Final Report

Skin Spot Management - fungicide application methods

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1. SUMMARY

A number of methods of seed tuber treatment have been investigated with the aim of improving the coverage and hence the efficacy of fungicide treatment. Surface coverage, more than residue level is important for disease control. Conventional hydraulic spray applicators on roller tables were more effective than a spinning disc applicator.

Four potential ways to improve tuber coverage and residues have been identified for conventional roller table spray applied equipment. These include swopping to a more effective nozzle, avoiding using a downward fan, improving the configuration of spray nozzles over a roller table and using an adjuvant in the spray solution to improve wetting and spreading.

A range of alternative methods of applying seed tuber treatments were evaluated. Cold and hot fogging gave inconsistent coverage on different surfaces of tubers. Dipping of tubers was very effective at achieving good surface coverage and an optimum dilution for the dipping solution has been identified. However, there are potential drawbacks for dipping and these are described. Different ways to dry tubers using an air knife were evaluated and optimum use of this system of drying tubers is described.

A key component of the project was to determine the biological efficacy of a fungicide, in preventing skin spot, under the various application methods. Field trials over two seasons have been completed and include a repeat evaluation of specific treatment methods undertaken in the first year. The tubers from harvest 2010 require further storage until visual analysis of skin spot symptoms can be satisfactorily carried out and the results will be reported as an annex to this report in May 2011.

Results to date have provided indications where improvements in existing equipment can be made. These include:

- Exchanging a Delavan hollow cone nozzle for the superior Lurmark Mint Green nozzle.
- Adding an adjuvant to the spray solution to improve coverage. This was effective in year 1 with Maris Piper but not King Edward but improved residues in year 2 with Desiree. By testing three contrasting adjuvants it is clear that they are not all effective and correct selection is important.
- Improvements in configuration can increase coverage and residue. Many roller tables rely on a single spray nozzle but increasing the area of table on which spray mist is applied by increasing the number of nozzles used improved application. To ensure that the spray volume is minimised, selection of lower output nozzles will be important. In this project the hollow cone nozzle with the least output was the Lurmark Grey
- Switching off a downward fan. The results in the first year of experimentation suggested that a downward fan would not improve coverage or residue

The seed tubers used in year 2 of experimentation were larger than in year 1 (35-55mm cf. 35-45mm). Without any other changes, the levels of coverage and residue were higher in the second year. This demonstrates that on a standard roller table larger tubers offer a greater target for the spray. Very few growers have variable pitch roller tables that can be adjusted to permit changes in pitch to present more tuber surface when smaller tubers are graded. As a

result, those treating seed potatoes on standard roller tables can only optimise coverage and residues by keeping the roller table as full as possible. To achieve this, more growers should utilise hoppers to collect seed and release in a uniform way.

Throughout the two years of experimentation, there was no evidence that dose or coverage affected seed tuber vigour or growth.

2. INTRODUCTION

Skin spot, caused by *Polyscytalum pustulans*, is a disease that has sporadic but potentially economically damaging consequences for those growing, packing and processing susceptible varieties such as Cara, Saturna and King Edward. Infected stocks can be treated with fungicides applied to seed. However, since 2-aminobutane (2-AB), one of the most effective fungicides for skin spot control, lost its essential status in 2007, there are concerns that there might be a consequential increase in the prevalence of this disease. As the pathogen is primarily seed-borne, minimising the impact of disease has traditionally focused on planting seed free from visible skin spot symptoms. However, environmental conditions also significantly affect disease development. This causes difficulties in determining the risk of disease developing in store, particularly because the disease has a long latent period. Thus visible signs of infection on tubers can take many weeks to appear after harvest.

Efficacy data on seed tuber treatment applications indicates that for many diseases, disease reductions fall well below the standards achieved by field spraying for control of foliar disease. This is considered to be due to the poor treatment of seed tubers rather than the lack of effectiveness of fungicides currently available. Existing residue data has demonstrated that the quantity of fungicide, applied as a spray to seed tubers, that reaches the target is frequently under 50%. Similarly, depending on tuber shape, the coverage of tuber surface is often well below two-thirds of the surface area. With at least one new and novel seed treatment likely to be introduced in 2011, there remains an imperative to find more effective ways to apply tuber fungicides.

For maximum efficacy the entirety of the tuber surface should be covered with the minimum effective concentration of fungicide. As described above, most current seed tuber application systems fail to provide this level of coverage. This failure was to be addressed at SAC and SBCSR (at the outset of the project, known as Sutton Bridge Experimental Unit) by different approaches:
There were three principal objectives for this project:

- Evaluation of novel application/delivery methods of fungicide.
- Evaluation of the efficacy of some novel seed tuber treatments
- Assessment of the potential for tuber dipping as an effective tuber treatment

At SAC, conventional spray mist roller table treatments were evaluated using different nozzles (with or without use of a downward fan), different nozzle configurations and the addition of adjuvant to the spray solution. Comparison was made to the spinning disc application method; dipping tubers; and an untreated control.

At SBCSR, two novel approaches were evaluated. The first was to examine developments in application technology that potentially lead to more effective and better controlled coverage of chemicals to potato tubers in store. The second was to re-examine the benefits and disadvantages of tuber dipping and, where possible, to provide practical procedures to overcome the disadvantages.

3. MATERIALS AND METHODS

3.1. General

In late 2008, a common seed stock was obtained for experimental work at both SBCSR and SAC. This was an untreated King Edward seed stock (35-45mm; Crop ID 02 07 1024 02), ex Greenvale AP, supplied in 50kg bags. This stock was suspected as having skin spot infection when purchased and was assessed for this disease at treatment. A second stock, of untreated Maris Piper, also supplied in 50kg bags with silver scurf infection was used at SAC to evaluate novel application/delivery methods only.

In late 2009 a common seed stock was again used at both SBCSR and SAC. This was an untreated Desiree seed stock (35-55mm; SE2, from Mr Patrick Sleigh, West Fingask, Oldmeldrum, Aberdeenshire) supplied in 50kg bags. The stock used was also suspected as having skin spot infection when purchased and was assessed for this disease at treatment using DNA testing methodology.

In late 2010 a further tuber stock for use in experiments at SBCSR was obtained. This was an untreated Desiree seed stock (35-55mm, SE3 from Mr Patrick Sleigh, West Fingask, Oldmeldrum, Aberdeenshire). It was delivered to SBCSR 18th October 2010. This stock was identified by PCR as high skin spot risk prior to harvest and supplied in 25 kg bags at harvest for immediate post harvest treatment.

All seed was stored at 5°C and ambient humidity prior to treatment and planting. Fungazil 100 SL (100 g/litre imazalil (9.26% w/w) supplied by BASF plc was used as the fungicide used at both institutes throughout the project.

3.2. Experiments at SAC

3.2.1. Evaluation of novel application/delivery methods of fungicide 2009/10

Treatments were applied mainly on 9 April 2009. Fungazil (active ingredient - imazalil 100g/l) was applied at 100 ml product /tonne to Maris Piper (carrying a burden of silver scurf) and King Edward (which was believed to have a high risk of skin spot). The fungicide was applied using a series of hydraulic nozzles (with or without a downward fan), different configurations of nozzles and with different adjuvants. The nozzles considered for use are shown in table 2 and those used are listed in table 3. The treatments are described in table 4. These treatments were compared to the fungicide applied through a spinning disc applicator, tubers dipped in a fungicide solution (200 tubers were dipped in a 1:50,000 solution of Fungazil for 1 minute, after which the tubers were removed and dried using forced ventilation) and an untreated control.

The untreated control tubers were passed across the grader before any spray applied treatments were made. The roller table was cleaned and dried between treatments to limit cross contamination or build up of imazalil residues between treatments. After treatment, tubers were placed in unused paper sacks and the tops left open to allow tubers to dry.

The effectiveness of fungicide application was measured in three ways, by:

- Residue analysis
- Estimation of surface coverage
- Biological efficacy

A sample of 20 tubers selected at random from each treatment was sent to Eclipse Scientific for determination of imazalil residue analysis.

To each (spray applied) treatment, fluorescein dye was added to the spray solution. After treatment 10 tubers were selected at random and the treated surface area assessed under UV light, as well as in natural light.

Using tubers from each treatment a replicated randomised block trial was established. The trial details are shown below. Assessments were made of emergence and crop vigour and after lifting tubers were stored in an ambient store before evaluating disease development and thus efficacy of control.

Location of test facilities:	Pitinnan, Daviot, Aberdeenshire (GR NJ756296) – Courtesy Mr Patrick Sleigh
Trial design:	Randomised block
Replicates:	4
Plot size:	4 drills x 6.25m
Tuber spacing:	25cm
Tubers per plot:	100
No. plots:	44
Husbandry treatments:	As per adjacent farm crop.
Trial Maintenance:	Farmer (fertiliser, weed control, blight and insecticide sprays)
Date of planting:	26 May 2009
Date of harvest:	27 November 2009

Pre-planting, the Maris Piper seed was severely infected with silver scurf and the King Edward with severe skin spot

3.2.2. Evaluation of novel application/delivery methods of fungicide 2010/11

Of the 11 treatments tested in 2009/10, five were selected for further testing. The same equipment and procedure was used as in the previous year. Only one stock was treated; that of Desiree SE2, with larger seed size than that used in the first year (35-55mm). Treatments were applied on 15 April (treatments 4 & 8) and 20 April (treatments 5 & 6) and are shown in table 5. Visual surface area coverage, residue analysis and biological efficacy were again used to measure the effectiveness of treatments. A replicated randomised block field trial was planted from the treated tubers. Assessments were made of emergence and crop vigour and, after lifting, tubers were stored before evaluating disease development and thus efficacy of control.

