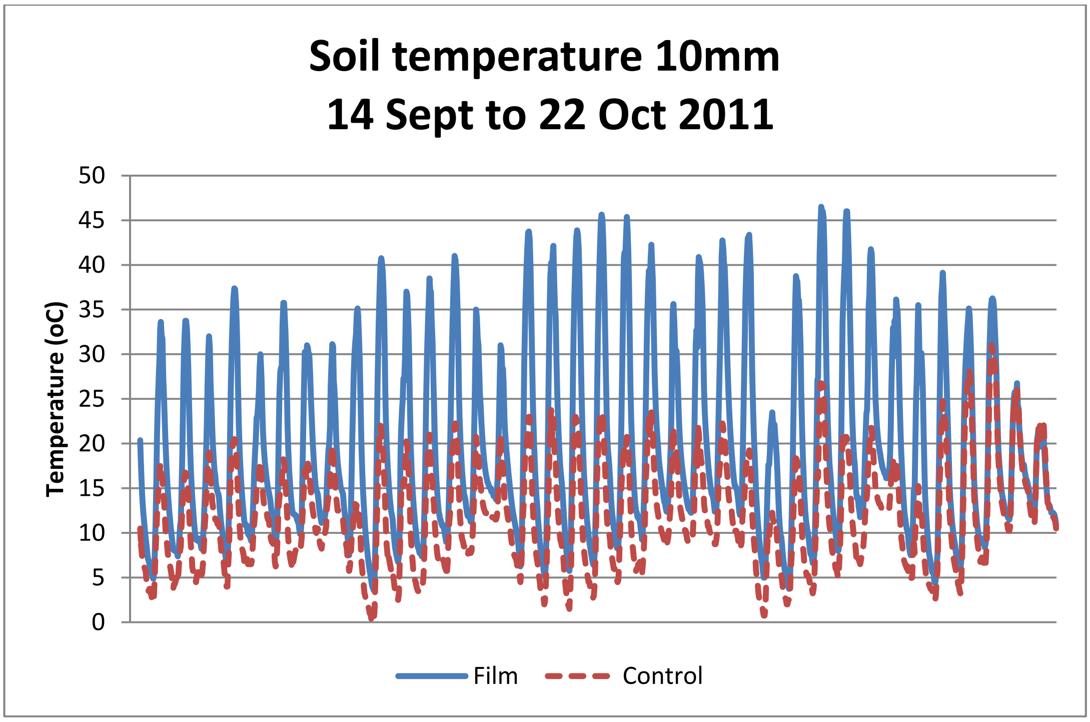

Figure 3: Soil temperature at 10mm, 14 Sept to 22 Oct 2011

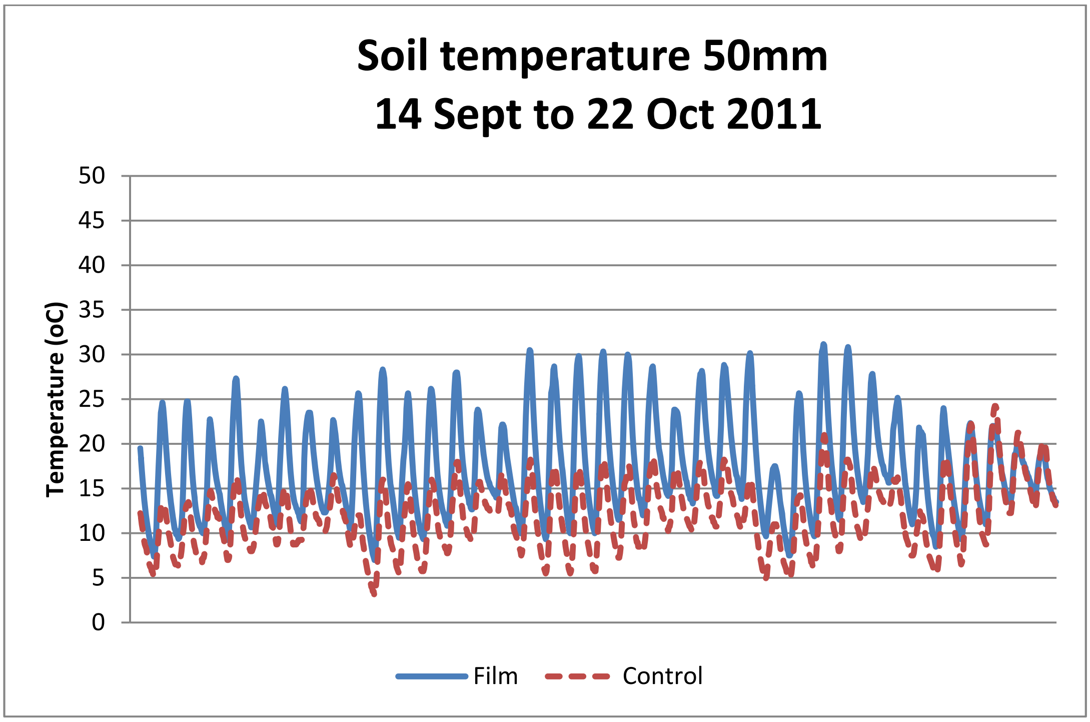

Figure 4: Soil temperature at 50mm, 14 Sept to 22 Oct 2011

Crop emergence

Crops were planted in September each year: 30/09/09, 01/09/10 and 13/09/11.

Increased soil temperature was effective in advancing crop emergence, and emergence was one to two weeks earlier in film treatments compared to controls. Crop emergence data for year three is presented in Figure 5.

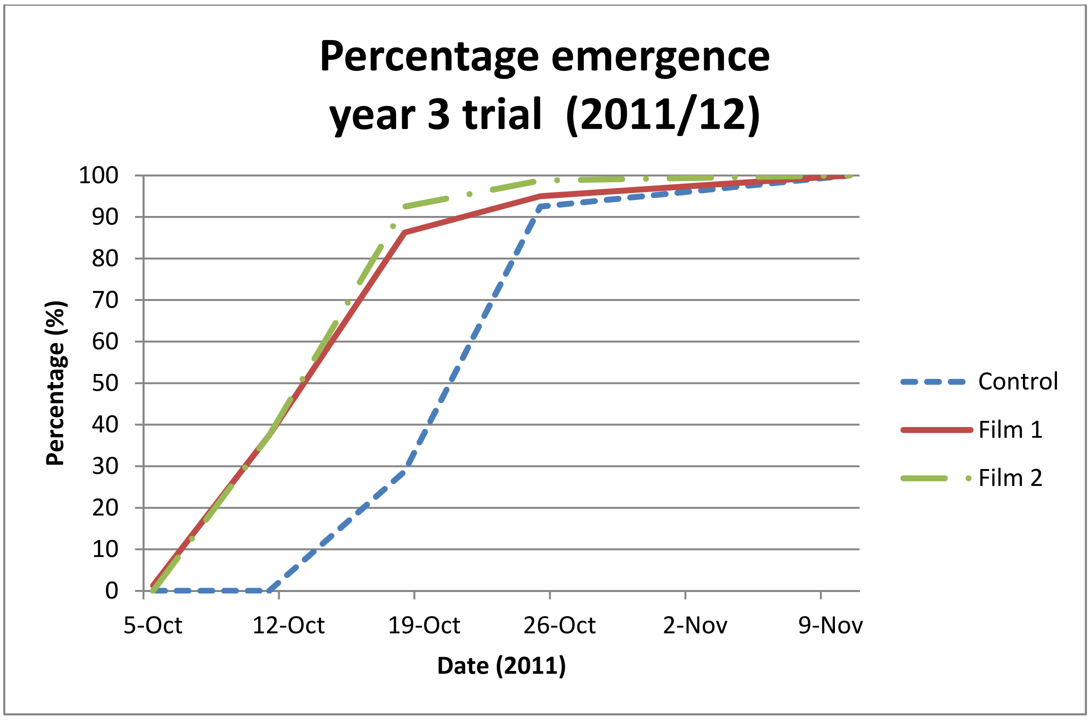

Figure 5: Crop emergence for year three trial 2011.

