Final Report

The Effect of Timing of Application of CIPC on Sprout Control Efficacy

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CONTENTS

1. SUMMARY

CIPC is the main sprout suppressant used on stored potatoes in GB. It is of particular importance to the potato processing industry because, currently, no viable alternatives are available. It is generally recommended that the first application of CIPC is made before sprout growth is initiated, although information does not exist, in the public domain, demonstrating its particular importance.

Experiments were conducted, over two seasons, whereby crops of a range of cultivars, were treated with an initial application of CIPC (50% w/v in methanol, at an application rate of 21 g per tonne in year 1 and 5 g per tonne in year 2) on one of three occasions. The closed-circuit application method, consisting of a cold fogger operated within a continuous, positive recirculation system, was successful and resulted in similar concentrations of CIPC depositing on samples on each of the three application occasions, in both seasons.

Although application efficiency was modest in year 1 (approximately 1.4ppm, or 7%, as deposit) sprout control was particularly effective, with measurable growth not occurring until after long-term storage (July). When it occurred sprout growth was also particularly variable. Although differences in the proportion of tubers with sprouts at the time of 'initial' application were evident, these did not correlate well with sprout length after storage, and the presence of sprouts at application did not necessarily give rise to poor sprout control at store unloading.

In year 2, the CIPC application rate was reduced. At this lower application rate however, sprout control was largely ineffective. At store unloading, effective control was evident only in the long dormancy cultivars (Fianna and Russet Burbank) when CIPC was applied late. Earlier application of CIPC to these cultivars resulted in poor control of sprouting (although tuber deposit analyses indicated that the application efficiency of the first application was lower than for the two later applications). This suggests CIPC concentrations were close to the minimum effective dose and indicate crops were under-dosed.

The cold-fogging method for applying CIPC, used in this trial, was selected to help ensure similar doses of chemical were delivered on each application occasion, so allowing the effects of application timing to be determined. By carrying out applications in a closed-circuit (ie no ambient air introduced to the store during application), consistent application efficiency was achieved. Although this was achieved, results indicate that further work would be required to determine the optimum CIPC concentration for use in the experiment.

There is insufficient data to draw conclusions about the impact of the dormancy/sprouting status of tubers at the time of initial CIPC application on the effectiveness of sprout control, and it was agreed that alternative approaches to determine the impact of the timing of CIPC applications on sprout suppression would be pursued.

In relation to commercial use, it should be stressed that the labels governing use of CIPC formulations generally state that the chemical should be applied before crops have broken dormancy. Users of CIPC should therefore ensure that the chemical is applied *before* the onset of sprout growth.

2. INTRODUCTION

The first application of CIPC to a crop is widely regarded as being particularly important. CIPC formulation labels and Good Agricultural Practice generally recommend that the initial application is made to crops while these are dormant. Some formulations indicate a higher dose rate is appropriate, where application is made to a crop where sprouting is already underway. While late application of CIPC is associated (anecdotally) with relatively poor sprout control efficacy, many initial, commercial applications are thought to be made too late, i.e. after dormancy break. An experiment was carried out in 2007-8 and 2008-9 in an attempt to obtain data showing the importance of timing of initial CIPC application for sprout control efficacy.

CIPC usage rates in GB are considerably higher than those of continental Europe and the USA. This may be in response, at least to some extent, to a reduced efficacy of the sprout suppressant, as a result of it being applied too late. The use of cultivars with longer dormancy, e.g. in Canada and the USA (Briddon & Jina, 2005), and the use of CIPC formulations applied at store loading, e.g. powders and liquid sprays used in mainland Europe, are both expected to result in more timely initial application.

The aim of the work was to determine if the condition of tubers (dormancy/sprouting status) at the time of initial CIPC application is critical to the ultimate outcome of a CIPC application programme. If timing is of importance then effective sprout control should be possible using reduced rates of CIPC, by optimising timing of application.

3. MATERIALS AND METHODS

3.1. 2007-08 season

Samples of the cultivars Pentland Dell, Russet Burbank and Vale's Sovereign were obtained from commercial sources in mid-November 2007 and sub-samples were held in normal atmosphere at 5°C, 10°C and at 10°C with the addition of 10 ppm ethylene. These storage pre-treatments were designed to bring about changes in dormancy and sprout growth. An initial CIPC application was made to material from the 5°C pre-treatment on 29 November 2007. Further applications were made to separate sub-samples, from all three pre-treatments, on 19 December 2007 and 8 January 2008.