Location of test facilities:	Balruddery Farm (SCRI), Inchture, Dundee, Tayside (GR NO 303329)
Trial design:	Randomised block
Replicates:	4
Plot size:	4 drills x 6.25m
Tuber spacing:	25cm
Tubers per plot:	100
No. plots:	20
Husbandry treatments:	As per adjacent farm crop.
Trial Maintenance:	Farmer (fertiliser, weed control, blight and insecticide sprays)
Date of planting:	17 May 2010
Date of harvest:	27 October 2010

	Common scab	Powdery scab	Silver scurf	Skin spot
% Incidence	60	38	66	86
% Severity	4.1	1.1	4.4	3

TABLE 1. DISEASE LEVELS ON DESIREE SEED AT TREATMENT 2010/11

Manufacturer	Type	Part number	Output per nozzle ml/min	Pressure bar	No. of nozzles	Application rate l/t @ 6 t/h
Delevan	Hollow cone	HC 1.5	80	2	2	1.6
Delevan	Hollow cone	HC 2	108	2	2	2.15
Lurmark (Mint Green)	Hollow cone	HAF014-80	92	3	2	1.8
Lurmark (Grey)	Hollow cone	HAF007-80	46	3	4	
Lurmark (FulcoTip)	Solid cone	FCX 6	53	2	4	2.1
TeeJet	Cone jet	TXVS-2	110	2	2	2.2
TeeJet	Even flat fan	TP 400 IE	320	2	1	3.2
Syngenta		AZ IF-0068	?	?	?	?
Syngenta		Original Amistar nozzles	?	?	?	?

TABLE 2. NOZZLES CONSIDERED FOR EVALUATION

						Application rate l/t		
Manufacturer	Type	Part number	Output per nozzle mls/min	Pressure (bars)	No. of nozzles	Maris Piper 2009	King Edward 2009	Desiree 2010
Delevan	Hollow cone	HC 1.5	80	2	2	1.69	1.95	1.86
Lurmark (Mint green)	Hollow cone	HAF014-80	92	3	2	1.99	2.29	2.04
Lurmark (Grey)	Hollow cone	HAF007-80	46	3	4	2.21	2.50	2.14
Spinning disk				-	1	2.80	3.22	-

TABLE 3. DETAILS OF HYDRAULIC NOZZLES AND APPLICATION RATES USED IN EXPERIMENTS

No.	Nozzle type	Configuration / adjuvant
1	None – Untreated control	-
2	Delavan Hollow cone	Two nozzles to treat width of roller table + downward fan
3	Lurmark Mint Green Hollow cone	Two nozzles to treat width of roller table + downward fan
4	Delavan Hollow cone	Two nozzles to treat width of roller table
5	Lurmark Mint Green Hollow cone	Two nozzles to treat width of roller table
6	Lurmark Grey Hollow cone	Four nozzles in pairs over the roller table + downward fan
7	Delavan Hollow cone	Adjuvant A - Banka (alkyl pyrrolidone)
8	Delavan Hollow cone	Adjuvant B - Silwett L-77 (80% w/w polyalkylene oxide modified heptamethyltrisiloxane)
9	Delavan Hollow cone	Adjuvant C - Slippa (polyalkyleneoxide modified heptamethyltrisiloxane)
10	Tuber dipping	Tubers dipped in a solution of Fungazil (tubers washed in water and drained for 5 mins in fresh air submerged for 1 min drained and dried as single layer using a fan
11	Spinning disc	

Tuber growth stages at application: Maris Piper – 213 (occasionally 214), King Edward - 214 (occasionally 215)

TABLE 4. TREATMENTS AT SAC 2009/10

No.	Nozzle type	Configuration / adjuvant
1	None – Untreated control	-
4	Delavan Hollow cone	Two nozzles to treat width of roller table
5	Lurmark Mint Green Hollow cone	Two nozzles to treat width of roller table
6	Lurmark Grey Hollow cone	Four nozzles in pairs over the roller table + downward fan
8	DelavanHollow cone	Adjuvant B - Silwett L-77 (80% w/w polyalkylene oxide modified heptamethyltrisiloxane)

Tuber growth stage at application: Desiree – Desprouted – 200

TABLE 5. TREATMENTS AT SAC 2010/11

3.3. Experiments at SBCSR

3.3.1. Assessment of cold mist application of fungicide

The production and controlled distribution of ultra low volume droplets is widely used for effective delivery of many chemicals for use in many industries including the food industry.

The Dynafog Cyclone generates directional ultra low volume droplets at a constant flow of 100 ml/min. The vertical projection angle of the flow can be varied. Preliminary experiments to gauge coverage provided by the cyclone were carried out in a 6 tonne store. Four double racks of trays (75cm x 50cm x 20cm) were placed on the floor around the store. Two trays were directly in line with the cyclone flow output and two out of direct line. Each upper tray was filled with around 25 kg washed and overnight dried tubers to provide at least three layers per tray. A fan (50 cm) was available in the store to provide additional circulation when required.

The recommended dose of Fungazil is 100 SL100 ml/tonne of tubers, a 1 minute application/per tonne with the Dynafog. One minute was used as a standard application time although less than one tonne of tubers were present in the store. For health and safety reasons water rather than active fungicide was used in these initial experiments.

Fluorescein based dyes were considered for visualising and quantifying coverage. However, health and safety concerns over the control of such hazardous chemicals within the experimental setup outweighed any perceived advantage. Two different methods were used to assess tuber coverage obtained with the Dynafog Cyclone.

In the first, water sensitive paper strips were placed at each of the different tuber layers within each tray, in both visible and hidden positions when viewed from above. In the second, a concentrated blue food dye was added to the water to provide a direct visual estimate of coverage.

3.3.2. Assessment of hot fog mist application of fungicide

This method of application was assessed in years 2008/2009, 2009/2010 and 2010-2011. In the first two years, treatments were applied at or close to planting. In year 2010-2011, tubers harvested 13th October 2010 were received and treated on the same day 18th October i.e. 5 days post harvest.

Xeda (http://www.xeda.com/) provided a sample of their product specially developed for hot fog application, Xedazil, an imazalil based fungicide fogging formulation containing 10% of Imazalil, produced by Janssen Pharmaceuticals. Their recommendations for application with an electrofogger were followed, Xedazil aerosol at 100g/t with an exit temperature average of 180°C.

Two x ½ tonne box were half filled with bulk Hermes. Nine nets filled with more than 50 target seed tubers were loaded in each box and covered with Hermes to fill the box. One box was stacked on the other and a plenum and fan positioned as in figure 1. Gaps between boxes and box and floor were sealed. Store and tuber temperature was 5°C. Xedazil was applied by electrofogger, as recommended. Following application the store atmosphere was recirculated for 4 hr with the plenum fan at low speed and air directed into plenum.

The tubers were left overnight before the apparatus was dismantled. Selected tubers from each net were cut in two, top and bottom halves placed into labeled paper bag for subsequent residue analysis. The remaining treated seed were stored at 5°C pending delivery to SAC for inclusion in a field trial. A related Xeda product (described here as Xedazil II) was similarly applied for comparison.