Early crop development

Early in the season, plants under the film treatments were more advanced than the controls (Figure 6).

Figure 6: Dutch Cream crop development.
"Film 1" top left (plot 33); "Film 2 (plot 36) on right; Buffer row in between (no film) – (26 October 2010, 8 weeks after planting).

Weeds

Pre-emergent herbicides were applied post-sowing prior to laying the films. Herbicides were less effective in the film treatments compared to the controls. This may have been due to disturbance of the soil surface during film application and/or due to extreme temperatures at the soil surface affecting herbicide efficacy.

Soil moisture

In year one, there was a significant interaction between time, film treatment and nitrogen treatment. Soil moisture immediately after planting was greater in the film treatments compared to the control. The film minimised evaporation from the soil surface.

In the irrigation demonstration (year one), holes were made in the film to facilitate emergence. The film otherwise remained intact and was not removed from the molds (note that film was removed in the main trial). Soil was drier in the film treatments compared to the control. Entry of water into the mold was limited by the film. However, there was some evidence that moisture moved laterally into the mold.

In the year two trial, there was a significant film effect on soil moisture. In potatoes, a majority of the roots are in the surface 300mm. Soil moisture measured at 300mm is presented in Figure 7. From about mid September to late September the control was drier than the film treatments.

At 400mm in the mold, from mid to late October, soil was drier in the "film 2" treatment compared to "film 1" and the control (Figure 8). This may have been due to a) increased water use, as the crop was more advanced; and/or b) remaining parts of film excluding rainfall and irrigation from the mold, as "film 2" remained intact longer than "film 1".

In the furrows (between the molds) there was less soil moisture in the control compared to film treatments. In film treatments soil moisture was 'shed' from the mold to the furrow. However, there was evidence of some lateral movement of soil moisture into the mold.

In year three, soil moisture loggers were not installed. During a site visit on 5th October 2011, soil in the centre of the mold was noticeably drier in film treatments compared to the control.

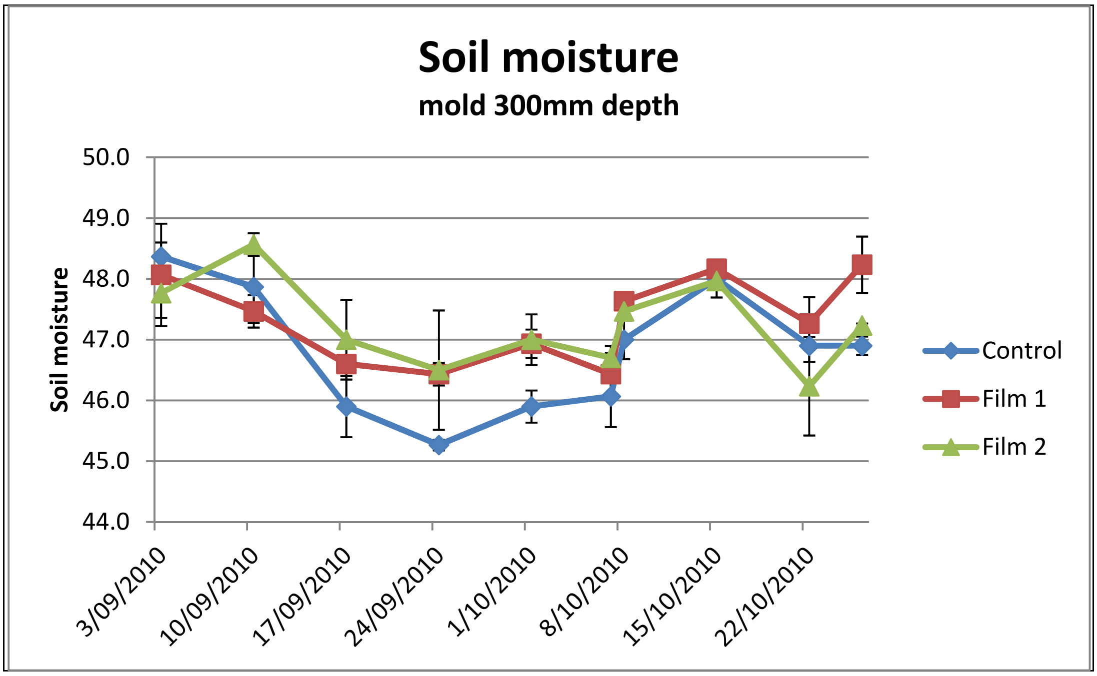

Figure 7: Soil moisture at 300mm (n=6). Error bars represent SEM.

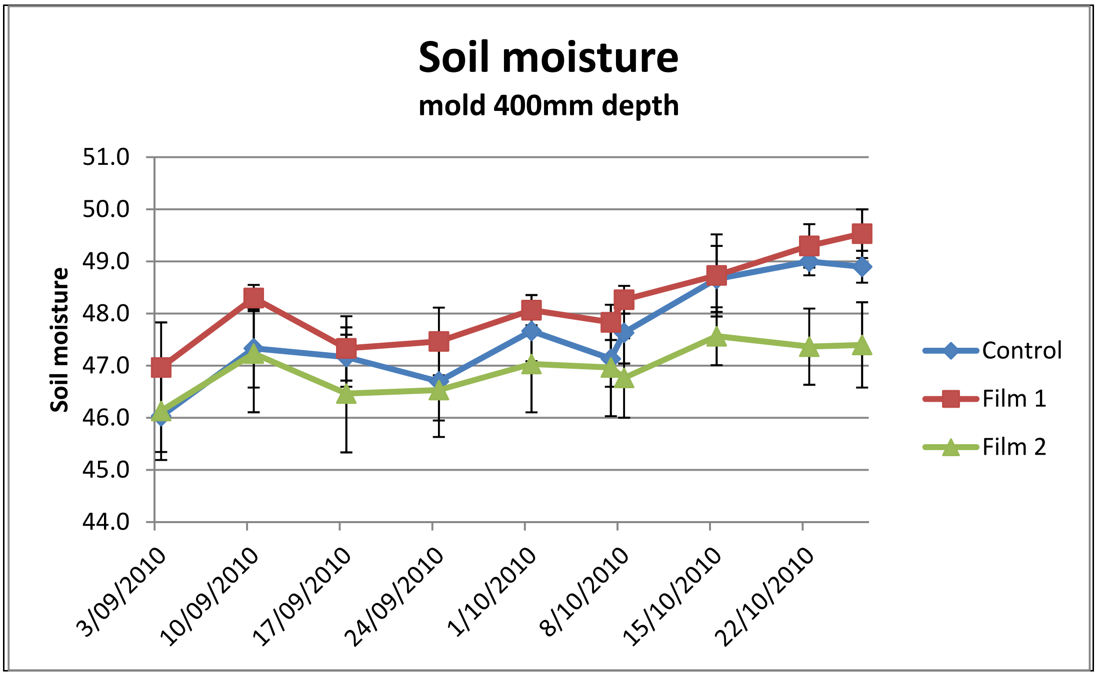

Figure 8: Soil moisture at 400mm (n=6). Error bars represent SEM.