CIPC applications (21g $tonne^{-1}$, 50% w/v in methanol) took place with netted samples located within full 1-tonne boxes using a Cyclone cold fogger (Curtis Dyna-Fog, PO Box 297, Westfield, IN 46074-0297, USA). The Cyclone is an electric fan-powered fogger which allows applications to be made within a sealed store (i.e. a 'closed-system'). Conventional foggers heat ambient air and introduce this to stores. This results in store pressurisation, and leakage of an air/fog volume equal to that introduced by the fogger. The use of the cold fogger effectively removes the store leakage component associated with traditional hot fogging. The fog applied was recirculated positively through crops for 24 hours (Fig. 1). All applications took place after equilibration of crops to a temperature of 7.5°C.

Untreated, 100 tuber sub-samples of each cultivar/treatment were transferred for dormancy assessment, by monitoring sprout growth during storage at 15°C, on each CIPC application occasion.

Twenty four hours after CIPC applications, sub-samples of three tubers (from the Pentland Dell 5^{o}C treatment) were obtained for CIPC deposit analysis. Remaining material, in 1-tonne boxes, was transferred to a separate, untreated store at 7.5C & 95% relative humidity which had not been treated with CIPC. Crops were monitored for sprout growth during storage. All material was unloaded on 3 July 2008 and 25-tuber sub-samples assessed for sprout growth.

3.2. 2008-09 season

Samples of the cultivars Desiree, Fianna, King Edward, Marfona, Maris Piper (A + B), Pentland Dell, Russet Burbank and Saturna (free of maleic hydrazide) were obtained from commercial sources. Three batches of sub-samples were placed into nets and held at 10°C. An initial CIPC application was made to the first batch of sub-samples on 23 October 2008. Further initial applications, to the second and third batches of sub-samples, were made on 12 November 2008 and 12 January 2009 respectively.

CIPC applications (20 ml, 50% w/v in methanol or 5 grammes per tonne) took place with netted sub-samples located systematically within full 1-tonne boxes. On each application occasion, two nets of each cultivar were treated, one in each of the boxes in the application system (Fig. 1). The applicator was located adjacent to the plenum chamber, with the flow of fog directed upwards towards the intake of the recirculation fan. The fan, drawing air/fog from the store headspace and into the plenum chamber, was operated for 24 hours after application.

CIPC applications were again made using a Cyclone cold fogger (Curtis Dyna-Fog, PO Box 297, Westfield, IN 46074-0297, USA). CIPC deposit/residue results were obtained using sub-samples of the cultivar Russet Burbank. Deposit samples were obtained 24 hours after application and residue samples at the end of storage. Treated crops were maintained at 10°C and 95% relative humidity.

At the time of each CIPC application, untreated 100-tuber sub-samples of each cultivar were transferred for dormancy assessment, by monitoring sprout growth during storage at 15°C and 95% relative humidity. Crops were unloaded on 5 February 2009 and 25-tuber sub-samples of each cultivar assessed for sprout growth.