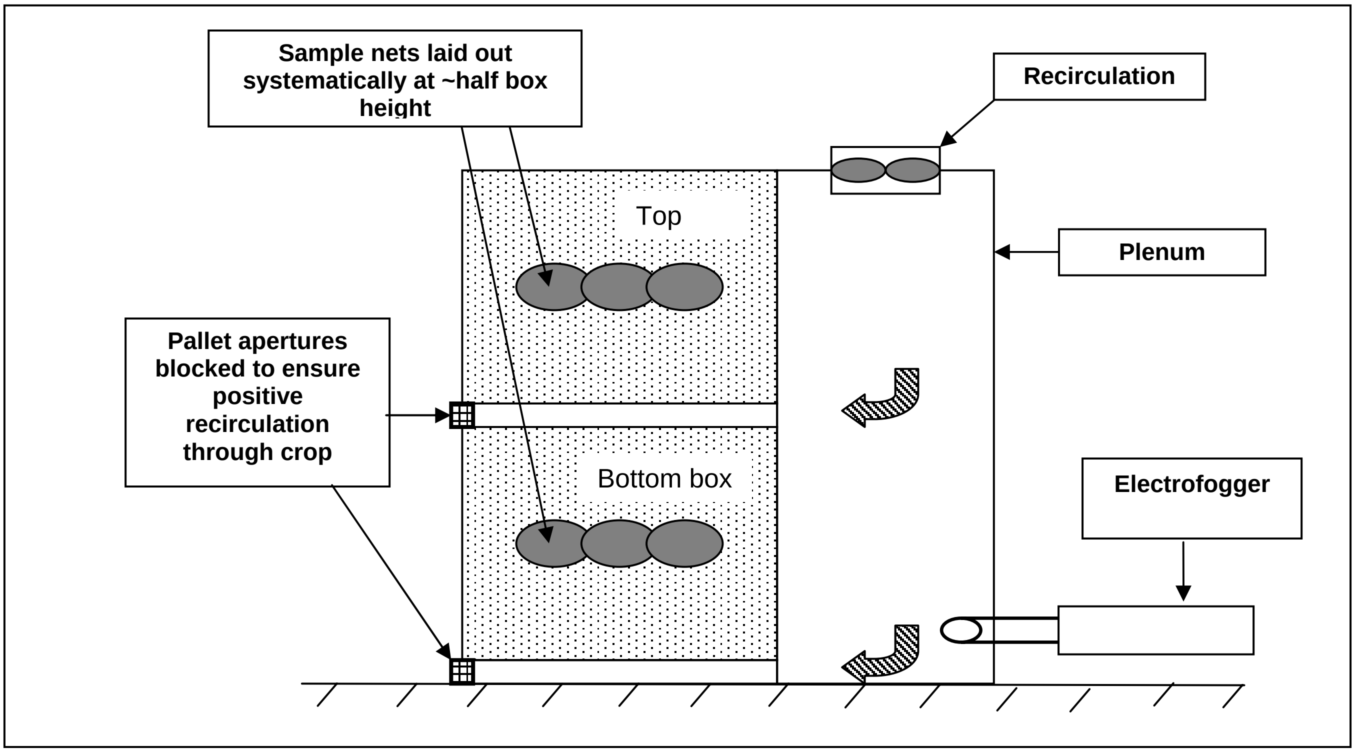


FIGURE 1. SCHEMATIC DIAGRAM SHOWING LAYOUT FOR HOT FOG APPLICATION

3.3.3. Dipping application of fungicide to seed tubers

Dipping offers a method of complete coverage at controlled concentrations of fungicide, each tuber can be completely exposed to an effective dose of fungicide. The following experiments were carried out to determine the effective range of fungicide concentrations on tubers to prevent skin spot infection. For the purposes of this component of the project, dipping was separated from drying.

100 tubers were washed for 2 minutes, drained and placed in a seed net. They were left a further 5min before treatment. Three nets were simultaneously submerged in 50 l tap water containing Fungazil at various dilutions (1/1000 - 1/50,000) for 1 min. Five randomly selected tubers from each net were placed in paper bag, pending residue analysis. The remaining tubers were decanted from the net and spread as single layer on a mesh tray 1.5 m in front of

a medium speed fan. They were left to dry further overnight in a room at 10°C before being stored at 5°C pending delivery to SAC for inclusion in a field trial.

3.3.4. Evaluation of methods for drying of potato tubers

One potential problem with the wetting or dipping of tubers is that rots become more likely and can also be spread to other tubers via contaminated solutions. Indeed most store managers spend a great deal of time and effort in ensuring their crop is dry. However there are some potential advantages and a list of advantages and disadvantages is included in the Appendix. This section details attempts to overcome a disadvantage by evaluating methods of effectively drying potatoes. Drying is best achieved on a roller and should be accomplished within the time from last wetting to end of roller and should be effective on a fully laden roller. The desired result is one in which the tubers can safely be stored without compromising their biological integrity. Practical solutions investigated included air drying e.g. fan or air knife, with or without warm air.
Commercially graded tubers are stored at a range of different degrees of hydration. Commercial fungicide application does not include drying prior to storage or bagging up, and the low additional volumes of solution apparently are not a problem.

In the experiments below the approach was that all the additional water taken up by or on the tuber should be removed within the time on the roller table.

The standard experiment consisted of a tray of 100 tubers of known dry weight which were dipped for 2 minutes in ambient temperature tap water, briefly drained and tipped into a dry tray. The wet weight of tubers and tray was measured prior to the trial. Typically 100 tubers, weight around10 kg, absorbed around 50 g water. For comparison Fungazil 100 SL is typically applied at 100 ml/tonne and stored without drying.

Initial trials were based on a single layer of static tubers in an open tray with or without fans. At 12°C, dipped tubers took around 16 hours to lose the additional water. A fan greatly improved the rate of water removal. With a fan at medium speed 1m from the tubers 1 hour was sufficient to remove the additional water.

Subsequent experiments took place on a Downs 2.2m x 0.75m roller table on which various parameters could be altered. These included: speed of roller, a Vostermans Ventilation BV model. TB4E50 fan to increase air flow, a baffle placed under the roller table to deflect the airstream, a cowl to direct airflow, a 31” airknife which could be operated at various air pressures and at different angles to the tubers. The combinations of parameters compared are given in the results. Following the first pass, the tubers were immediately passed back across the roller table for a second time.

3.3.5. Efficacy of treatments on disease (skin spot) development

3.3.5.1. 2008-2010

In the 2008-2010 season 450 tubers of each sample was sent to SAC (29/4/2009) to be included in the field trial (see section 3.2.1. for details). Simultaneously 50 tubers of each sample were sent to Fera (CSL at the start of this project) for skin spot DNA testing prior to planting.

The treatments included in the trial and sent for residue testing were:

A = washed control untreated
B = 1/1,000 Fungazil dipped
C = 1/10,000 Fungazil dipped
D = 1/50,000 Fungazil dipped
E = Xedazil hot fogging treatment
F = Xedazil II hot fogging treatment

Following a rain-delayed harvest, sample tubers from each plot in the SAC trial were received at Sutton Bridge on 11th December 2009. Tubers were immediately graded to remove diseases and defects and placed at 7°C and 95% RH for long term storage. Disease assessment was made on 100 tubers of each treatment 25th May following 23 weeks of storage.

3.3.5.2. 2010-2011

Tubers were received on 16th April 2010. Limited tuber numbers and field plot space reduced the numbers of treatments that could be evaluated. The following treatments were applied:

A = Unwashed untreated control
B = 1/1000 Fungazil dipped
C = Xedazil hot fogging treatment

Tubers from imazalil treatments were sent for residue testing. Tubers from each treatment were returned to SAC (29/4/2009) to be included in the field trial (see section 3.2.2. for details).

Simultaneously 50 tubers of each sample were sent to CSL (Fera), for skin spot DNA testing prior to planting.

Following another rain-delayed harvest, sample tubers from each plot in the SAC trial were received at Sutton Bridge on 24th Nov 2010. Tubers were immediately graded to remove diseases and defects and placed at 7°C and 95% RH for long term storage. Disease assessment will be made in 2011.

4. RESULTS

4.1. Experiments at SAC

4.1.1. Evaluation of novel application/delivery methods of fungicide 2009/10

4.1.1.1. Residue analysis

The results are shown in table 6. The greatest residue detected on either variety was 2.3 (mg/kg). All residue levels were under 25% of the potential maximum dose with most results under 15% of potential dose. Treatment 6 (4 Lurmark Grey nozzles) consistently gave the greatest residue. The results also suggested that use of a downward fan was less effective than without a fan, that Silwett was the most effective adjuvant and residues were increased on Maris Piper (but not King Edward) when compared to the same application without adjuvant. Residues from the spinning disc applicator were the lowest of all treatments.

4.1.1.2. Surface area coverage

Overall there was close correlation between the two methods of surface coverage assessment (table 7, figure 2). Correlation coefficients were 0.85 (Maris Piper) and 0.82 (King Edward) (table 8)

4.1.1.3. Biological efficacy

4.1.1.3.1. Emergence and vigour assessments

Plants were assessed for emergence and vigour and the results are shown in table 9. There were few differences between spray applied seed tuber treatments and the untreated control in emergence and vigour. There was a trend for the dipping treatment to have a reduction in emergence and vigour but the effects were mostly non-significant.

4.1.1.3.2. Disease assessments after harvest

Silver scurf and skin spot developed on both varieties after storage. The incidence and severity of infection for each treatment are shown in table 10. Average severity levels for both diseases were low, although surface area coverage is never high with skin spot and a few spots can have a major effect out of proportion to the surface area. The relationship between imazalil residue and disease incidence is shown in figure 3. These confirm that disease control was proportional to residue. In consequence, the correlation between residue and disease incidence was high for both diseases, but particularly King Edward (table 8).