CO2 concentration

CO_2 concentration was greater under film compared to the control (Figure 9).

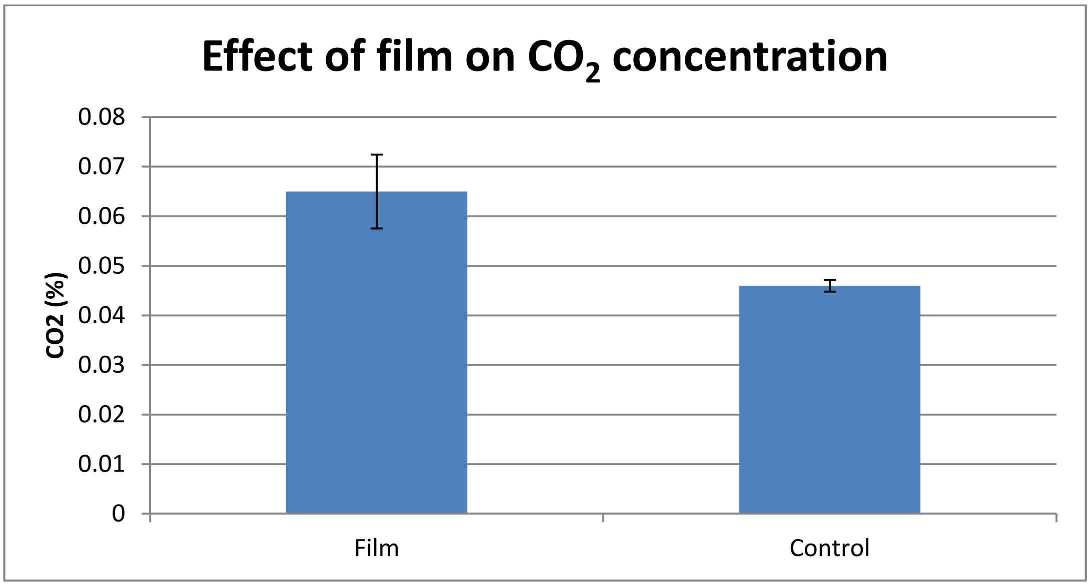

Figure 9: Effect of film on CO2 concentration, sampled on 11th September 2010. Film n=5 control n=4. Bars represent SEM.

Incident radiation

The film reduced maximum daily radiation by between 18 and 39 percent (Figure 10).

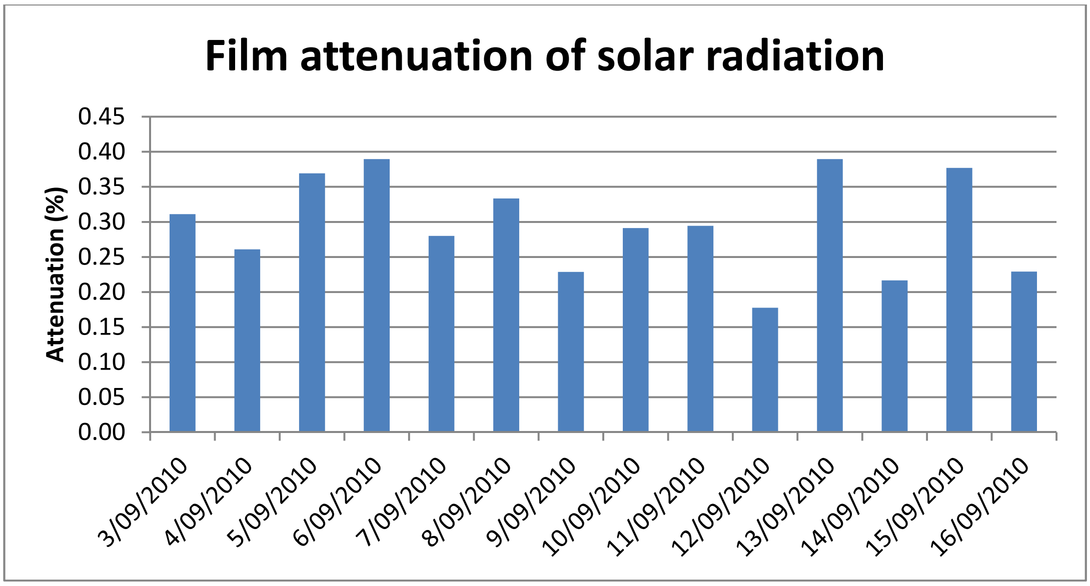

Figure 10: Attenuation of solar radiation by the film.

Soil nitrate

On 3rd November 2010, one month after planting, one composite sample was taken for each of the following positions – mold 0-30 cm; mold 30-60 cm; furrow 0-30 cm – for each film treatment and the control (*i.e.* a total of nine samples for analysis) (Figure 11, Figure 12, and Figure 13).

NO_3 (and total available N) in the mold at 30-60cm was lower in the “film 2” sample compared to both the “film 1” and control sample.

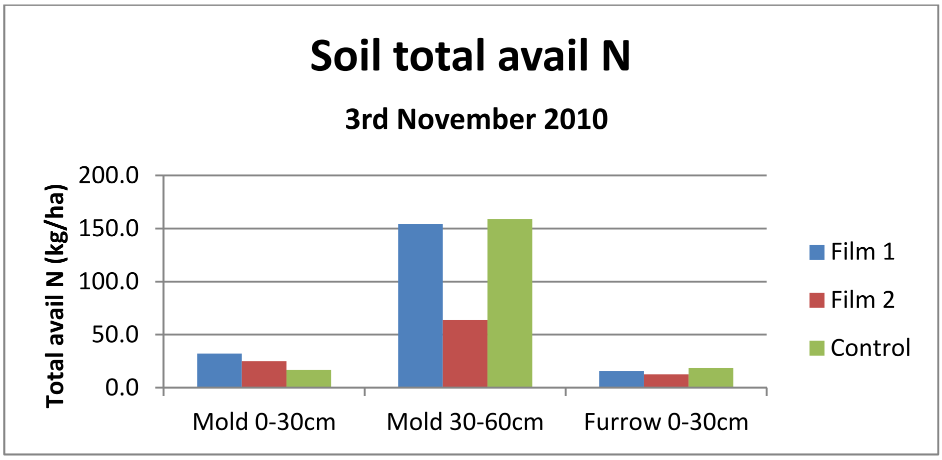

Figure 11: Total available soil N (NO_3 + NH_4), 3rd November 2010 n=1.