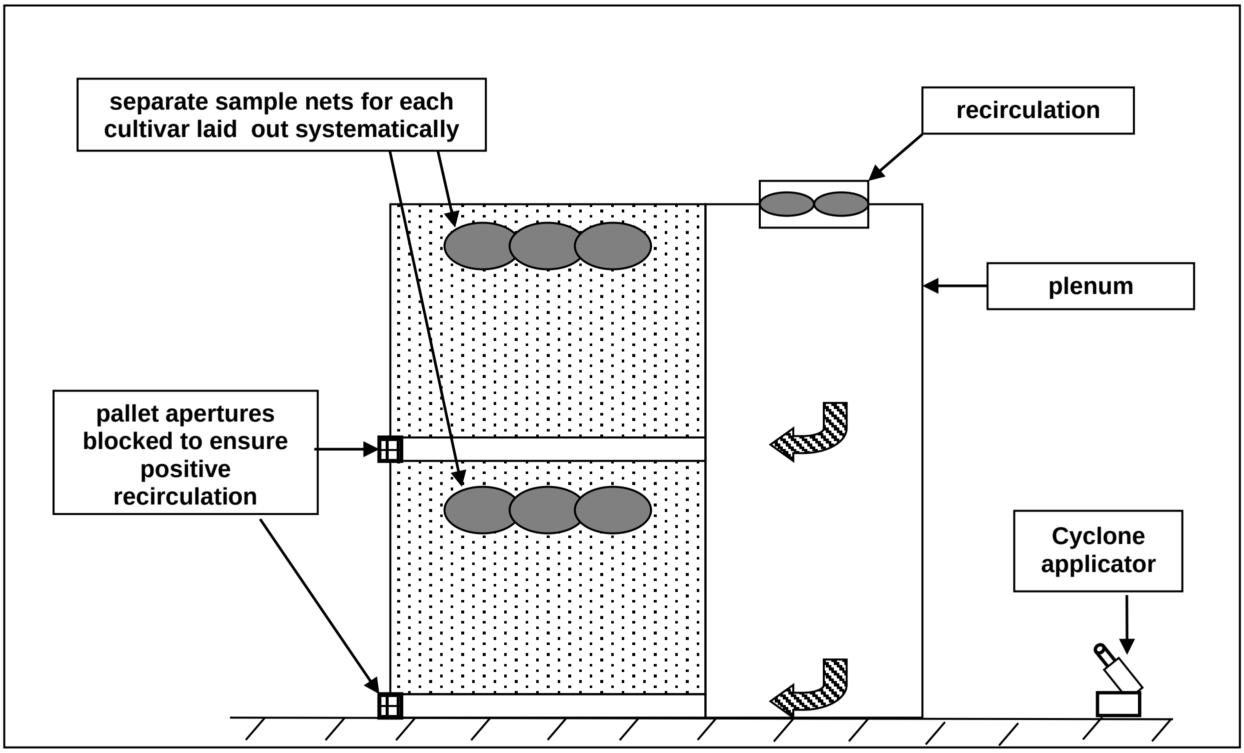


FIGURE 1. SCHEMATIC DIAGRAM SHOWING LAYOUT OF SAMPLES AND APPLICATOR FOR CIPC APPLICATIONS.

4. RESULTS

4.1. 2007-08 season

Samples of Pentland Dell (3 individual tubers), from the 5°C storage pre-treatment, were analysed for CIPC deposit concentration (as opposed to residue), 24 hours following application. These results are used to indicate the reproducibility of applications taking place over time.

Results (Table 1) indicate the application system resulted in good reproducibility between applications, with mean deposit levels in the range 1.3-1.5 mg kg^{-1} (mean 1.4 mg kg^{-1}, standard deviation 0.48). A higher concentration of CIPC consistently deposited on samples in top boxes (mean 1.8 mg kg^{-1}, standard deviation 0.15) compared with bottom boxes (mean 1.0 mg kg^{-1}, standard deviation 0.20). This occurred as a result of the delivery of a larger volume of air/fog (as measured just prior to application) into the pallet aperture of the top box.

Application	CIPC deposit (mg kg^{-1})	Standard Deviation	Box Position	CIPC deposit (mg kg^{-1})	Standard Deviation
1	1.5	0.37	top	1.8	0.03
			bottom	1.2	0.19
2	1.4	0.65	top	1.9	0.29
			bottom	0.8	0.10
3	1.3	0.43	top	1.6	0.29
			bottom	1.0	0.30
Mean	**1.4**	0.48	top	1.8	0.15
			bottom	1.0	0.20

TABLE 1. CIPC DEPOSIT LEVELS ON SAMPLES OF PENTLAND DELL PRE-TREATED AT 5°C.

4.1.1. Dormancy assessment

The progress of sprout growth of untreated samples, following transfer to a store at 15°C at each CIPC application, is shown in Figure 2. This data is used to calculate the proportion of tubers with sprouts at the time of application and dormancy (duration of storage until 50% of tubers are sprouted), for correlation against mean sprout length of samples after storage.

Results confirm cv Pentland Dell to have a short dormancy and cv Russet Burbank to have a relatively long dormancy. Data indicate Vale's Sovereign to have a dormancy slightly shorter than that of cv Russet Burbank. At application 2, for cvs Pentland Dell and Vale's Sovereign, and for all cultivars at application 3, sprout growth was largely unimpeded (absence of 'S' shaped curve) indicating that crops were not dormant, at the time of application.