Test no.	Treatment		Result (mg/kg)
335	2	M.Piper.	0.56
336	3	M.Piper	1.2
337	4	M.Piper	0.93
338	5	M.Piper	1.3
339	6	M.Piper	2.3
340	7	M.Piper	1.4
341	8	M.Piper	1.9
342	9	M.Piper	0.97
343	11	M.Piper	0.3
344	2	King Edward	0.66
345	3	King Edward	0.86
346	4	King Edward	1.6
347	5	King Edward	0.97
348	6	King Edward	1.5
349	7	King Edward	1.1
350	8	King Edward	1.6
351	9	King Edward	1.0
352	11	King Edward	0.55

Average residue levels

Treatment	mg/kg
2	0.61
3	1.03
4	1.265
5	1.135
6	1.9
7	1.25
8	1.75
9	0.985
11	0.425

TABLE 6. RESIDUE ANALYSIS SAC 2009/10 (SEE TABLE 4 FOR AN EXPLANANTION OF THE TREATMENT CODES)

Date	09/04/2009	09/04/2009
Method of assessment	Visual	UV light
	%area	%area
Treatment number and name		
1. M Piper Untreated Check	-	-
2. M Piper Delevan + fan	42	68.8
3. M Piper Lurmark Mint Green + fan	62.2	70.6
4. M Piper Delevan – fan	50.6	71
5. M Piper Lurmark Mint Green – fan	62.7	80.6
6. M Piper Lurmark Grey 4 nozzles + fan	90.44	76.4
7. M Piper Delevan + Banka	59.2	55.2
8. M Piper Delevan + Silwett L-77	48	69.4
9. M Piper Delevan + Slippa	45.4	60.8
10. M Piper Dipping	-	-
11. M Piper Spinning disc	29.2	29.6
1. K Edward Untreated Check	-	-
2. K Edward Delevan Standard + fan	48.2	70.4
3. K Edward Lurmark Mint Green + fan	84.7	77.2
4. K Edward Delevan Standard – fan	46	73
5. K Edward Lurmark Mint Green – fan	42.6	65.6
6. K Edward Lurmark Grey 4 nozzles + fan	97.1	85
7. K Edward Delevan Standard + Banka	72.4	61.2
8. K Edward Delevan Standard + Silwett L-77	65.8	64.4
9. K Edward Delevan Standard + Slippa	65.6	69.6
10. K Edward Dipping	-	-
11. K Edward Spinning disc	48	34.6
LSD (P=.05)	-	-
CV	-	-

TABLE 7. ESTIMATED SURFACE AREA COVERAGE BY DIFFERENT NOZZLE SYSTEMS ASSESSED BY TWO METHODS. SAC 2009/10

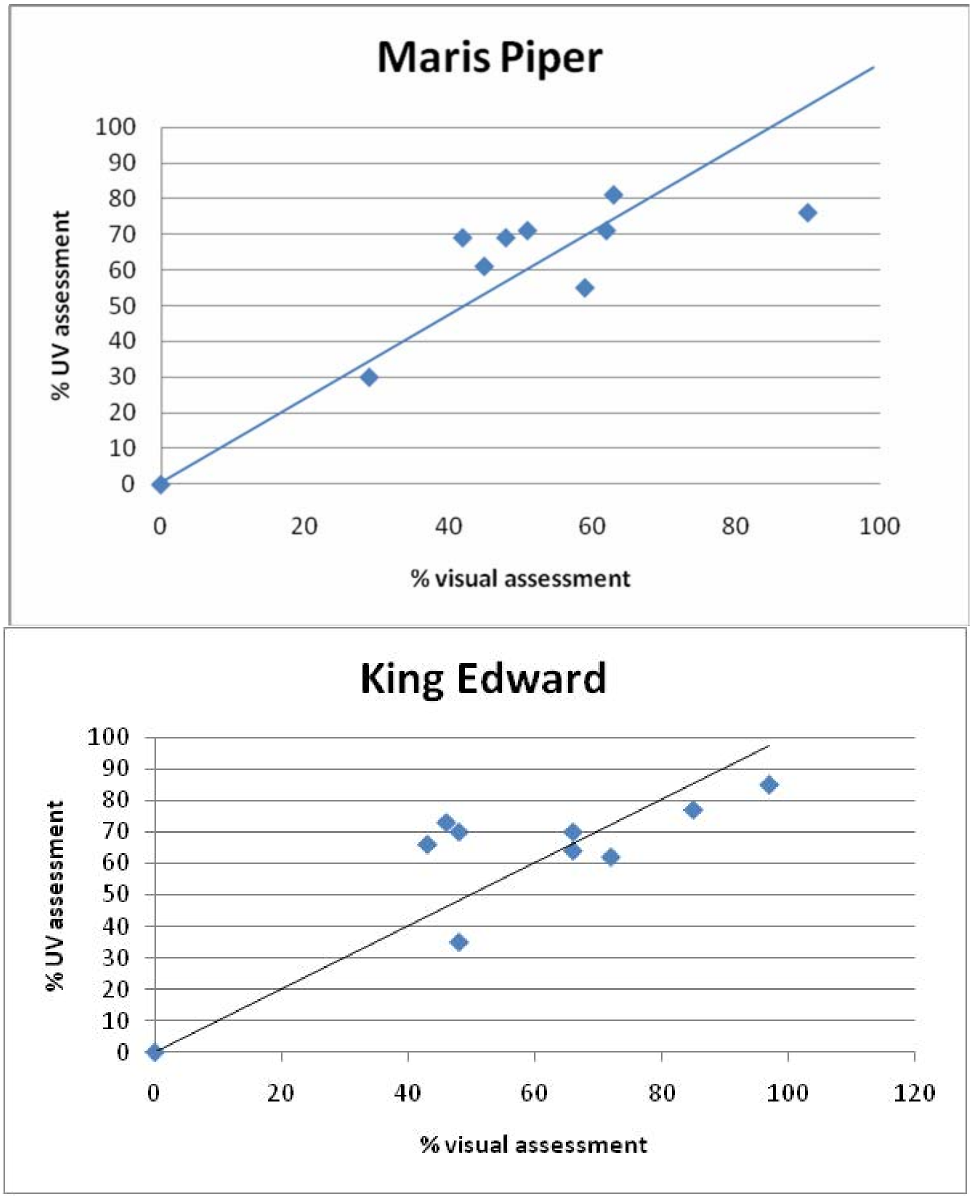


FIGURE 1. RELATIONSHIP BETWEEN VISUAL AND UV METHODS OF SURFACE COVERAGE

	Maris Piper				
	Residue (mg/kg)	% coverage - visual	% coverage - UV	Silver scurf incidence	Skin spot incidence
Residue	1				
% coverage – visual	0.87	1			
% coverage - UV	0.72	0.85	1		
Silver scurf incidence	-0.82	-0.86	-0.90	1	
Skin spot incidence	-0.75	-0.78	-0.70	0.83	1

	King Edward				
	Residue (mg/kg)	% coverage - visual	% coverage - UV	Silver scurf incidence	Skin spot incidence
Residue	1				
% coverage – visual	0.66	1			
% coverage - UV	0.78	0.82	1		
Silver scurf incidence	-0.93	-0.55	-0.77	1	
Skin spot incidence	-0.92	-0.81	-0.88	0.82	1

Table 8. Correlations between residue levels after treatment, coverage of tuber using two methods of assessment and incidence of silver scurf or skin spot after harvest and storage

Date Assessment Unit	17/06/2009 Emergence* No's/plot		17/06/2009 Vigour** 1-9		25/06/2009 Vigour 1-9		03/07/2009 Vigour 1-9	
Treatment number and name								
1. M Piper Untreated Check	48.3	abc	6.3	a	8.8	a	7.3	a
2. M Piper Delavan + fan	48	abc	7.8	a	8.5	a	7.5	a
3. M Piper Lurmark Mint Green + fan	45.5	a-d	7.5	a	8.3	a	7.3	a
4. M Piper Delevan – fan	49	a	7.3	a	8.5	a	7	a
5. M Piper Lurmark Mint Green – fan	47.8	abc	6.5	a	8.5	a	7.3	a
6. M Piper Lurmark Grey 4 nozzles + fan	47.3	abc	6.8	a	8	ab	6.5	a
7. M Piper Delavan + Banka	48.8	ab	7	a	8.5	a	6.8	a
8. M Piper Delavan + Silwett L-77	48.5	abc	6.3	a	8.5	a	7	a
9. M Piper Delavan + Slippa	48.5	abc	7	a	8.5	a	6.3	a
10. M Piper Dipping	44	bcd	5.5	a	7.5	abc	6	a
11. M Piper Spinning disc	48	abc	7	a	8.5	a	7.3	a
1. K Edward Untreated Check	44.3	a-d	6	a	6.8	bcd	6.5	a
2. K Edward Delavan + fan	47.8	abc	6.5	a	7.5	abc	7.5	a
3. K Edward Lurmark Mint Green + fan	45	a-d	7	a	7.3	abc	7.8	a
4. K Edward Delavan – fan	43.8	cd	4.8	a	6	cd	6.5	a
5. K Edward Lurmark Mint Green – fan	45.5	a-d	6.8	a	6.5	bcd	6.5	a
6. K Edward Lurmark Grey 4 nozzles + fan	48.5	abc	6.5	a	6.5	bcd	7.3	a
7. K Edward Delavan + Banka	44.8	a-d	6	a	6.8	bcd	7.3	a
8. K Edward Delavan + Silwett L-77	47.8	abc	7.5	a	7.5	abc	7	a
9. K Edward Delavan + Slippa	45.5	a-d	6.5	a	6.8	bcd	7	a
10. K Edward Dipping	41.3	d	5	a	5.8	d	6	a
11. K Edward Spinning disc	45.5	a-d	6.5	a	6.5	bcd	7	a
LSD (P=.05)	2.64		1.68		0.93		1.42	
CV	4.02		18.13		8.72		14.48	