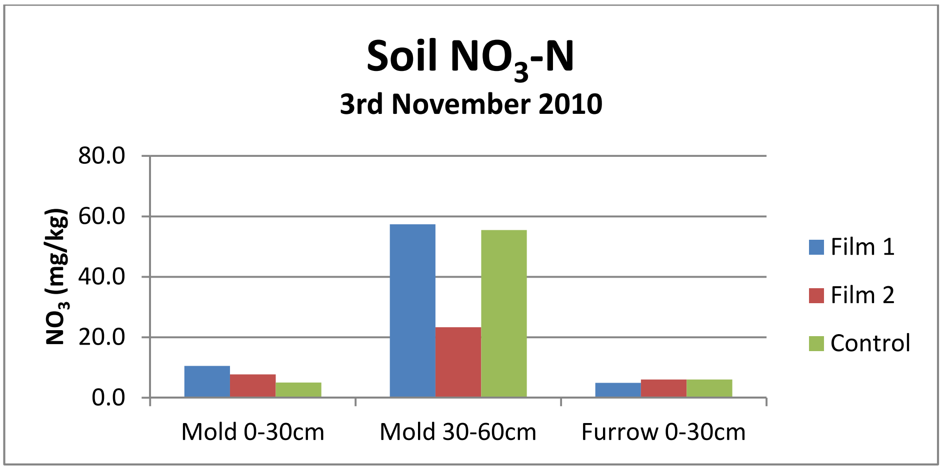

Figure 12: Soil NO_3-N 3rd November 2010 n=1

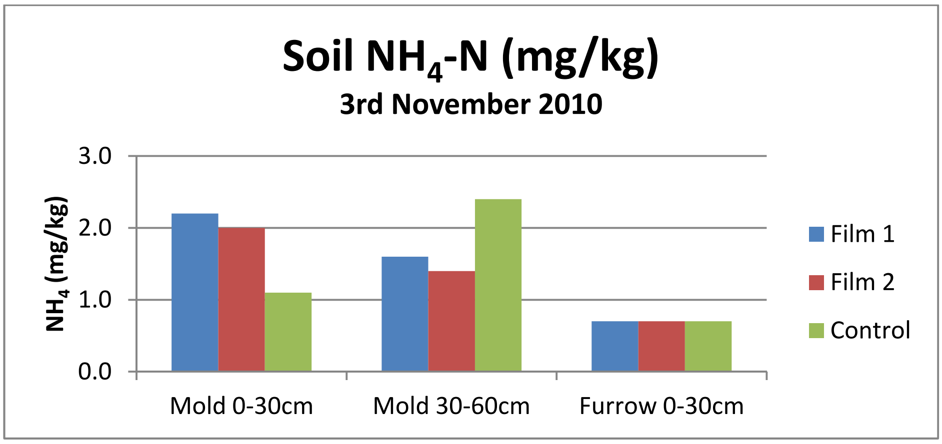

Figure 13: Soil NH_4-N 3rd November 2010 n=1

Petiole nitrate

In year one, in the nitrogen trial, there was a significant ($P<0.001$) time x nitrogen interaction (Table 5); there were no other significant treatment effects on petiole nitrogen.

Table 5: Petiole nitrogen (ppm). There was a significant time x nitrogen interaction. LSD = 439 for comparisons within the table.

	Petiole N (ppm)	
	8th December 2009 (6.5 weeks after planting)	**19th January 2010 (16 weeks after planting)**
120 N	802	198
200 N	4150	1306
300 N	5023	4154

There was no significant film treatment effect on leaf nitrogen. The nitrogen treatment effect was expected, as different basal nitrogen rates were applied at planting.

In year two, petiole nitrate results for 6th November indicated that nitrogen was below optimal and therefore a top dressing of urea was applied on the 12th of November 2010.

Petiole N for the two sampling dates is listed at Table 6. Petiole N in the Dutch Creams at 6th November was significantly less in both films compared to the control. This was most likely due to more advanced growth in the film treatments.

Table 6: Petiole N (ppm) in two potato varieties at sampling.

	Petiole N (ppm)	
	6th November 2010 (9.5 weeks after planting) n=6	**23rd November 2010 (12 weeks after planting) n=3**
Russet Burbank		
Film 1	3787	2150.0
Film 2	4028.5	3033.3
Control	3972.5	3091.7
L.S.D.	ns	ns
Dutch Cream		
Film 1	3469.2	2883.3
Film 2	3489.5	2216.7
Control	3818.5	3100.0
L.S.D.	290	ns

Tuber yield

Destructive sampling

Early in the season tuber growth and development was more advanced in the film treatments compared to the controls, e.g. Figure 14 and Figure 15.

Figure 14: Dutch Cream – total of six plants (3 plots x 2 plants) harvested from control (left), film 1 (centre), and film 2 (right), (9th November 2010, 10 weeks after planting).

Figure 15: Russet Burbanks - total of six plants (3 plots x 2 plants) harvested from control (left), film 1 (centre), and film 2 (right), (9th November 2010, 10 weeks after planting).

Final harvest

A summary of key results from **final** harvests for the three years is presented in Table 7.

Table 7: Summary of final yield results
ns = no statistically significant differences were detected (P>0.05)

Trial	**Year one**	**Year two**	**Year three**
Variety used	**Russet Burbank (RB)**	**Russet Burbank (RB) & Dutch Cream (DC)**	**Dutch Cream and Nicola**
Films evaluated	**One film**	**Two films: trial 524 trial 525**	**Two films Film 1: trial 552 Film 2: trial 557**
Variable evaluated	Comments		
Plants / m	ns	ns	ns
Stems / m	More stems in film treatment	RB: more stems in film 2 treatment compared to both film 1 and control. DC: ns	ns
Total tubers	Fewer tubers in film treatment	RB: more tubers in both films compared to control DC: ns	ns

Trial	Year one	Year two	Year three
Variety used	Russet Burbank (RB)	Russet Burbank (RB) & Dutch Cream (DC)	Dutch Cream and Nicola
Films evaluated	One film	Two films: trial 524 trial 525	Two films Film 1: trial 552 Film 2: trial 557
Variable evaluated	Comments		
Total weight (including rejects)	Less weight in film treatment compared to control	ns	ns
Weight of usable tubers (excludes rejects)	Less weight in film treatment compared to control	ns	ns
External defects – Soft rot	Less rot in film treatment	ns	ns
External defects – 'ugly'	More 'ugly' tubers in film treatments	ns	ns
Internal defects – Brown Centre	ns	ns	ns
Internal defects – Hollow Heart	Greater number of tubers with Hollow Heart in film treatment	ns	ns
Tuber Specific gravity	Film x nitrogen interaction	ns	(not measured)

A précis of these results follows:

Number of plants / m

There was no significant treatment effect on the number of plants ($P>0.05$).

Number of stems / m

In year one, there was a significant ($P<0.001$) film effect on number of stems per 10m row. There were more stems in the film treatment compared to the control.

In year two, there was a significant ($P=0.036$) treatment effect on number of stems per 10m row. There were more stems in "film 2" compared to both "film 1" and the control.

In year three, there was no significant treatment effect on number of stems per 5m row ($P>0.05$).

Total number of tubers

In year one, there was a significant ($P<0.001$) film effect on the total number of tubers per 10m of row. There were fewer tubers in the film treatment compared to the control.

In year two, in the Russet Burbank trial there was a significant ($P=0.043$) film effect on the total number of tubers per 10m of row. There were more tubers in both of the film treatments compared to the control. In the Dutch Cream trial there were no significant treatment effects on number of tubers.

In year three, there was no significant effect on number of tubers.

Total weight (including rejects)

In year one, there was a significant (P=0.001) film effect on total weight per 10m row harvested. Total weight was lower in the film treatment compared to the no-film control (Table 8).