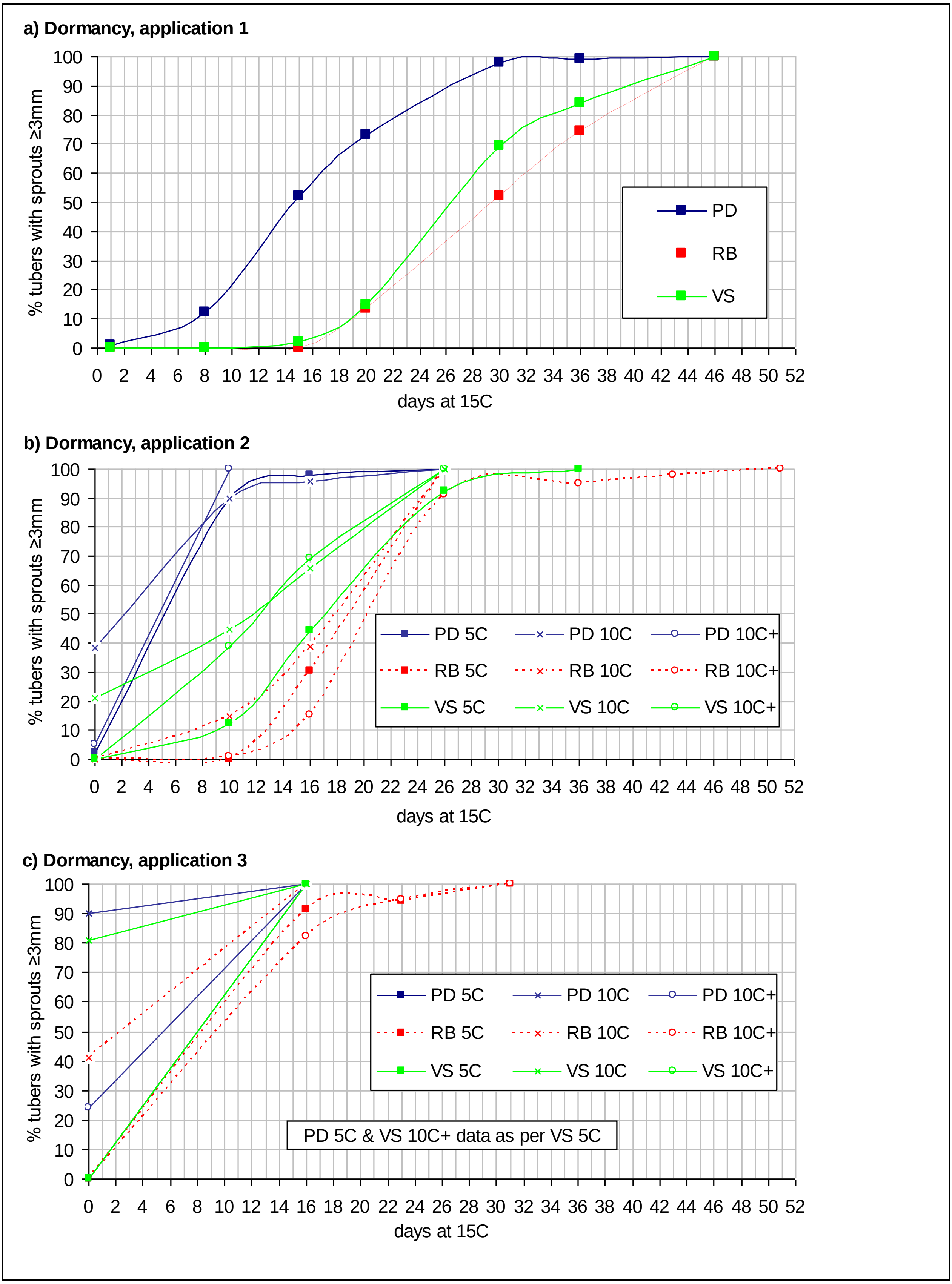


FIGURE 2. PROGRESS OF SPROUT GROWTH IN DORMANCY ASSESSMENT IN CVS PENTLAND DELL (PD), RUSSET BURBANK (RB) AND VALE'S SOVEREIGN (VS).

4.1.2. Sprouting

In general terms, mean sprout length after storage (Table 2) was extremely variable, with particularly high standard deviation values. Samples typically consisted of a small number of tubers with relatively long sprouts and a larger number of tubers with virtually no sprouting.

Notwithstanding this variability, sprout length was greater in samples taken from bottom boxes of the stack compared with the top boxes. This is likely to be as a result of a lower concentration of CIPC depositing on samples in the bottom boxes.