Emergence out of 50

TABLE 9. EMERGENCE AND VIGOUR ASSESSMENTS. SAC 2009/10

Disease		Silver scurf				Skin spot			
Assessment date		11/02/2010		11/02/2010		11/02/2010		11/02/2010	
Rating Unit		% Severity		% Incidence		% Severity		% Incidence	
Treat. No.	Variety								
1	KE	1.69	bc	44.00	abc	1.45	a	66.00	a
2	KE	0.95	cd	30.00	bcd	0.43	b	39.50	bcd
3	KE	1.24	cd	26.00	bcd	0.85	ab	42.50	bc
4	KE	0.24	d	15.50	d	0.34	b	33.00	b-e
5	KE	1.39	cd	26.50	bcd	0.91	ab	46.50	b
6	KE	0.79	cd	24.00	cd	0.34	b	26.50	b-f
7	KE	0.79	cd	25.00	cd	0.54	b	37.50	bcd
8	KE	0.38	cd	15.50	d	0.42	b	31.50	b-f
9	KE	0.97	cd	30.50	bcd	0.38	b	38.50	bcd
10	KE	1.62	bc	41.00	abc	1.76	a	73.00	a
11	KE	2.74	a	41.00	abc	0.90	ab	47.50	b
1	MP	2.48	ab	58.50	a	0.94	ab	31.50	b-f
2	MP	0.57	cd	30.50	bcd	0.44	b	19.50	c-f
3	MP	0.62	cd	28.00	bcd	0.10	b	5.50	f
4	MP	0.84	cd	36.00	bcd	0.29	b	19.50	c-f
5	MP	0.74	cd	33.50	bcd	0.11	b	13.00	def
6	MP	0.38	cd	23.50	cd	0.11	b	10.00	ef
7	MP	0.89	cd	33.50	bcd	0.13	b	12.50	def
8	MP	0.53	cd	25.00	cd	0.13	b	9.00	ef
9	MP	0.88	cd	33.00	bcd	0.23	b	20.50	c-f
10	MP	0.89	cd	47.50	ab	0.42	b	27.50	b-f
11	MP	0.95	cd	41.50	abc	0.36	b	15.50	def
LSD (P=.05)		0.722		12.371		0.619		15.486	
CV		49.77		27.12		83.26		36.17	

TABLE 10. INCIDENCE AND SEVERITY OF SKIN SPOT AND SILVER SCURF AFTER STORAGE FOLLOWING A RANGE OF SEED TUBER TREATMENTS

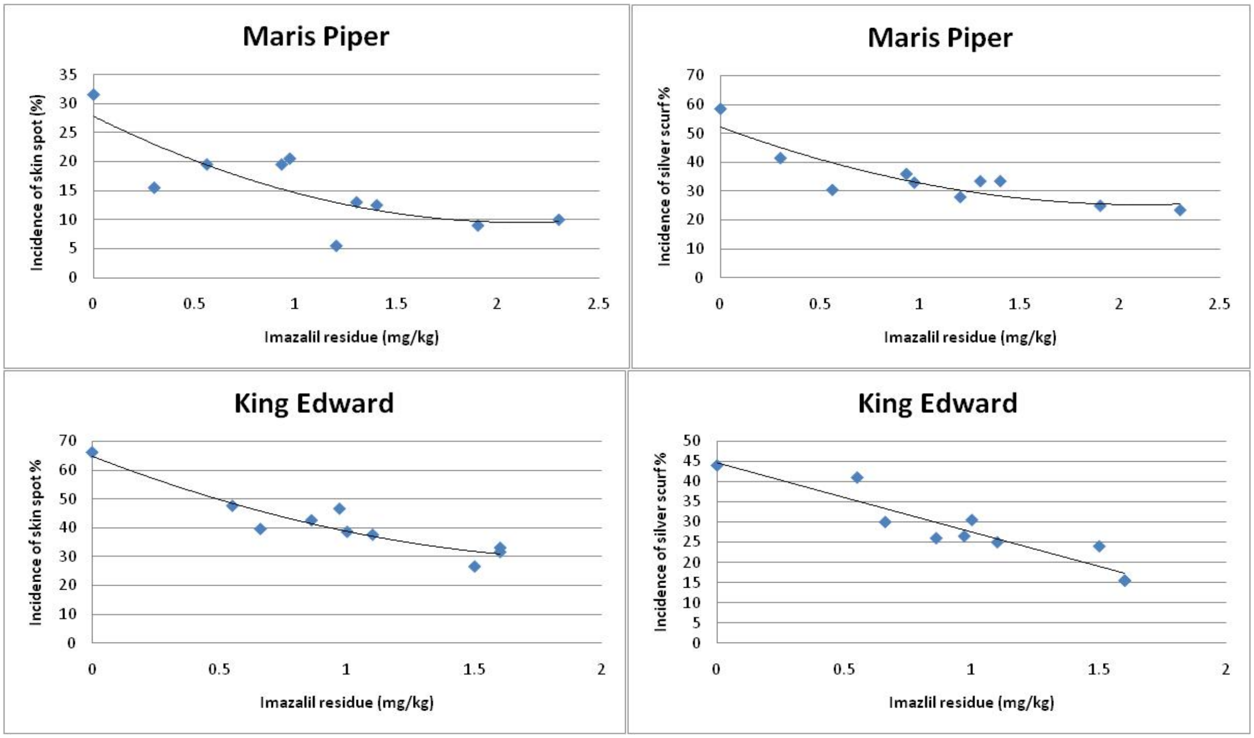


FIGURE 2. RELATIONSHIP BETWEEN IMAZALIL RESIDUE AND AVERAGE INCIDENCE OF SKIN SPOT AND SILVER SCURF ON MARIS PIPER AND KING EDWARD

4.1.2. Evaluation of novel application/delivery methods of fungicide 2010/11

4.1.2.1. Residue analysis

The results are shown in table 11. The residue levels were much higher in 2010/11 than 2009/10. The highest residue was once again using the Lurmark Grey/ 4 nozzles application. The Lurmark Mint Green nozzles resulted in greater residue than the Delavan nozzles, although adding a spreader/wetting agent to the spray solution substantially increased residue with the Delavan nozzle.

4.1.2.2. Surface area coverage

In general, surface coverage was higher in 2010/11 than in 2009/10. The relationship between surface coverage and imazalil residue was strong (Correlation coefficient 0.86; figure 3).

Test no.	Treatment		Result (mg/kg)
510	4	Desiree	1.6
511	5	Desiree	3.9
509	6	Desiree	5.0
512	8	Desiree	4.3

TABLE 11. RESIDUE ANALYSIS. SAC 2010/11

Date	20/04/2009
Method of assessment	Visual %area
Treatment number and name	
1. M Piper Untreated Check	-
4. M Piper Delevan No fan	79.6
5. M Piper Lurmark Mint Green No fan	90.8
6. M Piper Lurmark Grey 4 nozzles + fan	94.9
8. M Piper Delevan + Silwett L-77	85.1

TABLE 12. ESTIMATED SURFACE AREA COVERAGE BY DIFFERENT NOZZLE SYSTEMS ASSESSED VISUALLY. 2010/11

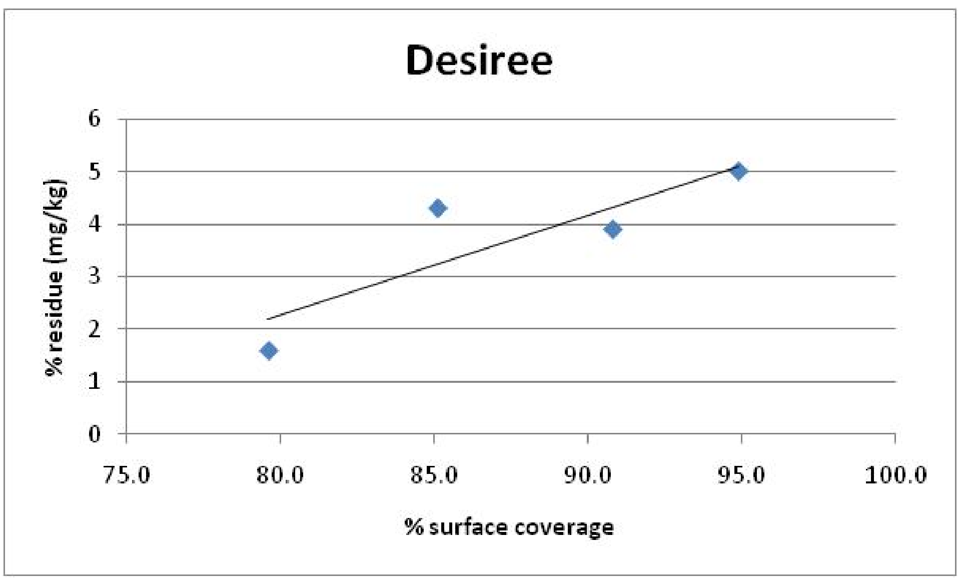


FIGURE 3. RELATIONSHIP BETWEEN VISUAL SURFACE COVERAGE ASSESSMENT AND RESIDUE OF IMAZALIL, 2010/11

4.1.3. Biological efficacy

4.1.3.1. Emergence and vigour assessments

Plants were assessed for emergence and vigour and the results are shown in table 13. There were no significant differences between spray applied seed tuber treatments and the untreated control in emergence and vigour.