Table 8: In year one there was a significant (P=0.001) film effect on total weight per 10m row harvested.

Film treatment	Total weight (including rejects) (kg/10m row)
Film	53.08
No film	57.81
L.S.D.	2.60

In years two and three, there were no significant effects on total weight at final harvest.

Yield structure (tuber size distribution)

Yield structure results are shown for year two and year three (Figure 16 to Figure 19). In year two, tubers were graded into size categories for processing potatoes. In year three, tubers were graded into size categories for fresh market potatoes.

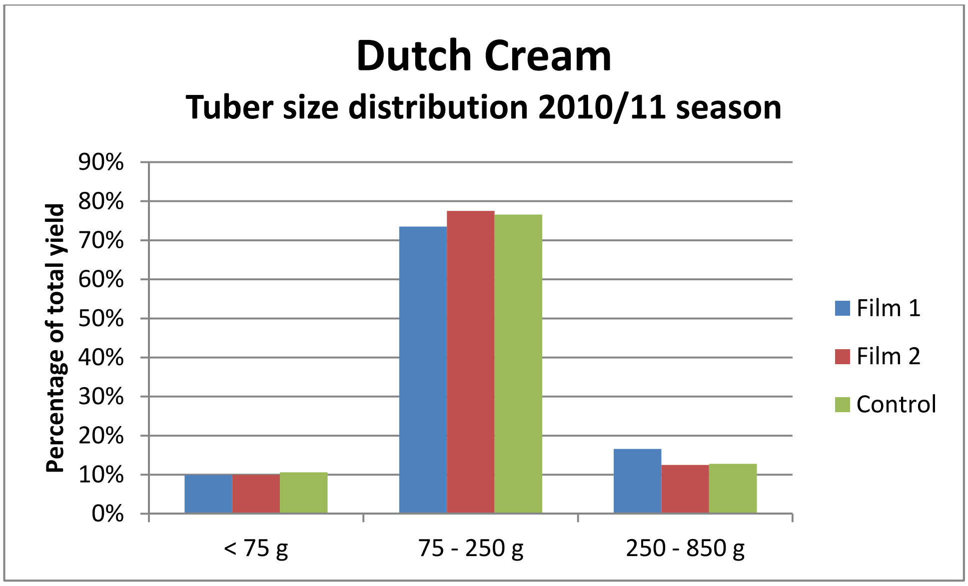

Figure 16: Dutch Cream tuber size distribution 2010-11 season (year two)

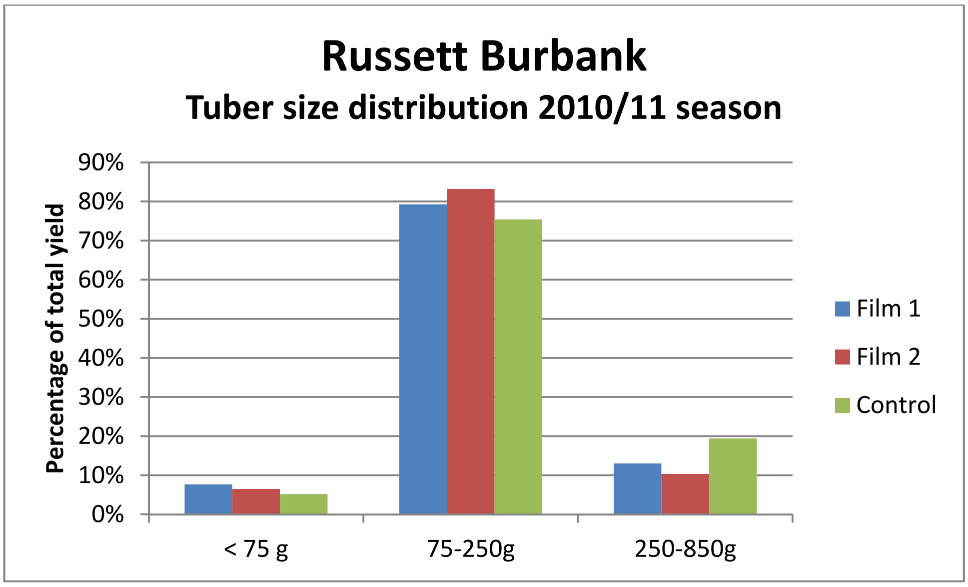

Figure 17: Russet Burbank tuber size distribution 2010-11 season (year two)

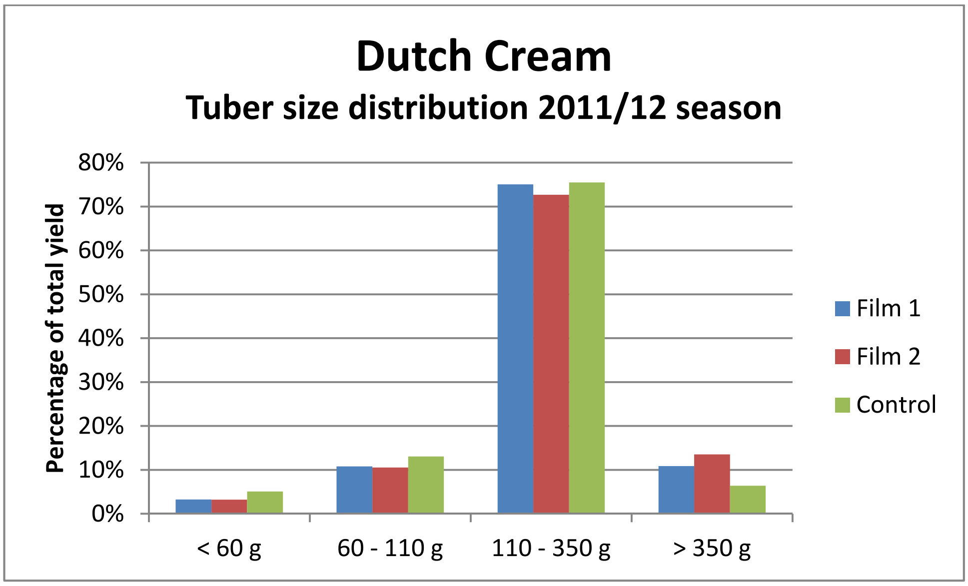

Figure 18: Dutch Cream tuber size distribution 2011-12 season (year three)

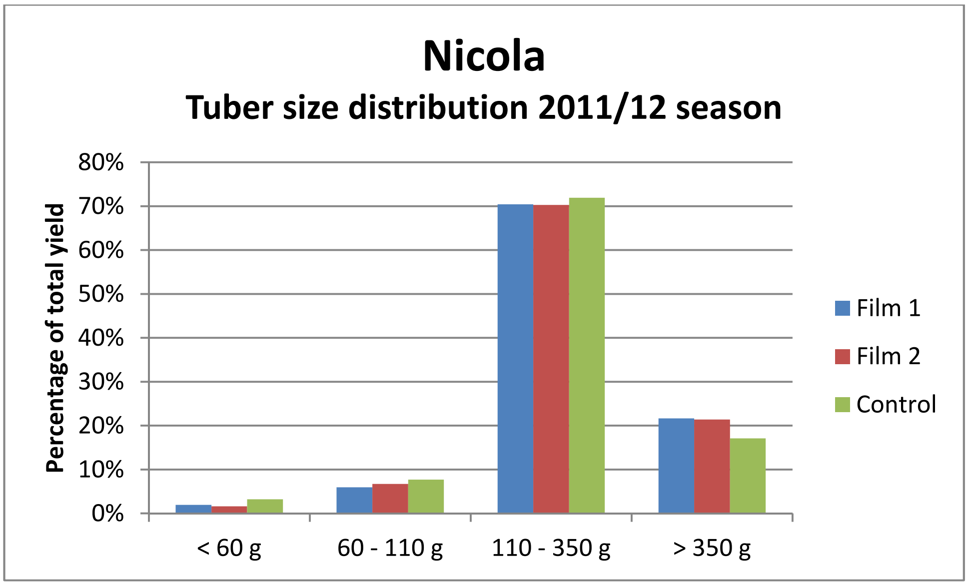

Figure 19: Nicola tuber size distribution 2011-12 season (year three)

External defects

Soft rot

In year one, there was a significant film effect on both the weight (P=0.001) and number (P<0.001) of tubers with soft rot. There was less soft rot in the film treatment compared to no-film control.