			Application 1		**Application 2**		**Application 3**	
Cultivar (cv)	**Treatment**	**Box** Position	**Mean**	SD	**Mean**	SD	**Mean**	SD
Pentland Dell	5°C	Top	**3.2**	5.58	**4.4**	5.07	**7.2**	9.79
		Bottom	**4.8**	8.71	**14.8**	14.80	**14.0**	7.29
		Mean	**4.0**	7.29	**9.6**	12.16	**10.6**	9.21
	10°C	Top			**4.0**	4.05	**9.5**	11.06
		Bottom			**4.2**	4.55	**11.8**	10.42
		Mean			**4.1**	4.26	**10.6**	10.70
	10°C + ethylene	Top			**2.8**	3.93	**6.2**	4.81
		Bottom			**9.2**	11.03	**2.6**	1.08
		Mean			**6.0**	8.81	**4.4**	3.88
cv Mean			**4.0**	7.29	**6.6**	9.24	**8.6**	8.90
Russet Burbank	5°C	Top	**2.8**	2.53	**7.8**	12.27	**4.4**	4.01
		Bottom	**12.1**	15.03	**11.0**	9.37	**17.5**	15.63
		Mean	**7.3**	11.55	**9.4**	10.92	**11.0**	13.07
	10°C	Top			**2.4**	2.53	**5.3**	5.25
		Bottom			**7.1**	9.03	**17.7**	12.83
		Mean			**4.7**	6.98	**11.5**	11.56
	10°C + ethylene	Top			**2.5**	2.08	**17.3**	19.97
		Bottom			**8.9**	8.60	**37.4**	31.54
Mean		**Mean**			**5.7**	6.98	**27.3**	28.03
cv Mean			**7.3**	11.55	**6.6**	8.68	**16.6**	20.41
Vale's Sovereign	5°C	Top	**3.6**	8.31	**0.8**	0.52	**3.5**	3.95
		Bottom	**5.6**	8.36	**12.3**	14.60	**14.8**	17.71
		Mean	**4.6**	8.31	**6.5**	11.77	**9.2**	13.93
	10°C	Top			**2.8**	7.76	**5.4**	5.56
		Bottom			**3.0**	4.05	**4.4**	3.52
		Mean			**2.9**	6.13	**4.9**	4.63
	10°C + ethylene	Top			**0.9**	0.28	**1.2**	0.60
		Bottom			**5.4**	10.26	**1.0**	0.35
		Mean			**3.1**	7.53	**1.1**	0.50
cv Mean			**4.6**	8.31	**4.2**	8.90	**5.1**	9.04
Grand Mean			**5.2**	9.27	**5.8**	9.00	**10.1**	14.66

TABLE 2. MEAN SPROUT LENGTH (MM) OF SAMPLES AFTER STORAGE.

4.2. 2008-09 season

4.2.1. CIPC deposit & residue levels

Results of CIPC deposit and residue analyses (using cv Russet Burbank as an indicator) are shown in Tables 3 and 4 respectively.

Deposit samples (Table 3) were taken 24 hours after applications and indicate the reproducibility of applications taking place over a period of time. Netted sub-samples in top boxes generally received more CIPC than those in bottom boxes. This occurred as a result of the delivery of a larger volume of air/fog (as measured just prior to application) into the pallet aperture of the top box. Results indicate applications 2 and 3 were similar with mean deposit levels of 0.41 mg kg^{-1} and 0.40 mg kg^{-1} respectively, and with good agreement between *top* and *bottom* box values. Application efficiency was lower at application 1, with a mean deposit level of 0.28 mg kg^{-1}. This treatment also delivered a smaller concentration of CIPC to the *bottom* box, around 25% of that delivered to the *top* box, while at applications 2 and 3 *bottom* box values were c. 50% of *top* box values.

Application	Box Position	CIPC deposit (mg kg^{-1})	**Mean**	SD
1	Top Bottom	0.42 0.10	**0.28**	0.175
2	Top Bottom	0.55 0.26	**0.41**	0.157
3	Top Bottom	0.54 0.27	**0.40**	0.150
Mean	-	-	**0.37**	0.166

TABLE 3. CIPC DEPOSIT LEVELS (MG KG^{-1}) OF CV RUSSET BURBANK.

Samples for residue analysis were obtained at store unloading in February 2009. Reflecting the deposit analyses, residue values of samples from *top* boxes were greater than those of samples from *bottom* boxes. Mean residue value was smallest following application 1 and greatest following application 3. Although deposit analysis indicated that the first application was not as efficient as later ones, higher residue values should be anticipated from later applications, as there is less time for redistribution and losses.

Application	Box Position	CIPC residue (mg kg^{-1})	**Mean**	SD
1	Top Bottom	0.09 0.01	**0.05**	0.049
2	Top Bottom	0.11 0.02	**0.07**	0.052
3	Top Bottom	0.14 0.09	**0.11**	0.061
Mean	-	-	**0.08**	0.059

TABLE 4. CIPC RESIDUE LEVELS (MG KG^{-1}) OF CV RUSSET BURBANK.