Date	**16/06/2010**		**24/06/2010**		**16/06/2010**	
Assessment	**Emergence**		**Emergence**		**Vigour***	
Unit	**%**		**%**		**1-9**	
Treatment number and name						
1. Desiree Untreated Check	98.0	ab	99.5	a	7.3	a
4. Desiree Delevan no fan	100.0	a	100.0	a	7.0	a
5. Desiree Lurmark Mint Green no fan	97.5	ab	99.0	a	4.8	a
6. Desiree Lurmark Grey 4 nozzles + fan	96.0	b	100.0	a	5.3	a
8. Desiree Delavan + Silwett L-77 no fan	98.0	ab	100.0	a	6.5	a
LSD (P=.05)	2.35		1.81		1.85	
CV	1.62		1.22		19.65	

TABLE 13. EMERGENCE AND VIGOUR ASSESSMENTS, 2010/11

4.1.3.2. Disease assessments after harvest

To be completed in 2011.

4.2. Experiments at SBCSR

4.2.1. Assessment of cold mist application of fungicide

Water sensitive paper reacted clearly and rapidly when it was both in direct line with the cyclone flow and clearly visible from above. Otherwise it was either scarcely, or not at all, affected. A subjective assessment of the colour change observed in the paper was that more than 90% of the cyclone output was deposited on the upper surface of the top layer of the tubers and less than 1% on the underside of the tubers. The remaining dye deposited in similar fashion on the next lower layer of tubers i.e. 90:1% to upper:lower surfaces. Tubers not in direct line of cyclone output displayed the same ratio of deposition, albeit at lower overall levels of deposition. The cyclone appeared to produce a broad range of droplet sizes as different sized spots on the water sensitive paper strips.

A larger number of tubers assessed in the food dye experiments provided essentially the same results; that 90 % or more of the deposition was on the visible upper surfaces of the tubers. Attempts to quantify the amount of food dye on the surface, by methanol washing the dye from the tubers was unsuccessful.

The use of a fan to provide additional circulation and to alter the overall pattern of flow was helpful in that larger deposition rates were observed on tubers in trays out of the direct line of flow of the cyclone. However, this increased circulation did not appear to affect the deposition ratio of food dye seen between the layers of tubers within a tray or between the upper or lower surfaces of a tuber. Similarly varying the trajectory angle of the Cyclone, with and without additional fan circulation, altered the distribution of food dye around the store without affecting distribution between either tuber upper and lower surfaces or between different layers of tubers.

4.2.2. Assessment of hot fog mist application of fungicide

4.2.2.1. Deposit analysis

The results in table 14 were obtained as the average of 9 tubers for each tuber location and position for each year of testing. Tubers in the top box received higher levels of fungicide. The results indicate an asymmetric distribution of chemical over the tuber surface with significantly more deposited onto the upper surface. That the lower surfaces received much less fungicide may impact on efficacy. The suggested application rate of the chemical is 10 mg/kg, with an MRL of 3 mg/kg. Overall the tubers were receiving less than 15% of the potential maximum dose.

Residue values for treatments for 2010-2011 have yet to be determined.

	2008-2009 Imazalil residue (mg/kg)	2009-2010 Imazalil residue (mg/kg)	Average Imazalil residue (mg/kg)
Top box top surface	0.8	2.0	1.4
Top box lower surface	0.2	0.61	0.405
Bottom box top surface	0.5	1.5	1.0
Bottom box lower surface	0.04	0.23	0.135

TABLE 14. RESIDUE ANALYSIS OF TUBERS TREATED WITH XEDAXIL I FROM DIFFERENT POSITIONS IN FOGGING BOX OVER TWO YEARS

4.2.3. Dipping application of fungicide to seed tubers

The residue testing results for two years of dipping trials are shown in table 15. In 2008-2009 where a wide range of dilutions were evaluated, low dilutions were tested as it is believed that the fungicide is effective at low levels provided that the surface coverage is high. In 2009-2010 a repeat dipping experiment was carried out at only one dilution (1/1000) shown in table 15. In 2010-2011 a range of dilutions (1/1000-1/10,000) were applied within 5 days of harvest. Residue levels for these treatments have yet to be determined.

Fungazil dilution in water	**2008-2009 Imazalil residue mg/kg**	**2009-2010 Imazalil residue mg/kg**
1/10	78	
1/100	23	
1/1,000	0.74	1.5
1/2500	0.46	
1/10,000	0.08	
1/50,000	~0.01	

TABLE 15. IMAZALIL RESIDUES RESIDUES ON TUBERS DIPPED IN DIFFERENT DILUTIONS OF FUNGAZIL

The 2008/9 results show a relationship between concentration of dipping solution and residue (figure 4). A dipping solution of 1/1000 Fungazil 100SL provides an approximate working concentration of 1 mg/kg, similar to the hot-fogged dose and probably within the likely effective range of chemical activity.

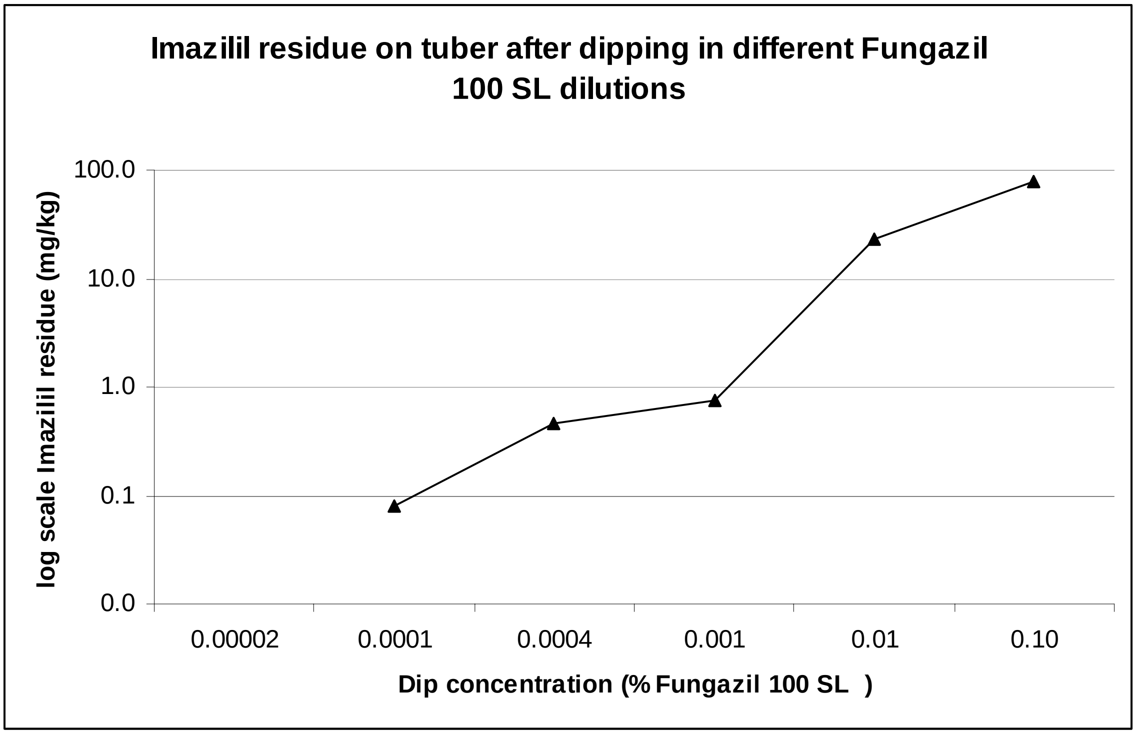


FIGURE 4. IMAZALIL RESIDUE ON TUBERS AFTER DIPPING IN DIFFERENT FUNGAZIL 100SL DILUTIONS.

4.2.4. Evaluation of methods for drying of potato tubers

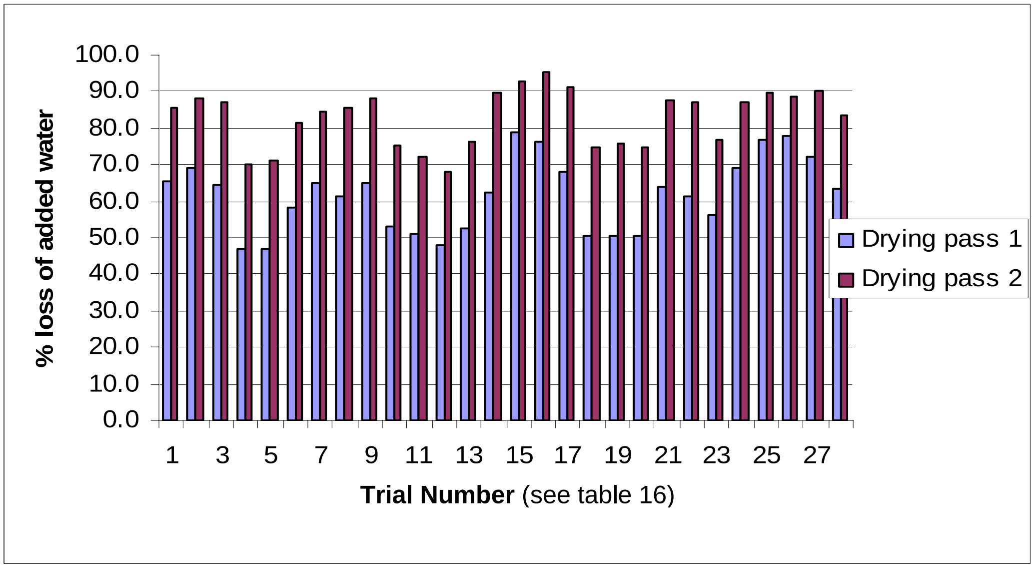
The results of 28 different evaluations of drying are shown in table 16. Data from table 16 has been converted to percentages of the initial dry weight and shown in figure 5. Analysis of this data indicates that roller speed is important, with the slower the speed the better. In the evaluations the roller table was set as a maximum to carry approximately 2 tonnes/hr but this was over a very short table (2.2m). The air knife made a significant difference to drying tubers, especially at high air pressure whereas the air knife angle made only a small difference. Surprisingly perhaps fan, baffle and cowl arrangements had little effect on drying

A second pass across the roller made a very large difference to drying. Following the second pass of tubers, there was an even, very thin sheen of water on the surface which disappeared very quickly, within a few minutes in static air.