There were no significant film effects on soft rot in year two or year three.

'Ugly' tubers

In year one, there was a significant (P=0.014) film effect on the number of 'ugly' tubers. There were more 'ugly' tubers in the film treatment compared to the no-film control.

There were no significant treatment effects on 'ugly' tubers in year two or year three.

Internal defects

Brown Centre

There were no significant treatment effects on the number of tubers with brown centre.

Hollow Heart

In year one, there was a significant (P=0.001) film effect on the number of tubers with hollow heart. There were more tubers with hollow heart in the film treatment compared to the no-film control.

Tuber specific gravity

In the year one nitrogen trial, there was a significant (P=0.013) interaction between film and nitrogen, on tuber specific gravity (SG) (Table 9).

Table 9: Film and nitrogen effects on tuber specific gravity.

	Tuber specific gravity (SG)	
Nitrogen treatment	**Film**	**No film**
N120	1.094	1.093
N200	1.090	1.095
N300	1.083	1.087

In the year two film trial, there was no significant (P>0.05) film effect on tuber SG. Mean SG across all plots was: Russet Burbank 1.095 (SD = 0.003) and Dutch Cream 1.084 (SD = 0.003).

Tuber SG was not measured in year three.

Discussion

Project aims

The original project proposal aimed to evaluate expected benefits from use of the film on early planted potato crops including potential water savings, nitrogen fertiliser savings, more uniform tuber size and yield benefits. Initially the project focussed on continuing previous research work in processing potatoes.

Results from year one indicated that although there were benefits in reduced nitrogen leaching and some potential for irrigation savings (early in the season), yield advantages were uncertain, particularly when crops were harvested at maturity. The most promising benefit with use of the film was from earlier crop emergence and potential for earlier harvest.

For economic use of the film in Tasmanian processing crops, a yield advantage is required as there are limited benefits from early harvest. Based on early results from this project and industry feedback, a fresh market variety (Dutch Cream) was included in year two and there was a 'last ditch' effort with a processing variety (Russet Burbank).

The effect of film on yield depended on time of harvest. At final harvest there was no significant difference in yield and therefore year three focussed on fresh market varieties.

In year three, two fresh market varieties were examined and the aim was to examine advantage of earlier emergence and earlier crop development to access early season markets. Films had been designed and developed for optimal degradation time for potatoes.

Planting times

Initial results demonstrated that use of the film in Tasmania should be restricted to early plantings. Where film was used on Tasmanian potato crops planted in October / November, plants were damaged by high soil temperatures (HAL project HG06152: *Evaluation of degradable polyethylene film for potato production*).

The relationship between rate of crop emergence and soil temperature is well known. At temperatures below 6^{o}C, very little development occurs. Development is slow at 9^{o}C, and the optimum temperature is around 18-24^{o}C (Pereira and Shock). Sale (1979) found that emergence was related to temperature up to an optimum of 22-24^{o}C. In this project, crops were planted in September. As expected, use of the film was effective in increasing soil temperatures.

In this project crop emergence was one to two weeks earlier in film treatments compared to the controls, and the crops were more advanced early in the season. However, at maturity or final harvest there was no statistically significant yield advantage with use of the film. This demonstrates that for crops planted in September, there may be advantages for very early harvests, which may lead to benefits for fresh market growers who aim for the 'new' season market. Further work is warranted on crops planted even earlier in the season, as it is possible that the benefits of earlier harvest may be greater in earlier plantings.

In each of the three seasons, trials were planted later than planned, due to ongoing and unseasonally wet conditions. This highlights an issue for potential future commercialisation of the technology. Where producers are prevented from planting due to wet conditions (which can be an issue, particularly on some soil types) potential benefits from use of the film may decline with any delay in planting.

Film degradation and performance

In previous work, film degradation was slower than required, making it necessary to make holes in the film to facilitate emergence. In this project, in year one, it was also necessary to make holes in the film at emergence and several weeks after emergence the film was manually cut and removed from the mold to allow penetration of water into the mold.

Degradable films used for the year two (2010-11) trials were a result of the ongoing development and improvement of the film degradation properties – both above and below the ground.

Two different film constructions were used with both films designed to degrade and allow easy plant penetration around the time of emergence.

“Film 1” by design was engineered to whiten during the degradation process and reduce any risk of crop damage from extreme soil temperatures. “Film 1” whitened as planned, and the above ground film embrittled at around the time of emergence.

“Film 2” remained intact longer than “film 1”, and degradation occurred around a couple of weeks after emergence. At final harvest the buried edge of both films remained intact. However, the remaining film had lost its physical property strength and therefore did not interfere with harvesting machinery. It was also promising that the above ground film degraded at around the time of emergence.

Two films were used in the 2011-12 trial and both performed similarly to “film 2” in the 2010-11 trial. The buried edge remained at harvest, and some film became wrapped around bearings on the harvester. However, in the previous year although the buried edge remained at harvest, there were no issues with machinery interference. This difference may have been due (at least partly) to different bed widths used in the two seasons: 1.64m beds were used in 2010-11 and 2m beds were used in 2011-12. Embrittlement of films in year two occurred approximately 40 days after planting (12/10/10) and in year three approximately 30 days after planting (11/10/10).

Further development of films should see further improvements in degradation of the films below the soil prior to harvest. Further work may be warranted on refining film types to suit crop growing conditions, including degradation rates for earlier plantings and the use of films that whiten.

Potential water savings

Water savings early in the season are possible with use of the film (first 1-2 irrigations). Soil moisture measured at 300mm depth from about mid September to late September indicated that the control was drier than the film treatments.

During this time no irrigation was applied. In year two, film was effective in retaining soil moisture early in the season and this was most evident at around 3 to 4 weeks after planting. In year three however, visual inspection of the soil indicated that soil in the mold was drier in the film treatments compared to the control (site visit 5th October 2011, 22 days after planting).

The film can limit penetration of water into the mold, and water is 'shed' from the mold into the furrow. There was some evidence of lateral movement of water into the mold under the film. Lateral movement of water is more likely in clay soils and would not be expected in sandy soils; work done in this project was on red Ferrosols with a high clay percentage. Movement of water in soils can also be influenced by soil compaction and the presence of hard pans. Results indicate potential water savings; however these savings will depend on soil type and structure. Soil moisture content at the time of laying the film will be important, to ensure adequate soil moisture for the first couple of weeks.