4.2.2. Sprout growth and dormancy at the time of CIPC applications

At the time of CIPC applications, 100-tuber untreated sub-samples were transferred to a store at 15°C and 95% relative humidity. Sprout length was assessed immediately, and at approximately weekly intervals thereafter. At the time of application 1 most cultivars showed no signs of sprouting (Table 5). A low incidence of sprouting (<10%) was apparent in source B of cultivar Maris Piper, a moderate incidence (<50%) in Maris Piper source A and a high incidence (97%) in cultivar King Edward. At application 2, high incidences of sprouting were evident in cvs. Maris Piper and King Edward, in cvs Desiree and Marfona sprouted tubers were infrequent and in cvs Fianna, Pentland Dell, Russet Burbank and Saturna sprouting remained absent. At the final application occasion, sprouting was evident in all cultivars but remained at a modest frequency (23%) in cv Fianna.

Cultivar		**Application**		
	Assessment	**1**	**2**	**3**
Desiree	% Tubers sprouted	0	6	100
	Mean sprout length	-	0.1	14.1
Fianna	% Tubers sprouted	0	0	23
	Mean sprout length	-	-	1.9
King Edward	% Tubers sprouted	97	97	100
	Mean sprout length	2.1	11.5	47.4
Marfona	% Tubers sprouted	0	1	100
	Mean sprout length	-	<0.1	14.3
Maris Piper A	% Tubers sprouted	43	93	100
	Mean sprout length	0.6	4.2	36.6
Maris Piper B	% Tubers sprouted	8	69	100
	Mean sprout length	0.1	1.7	35.7
Pentland Dell	% Tubers sprouted	0	0	98
	Mean sprout length	-	-	22.2
Russet Burbank	% Tubers sprouted	0	0	60
	Mean sprout length	-	-	2.3
Saturna	% Tubers sprouted	0	0	97
	Mean sprout length	-	-	7.8

TABLE 5. PROPORTION OF SPROUTED TUBERS AND MEAN SPROUT LENGTH (MM) AT THE TIME OF CIPC APPLICATIONS.

The dormant period of samples (days at 15°C for 50% of tubers to develop sprouts ≥3mm) at each application is shown in Table 6. The progress of sprout development of samples, from which this information is obtained, is shown graphically in the appendix. Results indicate that cvs Desiree, Fianna and Russet Burbank had the longest dormancy periods, while that of King Edward and Maris Piper was relatively short. At the third application only cvs Fianna and Russet Burbank showed any remaining dormancy, reflecting the significant proportion of tubers that remained unsprouted at this time. The cultivar Desiree is not usually associated with long dormancy, with a NIAB dormancy rating of 4, compared with 8 for cv Fianna (NIAB 1-9 scale where 9 is long dormant).

Cultivar	**Application**		
	1	**2**	**3**
Desiree	49	30	0
Fianna	39	27	5
King Edward	4	3	0
Marfona	30	15	0
Maris Piper (A)	9	4	0
Maris Piper (B)	11	4	0
Pentland Dell	33	19	0
Russet Burbank	59	39	4
Saturna	32	18	0

TABLE 6. DORMANCY PERIOD (DAYS) OF SAMPLES AT EACH APPLICATION OCCASION.

4.2.3. Sprouting

Mean sprout length varied considerably and at store loading was in the range 2.4mm – 55.5mm. Differences in sprout growth were evident as a result of cultivar and timing of CIPC application (Table 7). Overall mean sprout length after storage was greatest when CIPC was applied at application 1 and smallest, when CIPC was applied late. Sprout control was most effective in the long dormant cultivars Fianna and Russet Burbank.