Trial number	Sample tray Number	Air Knife Pressure (psi)	Knife Angle (°)	Fan Speed*	Cowl (Yes/No)	Baffle (Yes/No)	Roller Speed (tonne/hr)
1	2	6	45	H	N	Y	2
2	3	6	45	L	N	Y	2
3	4	6	45	O	N	Y	2
4	5	2	45	O	N	Y	2
5	6	2	45	L	N	Y	2
6	7	2	45	H	N	Y	2
7	1	6	90	O	N	Y	2
8	2	6	90	L	N	Y	2
9	3	6	90	H	N	Y	2
10	4	2	90	H	N	Y	2
11	5	2	90	L	N	Y	2
12	6	2	90	O	N	Y	2
13	7	2	90	H	N	N	2
14	8	6	90	H	N	N	2
15	1	6	90	H	N	N	1
16	2	6	90	O	N	N	1
17	3	-	-	H	N	N	1
18	4	-	-	H	N	N	2
19	5	-	-	H	Y	N	2
20	6	-	-	H	Y	Y	2
21	7	6	45	H	Y	N	2
22	8	6	45	H	Y	N	2
23	10	6	45	H	Y	N	2
24	8	6	45	H	Y	N	1.5
25	7	6	45	H	Y	N	1
26	6	6	45	H	Y	Y	1
27	5	6	45	H	Y	Y	1
28	4	6	45	H	Y	Y	1.5

* H = High speed,air flow 7760 m^3/hr; L = Low, air flow 1283 m^3/hr; O = No fan.

TABLE 16. EXPERIMENTAL PARAMETERS DURING INVESTIGATION OF DRYING OF POTATO TUBERS



Drying pass 1 and 2 refer to the first and second passages across the roller. X axis numbers refer to the trial number in Table 16.

FIGURE 5. PERCENTAGE LOSS OF WATER FROM DIPPED TUBERS UNDER VARYING DRYING CONDITIONS.

4.2.5. Efficacy of treatments on disease (skin spot) development

4.2.5.1. 2008-2010

Results from the first year of evaluation of dipped and fogged treatments are shown in table 17. Tubers dipped in 1/1000 Fungazil or hot fogged with Xedazil II had significantly reduced skin spot incidence and severity (P<0.05) compared to the washed control. Other treatments also achieved reductions in skin spot but they were not statistically significant. Hot fogging with Xedazil produced residues which depended on the orientation and position of the tuber (table 14. 0.8 – 0.04 mg/kg). This may have affected efficacy of skin spot control as although Xedazil treatment appears to reduce skin spot incidence and severity the results are not statistically significant. It may be that a quarter of this sample (bottom box, lower surface) is inadequately protected either because of poor coverage or an ineffective concentration of fungicide. If the latter were true it would indicate a target value greater than 0.05 mg/kg is required for adequate protection. This will be examined in year 2010-2011.

	Treatment	% Skin spot severity	% Skin spot incidence	S.D. % skin spot incidence
A	Washed control	0.8	49.0	14.0
B	1/1,000 Fungazil dipped	0.2	13.0	8.2
C	1/10,000 Fungazil dipped	0.4	39.0	13.6
D	1/50,000 Fungazil dipped	0.7	54.5	7.4
E	Xedazil I treatment	0.4	36.0	20.4
F	Xedazil II treatment	0.2	21.8	7.6

TABLE 17. POST STORAGE ASSESSMENT OF SKIN SPOT ON THE SAMPLE TUBERS.

Dipped tubers, expected to be evenly coated with fungicide, show significant protection with 0.74 mg/kg for 1/1000 Fungazil SL 100 solution and some reduction of skin spot incidence and severity following dip treatment in 1/10000 Fungazil SL 100. Xedazil II as applied in this trial does offer significant protection against skin spot. The difference between the two treatments, assuming an equal dose of Imazalil has been applied with the same distribution as for Xedazil II, is that it contains additional ingredients active against skin spot.

4.2.6. Pre-planting PCR analysis of skin spot

Table 18 shows the analytical results for levels of skin spot in tubers destined to be planted in the 2009 field trial. There was little difference in the skin spot DNA levels between the treatments, reflecting the fact that there has been little time for differential skin spot development.

Treatment	Test date	Mean log pg DNA/g peel
Seed	18 Mar 2009	5.86
Xedazil fogged	April 2009	6.03
Fungazil dipped 1/1000	April 2009	5.80
Untreated (washed)	April 2009	5.89
Untreated (unwashed)	April 2009	6.21

A log value >4 is indicative of high skin spot risk (Peters et al. 2009)

TABLE 18. PRE-PLANTING PCR ANALYSIS OF SKINSPOT LEVELS OF THE DIFFERENTLY TREATED TUBERS DESTINED FOR FIELD TRIALS.

4.2.6.1. 2010-2011

The tubers harvested in Nov 2010 have been placed in store for assessment in 2011

5. Discussion

5.1. Evaluation of novel application/delivery methods of fungicide

Historic data and experience has suggested that spray applied fungicide seed tuber treatment often results in low residues and poor disease control. The principles of application have been thoroughly described by publications from the PCL Potato Treater Group (formerly BCPC Potato Treater group) (Anon. 2004) but, in practice, effective treatment requires attention to detail and optimal treating equipment.

The disease control results from the one full year of experimentation have shown that high residue levels are not critical for control. Even though residues rarely exceeded 15% of maximum potential target dose, at least 50% reduction in incidence of skin spot and silver scurf occurred. To achieve a reduction in incidence is notable as normally a reduction in severity is more likely to occur than incidence.

Since in both years of experimentation residues were closely linked to surface coverage, it would seem that the priority for seed tuber treatment is to achieve as close to 100% coverage as possible. In the first year, coverage rarely exceeded 80% and was frequently less. In the second year coverage was greater, often around 90%. Given the difficulties of treatment that relate to tuber shape, achieving 90% coverage would appear to be practically the best possible. It will be interesting to see whether the better residue levels achieved in the second year of experimentation result in improved disease control and confirm a practical target of 90% coverage.

The comparison of different configurations, nozzles and adjuvants has provided indications where improvements in existing equipment can be made. These include:

- Exchanging a Delavan hollow cone nozzle for the superior Lurmark Mint Green nozzle.
- Adding an adjuvant to the spray solution to improve coverage. This was effective in year 1 with Maris Piper but not King Edward but improved residues in year 2 with Desiree. By testing three contrasting adjuvants it is clear that they are not all effective and correct selection is important.
- Improvements in configuration can increase coverage and residue. Many roller tables rely on a single spray nozzle but increasing the area of table on which spray mist is applied by increasing the number of nozzles used improved application. To ensure that the spray volume is minimised, selection of lower output nozzles will be important. In this project the hollow cone nozzle with the least output was the Lurmark Grey
- Switching off a downward fan. The results in the first year of experimentation suggested that a downward fan would not improve coverage or residue

The seed tubers used in year 2 of experimentation were larger than in year 1 (35-55mm cf. 35-45mm). Without any other changes, the levels of coverage and residue were higher in the second year. This demonstrates that on a standard roller table larger tubers offer a greater target for the spray. Very few growers have variable pitch roller tables that can be adjusted to permit changes in pitch to present more tuber surface when smaller tubers are graded. As a result, those treating seed potatoes on standard roller tables can only optimise coverage and residues by keeping the roller table as full as possible. To achieve this, more growers should utilise hoppers to collect seed and release in a uniform way.

Throughout the two years of experimentation, there was no evidence that dose or coverage affected seed tuber vigour or growth.

5.2. Assessment of cold mist application of fungicide

The recommended dose of 100 ml/tonne is around 1 minute/tonne application using Dynafog. This provided unsatisfactory overall coverage to the tubers in the above conditions. Based on the suppliers recommended application rate and a 90:1 % deposition rate on the upper and lower tuber surfaces respectively of the upper tuber layer. This means the upper surfaces of this layer would receive some 5 times more chemical than required but the lower surface would receive only 0.1 of the required chemical. The situation for the lower layers of tubers is even worse: the top surface of the second layer would receive 0.5 times and the lower surface 0.01 times the recommended dose.

Roller table spraying is thought to provide effective coverage of greater than 50% of tuber. This is significantly better than the above experience with the Cyclone. Application on a roller table is to a single layer of tubers, the cold fog application setup was to at least three layers and contact between tubers in layers will reduce the area of tuber available to the fungicide.