Potential nitrogen fertiliser savings

Nitrate leaching was reduced with use of the film. It was not possible to quantify potential nitrogen fertiliser savings within the scope and budget of this project. Results from year one indicated that film reduced nitrogen leaching. However, these films were intact for longer than optimal for crop emergence and development. With films that degrade at around emergence, the reduction in nitrate leaching may not be substantial, but this will depend on the season and rainfall after planting.

It is unclear if any fertiliser savings would be substantial. Results highlighted the need to match nitrogen fertiliser with crop demand, and in crops using film, nitrogen fertiliser will be required earlier as the crop is more advanced. Future work examining crop N status should consider taking samples more often, and analysis should consider days from emergence.

In potatoes, nitrogen is mostly taken up from the soil in the form of nitrate, and is mostly taken up from the 0-30 soil profile. In year two, one month after planting, there was less soil nitrate in the mold at 30-60cm, for "film 2" compared to both "film 1" and the control. This may have been due to the increased growth and possibly greater top growth in "film 2"; this increased growth may have increased the uptake of N from the soil. "Film 2" remained intact longer compared to "film 1" and this may have reduced nitrate leaching to the zone below 30cm in "film 2".

Considerable time and resources are required for a more detailed examination of nitrate and potential nitrate savings, and this may not be warranted until the film technology is further developed. However, any future work on nitrogen fertiliser savings should consider the complex interactions between soil nitrogen and the effect of film on soil temperature (and therefore soil N mineralisation), different growth stages of the different treatments (i.e. film treatments were more advanced) and potentially increased top growth in film treatments.

Number of plants / final percentage emergence

There was no significant effect on number of plants per metre, and therefore no effect on final percentage emergence.

Number of stems

In year one, there were more stems in the film treatment compared to the control, and stems were also observed to be more branched in the film treatments. This may have been due to high soil temperatures as film degradation was slower than optimal. Struik et al (1989) found that the number of branches per stem was increased by an increase in stolon temperature. [In year one it was necessary to make holes in film at emergence and to cut and remove the film several weeks later.]

In year two, in the Russet Burbanks there were more stems in "film 2" compared to both "film 1" and the control; but there was no significant effect in Dutch Creams. Temperatures were greater in "film 2" compared to "film 1", indicating a temperature response in the Russet Burbanks. Increased branching was not obvious in year two, and it is most likely that in year one, the high soil temperature influenced stem branching. [In year two the film degradation commenced at around emergence time and there was no need to make holes in film nor cut or remove the film.]

In year three, there was no significant difference in stem numbers. Dutch Cream and Nicola was examined, and the films used were very similar to "film 2" used in year two. Russet Burbank is most likely more sensitive to increased soil temperature than Dutch Cream or Nicola.

Number of tubers

In year one, there were fewer tubers in the film treatment compared to the control (Russet Burbanks). However in year two, there were more tubers in the Russet Burbank film treatments, but no significant difference in the Dutch Creams. In year three there was no significant difference in either Dutch Creams or Nicola.

Tuber initiation is most likely more temperature sensitive in Russet Burbank. In year one there were fewer tubers and this may be attributed to high temperatures during the tuber initiation phase. Sale (1979) found that tuber initiation was promoted by low temperatures. High temperatures can delay, impede or inhibit tuber initiation (Struik et al, 1989). A review of potato crop development and tuber initiation in relation to temperature suggests minimum temperature (0-7^{o} C), optimum (15-20^{o} C) and maximum (25-30 ^{o}C) for tuber initiation rates (Kooman and Haverkort, 1995).

In year two however, there were more tubers (in RBs), and this is possibly also a temperature response, and may relate to timing of increased soil temperature. In year two, films degraded more rapidly than in year one.

In a commercial processing crop, it can be beneficial to have fewer tubers, if tubers are of a good size. In processing crops the target size range for french fry production is 250 to 850 grams. However, in fresh market crops the target size range is around 120 to 300 g, and can range from 60 to 350 grams (60 to 110g for packs < 1kg; 110 – 350g for packs > 1kg and loose) (Woolworths 2011), but this can depend on the variety and the market. In seed crops, producers aim for a larger number of smaller tubers. Producers manipulate tuber numbers and sizes through plant spacing.

Crop yield

The effect of film on crop yield depended on harvest time. Early in the season the film treatments were more advanced. However, at final harvest there was no statistically significant yield advantage. Use of the film reduced the length of the early growth phase (sprout development and vegetative growth), and brought forward the next phase i.e. the early growth phase was hastened.

In early harvested crops, and depending on time of harvest, yield benefits of up to 10% may be possible. Clearly, growers would need to 'weight up' the overall yield compromise for early harvest compared to harvesting at maturity, and the value of any market premiums for early harvested potatoes.

Tuber size distribution

Previous work indicated that use of the film may improve tuber size distribution (more uniform tuber sizes). It is possible that the results from the previous work were influenced by other factors possibly related to film performance. Results from the second and third year trials in the present study did not indicate more uniform tuber sizes with use of the film, and films used in these two years were designed to degrade at the desired time. In processing crops the target size range is 250 to 850 g, and for fresh market crops the target size is 60 to 350 g. Growers manipulate tuber size distribution through plant spacing (plant density), and is also influenced by other factors e.g. yield and seed size.

Crop quality

In year one there were more 'ugly' and hollow heart tubers in the film treatments. However, this was most likely a response to high soil temperatures and moisture stress related to film performance in that year. It was promising that there were no significant film effects on tuber quality in year two or year three; degradation of these films commenced at around the time of emergence.

The future for commercialisation of the technology

At an individual farm level, the net benefit of using film will depend on various factors including growing region (e.g. frost risk), planting dates, harvest dates and target markets. The yield benefit may plateau with later harvest dates and price premiums (for 'new season' potatoes) would also plateau.

The cost of applying the film is approximately $ 300/ha (however, more work is required on development of application machinery and this may influence cost of the film). Based on average fresh market prices in Tasmania, a yield increase of less than 1t/ha is required to cover film costs (
Table 10).

Results from the early harvest (22nd December 2011) in year three indicated that the mean yield from film plots was equivalent to 49 t/ha, and from the control was 41t/ha.

At final harvest (19th January 2012) the mean **total** yield from film plots was equivalent to 66 t/ha and from control plots was 62 t/ha. However, there was no statistically significant difference (at final harvest), and there was no difference in the yield of potatoes within fresh market specifications (53t/ha and 52t/ha respectively).

Table 10: Break even analysis for cost of film application based on yield increase

Cost of film including application	$300/ha
Increased income required to cover net cost of film	$300/ha
Price - average $/t (fresh market)	$600/t
Pack-out	80%
Break even increase in saleable yield required to cover cost of film	0.5 t/ha
Break even increase in total harvested yield required to cover cost of film	0.63 t/ha

Other potential benefits not included in the above calculation:

- Reduction in water use
- Reduced nitrogen fertiliser

At final harvest, a greater proportion of the crop under film was comprised of tubers larger than 350g. Note that plant spacing was larger than desired, due to limitations with planting equipment at the site, and tuber size can be manipulated through plant spacing.

Clearly, producers would need to consider whether price premiums are possible with access to early season markets, and weight this up against loss of total yield compared to harvesting later or at maturity.

In Tasmania, there has been some interest from fresh market growers who aim for early season crops and for continuity of supply. The market for the film technology, at least in Tasmania, would be limited by the small size of the industry and limited markets for early season potatoes (‘new’ potatoes which attract price premiums).