Cultivar		Application			
	Box position	**1**	**2**	**3**	**Mean**
Desiree	Top	21.9	8.5	21.5	
	Bottom	26.2	17.6	16.0	
	Mean	**24.1**	**13.1**	**18.7**	**18.6**
Fianna	Top	21.7	8.2	2.5	
	Bottom	21.0	25.2	2.7	
	Mean	**21.4**	**16.7**	**2.6**	**13.6**
King Edward	Top	23.5	10.6	42.6	
	Bottom	33.8	25.9	30.3	
	Mean	**28.6**	**18.2**	**36.5**	**27.8**
Marfona	Top	36.2	22.2	8.8	
	Bottom	36.5	24.8	12.3	
	Mean	**36.4**	**23.5**	**10.6**	**23.5**
Maris Piper (A)	Top	52.3	25.5	30.5	
	Bottom	58.6	41.9	30.2	
	Mean	**55.5**	**33.7**	**30.3**	**39.8**
Maris Piper (B)	Top	49.2	35.9	32.7	
	Bottom	47.7	43.2	34.2	
	Mean	**48.5**	**39.5**	**33.4**	**40.5**
Pentland Dell	Top	36.0	39.0	16.1	
	Bottom	39.7	32.3	12.9	
	Mean	**37.8**	**35.7**	**14.5**	**29.3**
Russet Burbank	Top	10.5	14.4	2.5	
	Bottom	20.4	22.9	2.2	
	Mean	**15.5**	**18.6**	**2.4**	**12.2**
Saturna	Top	21.0	13.1	6.6	
	Bottom	18.3	22.6	6.6	
	Mean	**19.7**	**17.9**	**6.6**	**14.7**
Grand Mean		**31.9**	**24.1**	**17.3**	

TABLE 7. MEAN SPROUT LENGTH (MM) OF SAMPLES AFTER STORAGE.

4.2.4. Correlations

Correlation between dormancy of samples and sprout length of sub-samples after storage are shown in Figure 3. With all cultivars and applications data pooled, there was no correlation between between the period of dormancy of samples and the ultimate success of sprout control. With correlations for data separated by application occasion there is an indication that dormancy of samples influenced sprout control (lines of best fit have negative slopes), but not to an important extent (insignificant R^2 values).

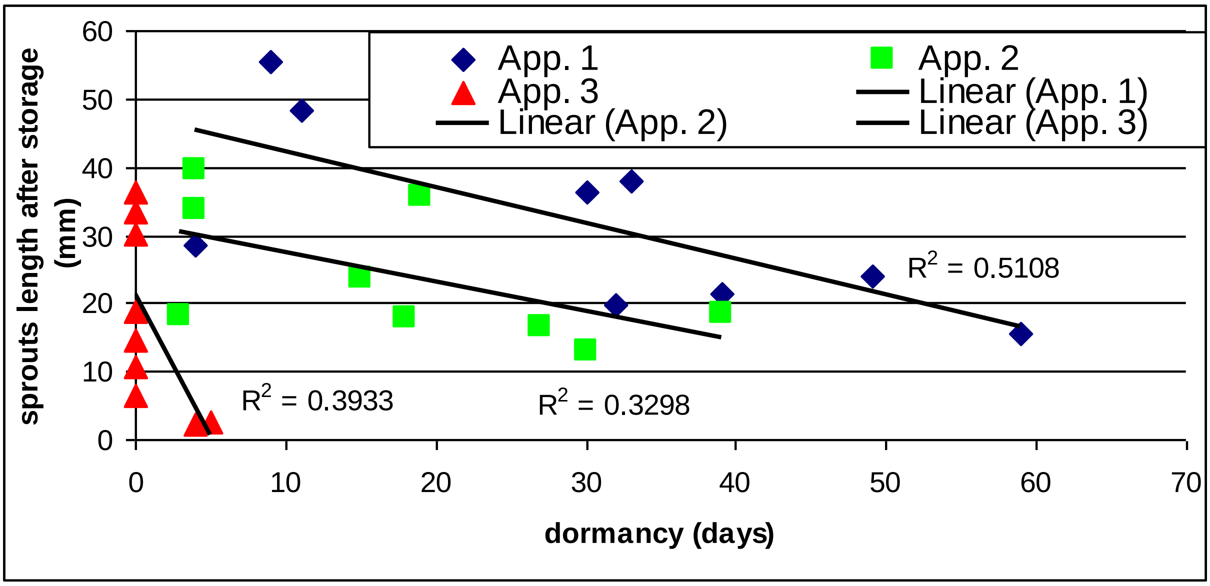


FIG.3 CORRELATIONS BETWEEN SPROUT LENGTH (MM) AND DORMANCY (DAYS).

5. Discussion

In these experiments varying dormancy/sprouting status of a range of cultivars at the time of CIPC application was unimportant in the ultimate success of sprout control. In year 1, very effective sprout control precluded correlation of data. Although an influence of dormancy was observed (year 2 data separated by application occasion), the influence was modest. However, the relatively high mean levels of sprouting from samples at application 1 (when dormancy levels were greatest) would contradict this observation.