It is possible that applying a greater volume of diluted active ingredient would be helpful. However, the major problem is that the droplets are not effectively circulated within the layers of tubers: essentially all the material deposits on the upper surfaces. Although not measured, the cyclone clearly delivered a wide range of droplet sizes. It is possible that additives could alter the population of sizes. A system that delivers a narrower range of smaller size drops e.g. a fine mist or smoke would allow greater permeation of product through the layers and hence a better distribution. This might be addressed by more vigorous additional circulation, particularly positive ventilation using a plenum. This approach was not followed up at this time on this system.

One Imazalil based product was sold as a smoke designed for the fumigation of small to large sized stores and greenhouses. Although still described on the internet, it is no longer commercially available. The reason given by ex-suppliers for the withdrawal from sale of this “smoke bomb” application method was that, despite the agent being carried around the greenhouse within a fine smoke, only the upper leaf surfaces of the plants were adequately protected as the smoke deposited on those surfaces.

5.3. Assessment of hot fog application of fungicide

Hot fogging is used to apply chemicals to many different stored vegetables and fruits and here was used to apply fungicide to boxed tubers under positive ventilation. The results were not completely successful as there was an asymmetric distribution of the agent with significantly more deposited onto the upper surfaces of tubers than the bottom surfaces and higher rates of deposition within the upper box than in the lower box. This will impact on efficacy. Although the dipping experiments have shown that 0.74 mg/kg of Imazalil is an effective dose only the upper surfaces of tubers receive around that level of fungicide. The lower surfaces did not receive an effective dose and will be unprotected from disease. For example the lower surfaces of tubers in the lower box receive considerably less (0.04%) than the recommended application rate of

the chemical of 10 mg/kg. The distribution was not specifically measured at the ends of the tubers which are difficult to successfully treat by for example spraying.
It might be possible to increase the application rate for example by increasing the dose rate. However, the major problem is the actual distribution of chemical over the tuber. This might be improved by different plenum and fan arrangements, although these fall outside the scope of the current trial.

5.4. Dipping application of fungicide to seed tubers

Dipped tubers will be reliably and uniformly coated with the dip solution. In the experiments reported above there was a good relationship between the fungicide residue detected on the tuber and the concentration of the fungicide in the dip. The recommended application rate of the chemical of 10 mg/kg would be achieved by dipping in a 1/200 dilution of Fungazil SL 100. Tubers dipped in 1/1000 Fungazil, with a residue level of 0.74 mg/kg, had significantly reduced skin spot incidence and severity ($P<0.05$) compared to the washed control. This indicates the significant advantages of dipping, complete tuber coverage with fungicide and reduced effective concentrations of fungicide. Ten times lower fungicide residue levels (0.07 mg/kg) were not effective in controlling disease. A standard curve of Fungazil SL 100 residue has been generated and will be examined for skin spot control efficacy following storage of the tubers. This will be reported as an addendum to this report.

5.5. Evaluation of methods for drying of potato tubers

A fast, cheap and convenient method for drying potatoes is important if dipping of tubers is to become a useful method of fungicide application. The above experiments demonstrate some important principles.

An acceptable degree of drying or wetting can be defined as that currently applying commercially. Fungazil 100 SL is typically applied at 100 ml/tonne and stored without drying so can be assumed a “safe additional water load” prior to storage. In the trials described above, none of the drying arrangements accomplished this level of drying. This was primarily due to the limited time tubers were exposed to moving air. The trial demonstrates that time in moving air is critical to drying. In the experiments roller speed was important, with the slower the speed the better. For the evaluations the roller table was set to carry 2 tonne/hr as a maximum, over a very short table (2.2m). The air knife made a significant difference to drying tubers, especially at high air pressure whereas the air knife angle made only a small difference. Surprisingly perhaps fan, baffle and cowl arrangements had little effect on drying. A second pass across the roller made a very large difference to drying. Following the second pass of tubers, there was an even, very thin sheen of water on the surface which disappeared within a few minutes.

Alternatives to the air knife, which required a large industrial generator and was very noisy, would find greater acceptance. Time in moving air appears the most important factor under the system used above. Maintaining an even distribution of water around the tubers is important to promote even drying. Factors which could be investigated to find a practical method of drying tubers include slowing the roller speed and /or extending the roller table, increasing the air flow around the tuber by for example forcing the tubers into different position within the air stream using screw rollers, warming the air, using an absorbent roller dried on the underside either by e.g. Infra red heat or by pressure,

6. GENERAL DISCUSSION

A number of methods have been investigated with the aim of improving the coverage and hence the efficacy of fungicide treatment. Based on residue analysis, some alternative nozzle systems and alternative application methods appear to offer better coverage than commonly used current methods. As yet, the most important result, the biological efficacy of any of the treatments has not been measured. This awaits further storage until visual analysis of skin spot symptoms can be satisfactorily carried out.

6.1. Commercial acceptance and uptake of different treatments

In the short term, it seems that many seed growers will persist with existing seed tuber application equipment. Servicing the equipment, replacing nozzles and checking spray patterns regularly will ensure the equipment is functioning correctly. Calibration is often made once a season or at best on a weekly basis rather than for every individual stock. Different seed tuber sizes used on a standard roller table will present levels of tuber surface to be treated, as the results between two years show.

New spray application equipment from Team Sprayers using rotary arm application as tubers pass over the roller table appears to result in a high level of coverage. This equipment overcomes many of the issues of current equipment. However, the machinery is expensive. Seed growers retaining their existing spray application equipment could improve coverage and residues by implementing the four improvements suggested in section 5.1. All these improvements are relatively low-tech and low cost but have shown in these trials to result in substantial benefits in disease control.

Alternative tuber treatment options tested in this project, except tuber dipping, have not shown significant improvements over conventional spray application on roller tables. The down-side of cold or hot fogging, apart from an apparent unevenness of chemical distribution is that all the fabric and boxes also receive treatment, potentially leading to health and safety issues.

Dipping in water is an effective way of ensuring coverage of tubers with a fungicide. This study has illustrated the concentration of dipping solution required to deliver sufficient active ingredient for disease control. However, there remains a reluctance by growers to dip potatoes because of the difficulties of drying and potential increase in bacterial disease. Few growers would have equipment for dipping although the technology to achieve it would not require great expense. The pros and cons of dipping are well described in the Appendix. Uptake will require growers testing the system on a commercial scale, probably in a limited way initially and learning how best to handle the dipped tubers.

6.2. Further work

1. An evaluation of a wider range of adjuvants to improve wetting and spreadability of spray applied seed tuber treatments
2. Survey of seed tuber application equipment and training on best practice

7. REFERENCES

Anon. (2004) Store Hygiene Training Video and other information, CD ROM, British Potato Council.

Peters, J., Woodhall, J., Stroud, G., Harper, G. (2010). Skin spot management: *Polyscytalum pustulans* qPCR assay. Potato Council research project report R413.

8. APPENDIX

8.1. Skin spot management through use of novel fungicide application methods

This document highlights the major benefits and disadvantages of fungicide dipping of tubers as a method of disease control. The overall benefit of dipping is the increased coverage of tubers and hence an increase in disease control, the potential significant disadvantage is the increased risk of infection by, especially, wet rot bacteria. A key issue is economic, whether the improved benefits of disease control by dipping outweigh the costs particularly as drying will be necessary after dipping thereby incurring cost.

8.1.1. Actual or potential advantages

- Complete coverage, including ends, of tubers is possible
- All tubers, irrespective of size, shape and position within batch are effectively covered in control agent
- Dipping has been shown by Geoff Hide to give a very high level of disease control (cf. experience with spray application), even at very low doses
- The applied concentration can be readily varied
- There is a possibility of combined application of multiple control agents, assuming they are compatible and miscible
- There is increased potential effectiveness of the control agent on washed tubers compared to any application on soil contaminated tubers
- Good control of operator and environmental exposure for example low aerosol and vapour agent atmospheres and possibly fewer health and safety issues than spray applications
- It is a simple system which can be safely visually monitored.
- It is low technology compared to spray nozzle application systems.
- There is a potential reduction in target and non-target diseases by a preliminary wash to remove soil and reduce inoculum on and around tuber
- Grading visually easier with washed tubers, prior to dipping
- Treatment could be achieved without moving potatoes, for example by dipping boxes

8.1.2. Actual or potential disadvantages

- There is a potential significant problem of increasing some diseases notably bacterial wet rots if tubers are not effectively dried
- Over time, there will be a progressive reduction in concentration of control agent in solution and increased contamination by soil and tuber debris (assuming no prior washing)
- There is no simple method of determining the change in concentration of agent in the dip over time
- The dipping solution may become increasingly contaminated with bacteria and spread of microbial agents is possible to healthy tubers. This may give rise to a potential increase in non-target diseases such as blackleg (*Pectobacterium atrosepticum*)
- Contamination of grader lines with the control agent may occur in subsequent processing

- There may be additional handling during washing and dipping and potential for bruising etc.
- Dipping, as with spray application, would have to take place at the end of a grading line and the additional equipment required for dipping and drying may impact on this requirement.
- Disposal of dipping solution may present environmental issues