It is difficult to estimate production of fresh market potatoes in Tasmania. However, based on industry estimates, about 10% of Tasmania’s total potato production is for the fresh market, which suggests that fresh market production is therefore probably between 25,000 - 30,000 t per year.

It is also difficult to estimate the number of fresh market growers. However, assuming that about 30% of growers might have a potential use for the film, and that growers will only use film on a portion of their crop, say 20% of their crop – it is likely that the film would be used on less than 50ha of potatoes in Tasmania.

Integrated Packaging is currently investigating potential for the film technology in other potato growing regions in Victoria and South Australia.

Once the target market for the technology has been more clearly defined, and potential benefits are examined in the context of that target market, a more comprehensive cost: benefit analysis may be warranted.

A summary of findings to date, in Tasmanian grown potatoes, includes:

- Use of the film increases soil temperature;
- Use of the film should be restricted to early plantings, as there is a risk of crop damage from high temperatures with later plantings;
- Increased soil temperatures result in a more rapid sprout development phase and earlier crop emergence, i.e. a reduction in the length of the early growth phase;
- There are potential yield advantages with very early harvest times. However, there may be no advantage at maturity;
- Earlier emergence and shortening of the early growth phase means that crops can be harvested earlier to take advantage of early season market premiums (particularly for fresh market, salad varieties);
- There is currently limited advantage with use of the film in Tasmanian processing crops as there are no premiums or advantages in earlier harvest;
- Films have been developed to degrade and become brittle at about the time of emergence to allow the plants to break through the film;
- Some films have been designed to whiten after a week or two, to reduce the risk of extreme soil temperatures which can damage the crop.These films may be useful for crops planted in late August or early September, when there is greater risk of high temperatures (as temperatures increase in the Spring). Extreme soil temperatures pose a risk until the film degrades and/or canopy cover is sufficient to shade the soil surface;
- Adequate soil moisture at the time of laying the film is likely to be important;
- There may be some savings in nitrogen fertiliser and water (savings in the first 1-2 irrigations);
- Herbicides were less effective for controlling weeds in film treatments compared to controls. This may have been due to disturbance of the soil and/or the effect of high temperatures under the film.

Critical success factors for commercialisation of the technology include:

- Development of machinery which can: effectively lay and anchor the film, operate in undulating paddocks and operate under varying soil moisture conditions (development machinery has been ‘on hold’ until results of research confirm feasibility);

- Development of herbicide protocols (e.g. products, rates and possible application in one pass with film application);
- Development of grower guidelines or 'rules of thumb' for use of the film e.g. soils, crop husbandry, performance with different potato varieties, where or when to use which type of film, and planting 'windows'.

Adoption of the technology may be limited by:

- Increased frost risk in some regions for very early plantings;
- Season variations affecting the decision to use film;
- The potentially small number of growers for whom the use of film would be advantageous.

Other research and development required for further development of the technology includes:

- Evaluation of performance in very early plantings (e.g. crops planted May to July), and design of films to suit very early plantings;
- Evaluation of performance on different soil types;
- Evaluation of response of different potato varieties (the response may be variety dependent);
- Further evaluation of potential yield advantages at final harvest at maturity.

It bears repeating that research over these three seasons was conducted at one site (Forthside Vegetable Research Station in Tasmania on Red Ferrosol soil) and only using two fresh market varieties (Dutch Cream and Nicola).

Technology transfer

A field day was conducted for members of the CRC for Polymers project team (Project: Degradable polyolefin films for agricultural production) on 16th February 2010 at the trial site. Attendees included representatives from Integrated Packaging Pty Ltd, Queensland University of Technology, University of Queensland, CRC for Polymers, CSIRO, and RDS Partners (then Rural Development Services).

A field day was conducted at the trial site on 26 October 2010. Attendees included growers, processors, agronomist and researchers.

Adoptability of film technology in potatoes was reviewed including:

- Telephone consultation with growers and industry stakeholders;
- A review of the characteristics of the innovation, using the Rogers framework (Rogers, 2003): relative advantage, compatibility, complexity or simplicity, trialability, and observability;
- Trialling the ADOPT model (model developed by the Future Farm Industries CRC) (Keuhne et al, 2011); and
- Preparation of a brief outline/report for the Reference Group.

The original project plan included delivery of results to a National Conference. However, the technology requires further development and is not yet ready for commercialisation. Integrated Packaging Pty Ltd is currently presenting findings to industry committees. Industry feedback will guide future development efforts and confirm feasibility of further work in other regions e.g. in Victoria and South Australia.

If further work continues, to ensure adoption of the technology, future activities should target:

- Increased grower awareness of the film technology, including trials in the target districts;
- Increased engagement with grower groups and grower advisors;
- Working closely with a larger grower to “champion” the technology (initial diffusion of technology is more likely with larger growers);
- Further research and development to refine the technology;
- Development of targeted information to support grower decision making e.g. information on which film to use, planting ‘windows’, performance on different soils.

Recommendations

For development of this technology in the future, activities should include:

- Further research and development to refine the technology including:
    - Evaluation of performance in very early plantings e.g. crops planted May to July;
    - Development and design of films to suit very early plantings;
    - Evaluation of performance on different soil types, and in different regions;
    - Evaluation of response of different potato varieties;
    - Development of machinery which can: effectively lay and anchor the film, operate in undulating paddocks and operate under varying soil moisture conditions (development of dedicated machinery has been 'on hold' until results of research confirm feasibility);
    - Development of herbicide protocols (e.g. products, rates and possible application in one pass with film application);
- Increased grower awareness of the film technology, including trials in target districts;
- Increased engagement with grower groups and grower advisors;
- Working closely with a larger grower to "champion" the technology (initial diffusion of technology is more likely with larger growers); and
- Development of targeted information to support grower decision making e.g. information on which film to use, planting 'windows', performance on different soils.

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References

Fulton, D. and Lucas, D. (2009), *Evaluation of degradable polyethylene film for potato production*. Horticulture Australia Project No. HG06152.

Kooman, P.L. and Haverkort, A.J. (1995), *Modelling development and growth of the potato crop*. In: Potato Ecology and Modelling of Crops under Conditions Limiting Growth. Proceedings of the Second International Potato Modeling Conference, held in Wageningen 17-19 May, 1994. Haverkort, A.J. and KacKerron, D.K.L., editors. p47.

Kuehne, G., Llewellyn, R., Pannell, D., Wilkinson, R., Dolling, P., & Ewing, M. (2011), *ADOPT: a tool for predicting adoption of agricultural innovations*. Paper presented at the 55th Annual National Conference of the Australia Agricultural & Resources Economics Society, Melbourne, Victoria, February 8-11, 2011.

Rogers, E. M. (2003), *Diffusion of Innovations* (5th ed.), Free Press, New York.

Sale, P.J.M. (1979), Growth of potatoes (*Solanum tuberosum* L.) to the small tuber stage as related to soil temperature. Aust. J. Agric. Res. 30:667-675.

Struik, P.C., Geertsema, J. and Custers C.H.M.G. (1989), Effects of shoot, root and stolon temperatures on the development of the potato (*Solanum tuberosum* L.) plant. III Development of tubers. Potato Research 32, 151-158 (abstract).

Woolworths (2011), Produce specifications. Washed and brushed, Dutch Cream, Grade One.