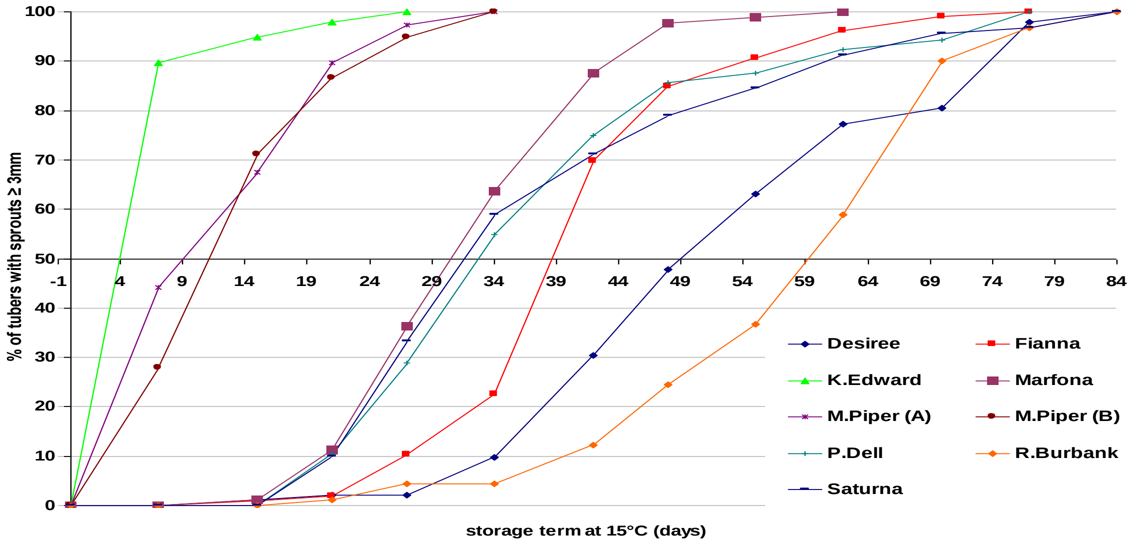
Effective sprout control was observed at store unloading in the cultivars Fianna and Russet Burbank following late application of CIPC. Similar applications but at earlier timings did not result in effective sprout control. Deposit and residue levels (0.40 mg kg^{-1} & 0.11 mg kg^{-}respectively) are likely therefore to be close to the minimum effective dose of CIPC required for sprout control.

Low levels of sprouting in year 1, and high levels of sprouting in year 2 make data unsuitable for correlation. Data should not be used to support advice on the timing of CIPC application.

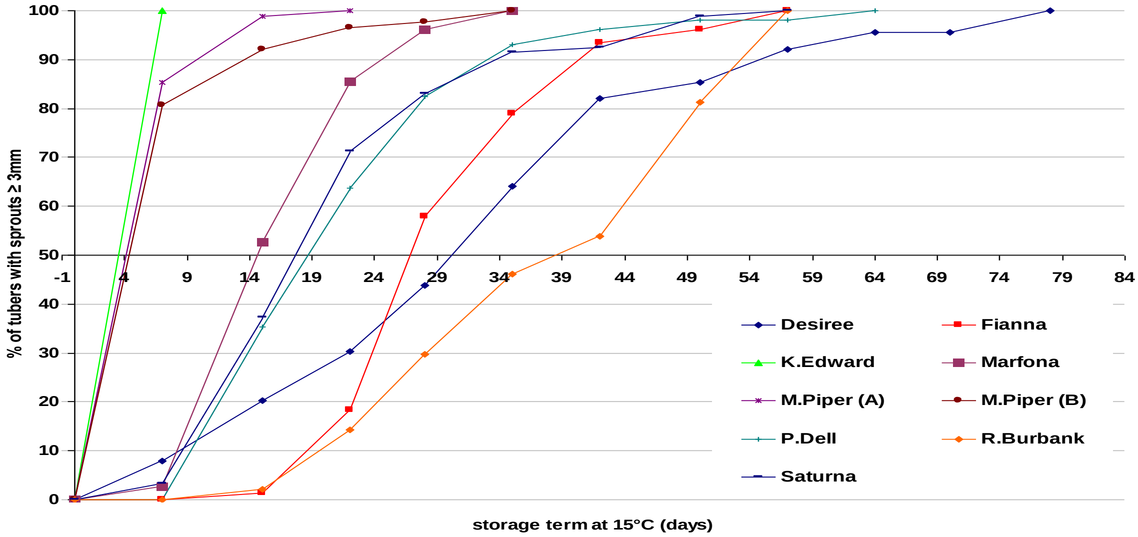
6. Appendices

6.1. Sprout growth of untreated samples for calculation of dormancy.

a) Application 1



b) Application 2



c) Application 3