Project Report

Optimisation of CIPC application and distribution in stored potatoes

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1. CONTENTS

2. INTRODUCTION

In stored potatoes, it is essential to control sprouting to minimise weight loss and prevent undue deterioration of crop quality. The primary method of suppressing sprouting in store is to treat potatoes with a sprout suppressant chemical. In Great Britain, chlorpropham (CIPC) is most extensively used especially in the processing sector where the need for storage at temperatures in the range 7-10C - to obtain the necessary fry colour demanded by the market - means the use of a sprout suppressant is essential to prevent growth in store (Anon., 1994). CIPC, when applied as a thermal fog, is usually delivered via the store's ventilation system or fogged directly into the store itself.

Environmental pressure is increasing on the potato processing sector, especially through its retail markets, to further improve the efficiency of its use of CIPC. Such improvements will also help the industry to meet the new maximum residue limit on CIPC which is due to be imposed as part of European legislation to be introduced in 1999.

This report covers a major set of trials which were funded by the British Potato Council (BPC), in conjunction with the Potato Processors' Association (PPA), to optimise the use of CIPC in potato stores.

Studies have been undertaken by the University of Glasgow (GU) to develop techniques to accurately measure the deposition of CIPC in potato stores (Duncan & Boyd, 1994); by Sutton Bridge Experimental Unit (SBEU) and GU to identify the minimum amounts of CIPC required by tubers to suppress sprouting (Storey & Briddon, 1996); by Silsoe Research Institute (SRI) to model distribution of fogged chemical within a store (Burfoot *et al*., 1994, 1996) and to develop a suitable technique for measurement of particle size within CIPC fog (Miller *et al*., 1997(a)).

In this trials series, three main experiments have been conducted at SBEU. Work was undertaken to look at the effects on the distribution of CIPC – in isolation as much as possible – of:

(a) particle size
(b) temperature gradient
(c) use of ventilation

The aim has been to validate the effects of these various parameters on the distribution of the chemical on a semi-commercial scale using the12-tonne capacity experimental stores at SBEU.

In addition, further work has been done to evaluate the rate of deposition of CIPC fog. This is being reported separately by Briddon & Jina (2000).

The work was carried out collaboratively between three research organisations: British Potato Council's Sutton Bridge Experimental Unit (operating formerly as Sutton Bridge Experimental Unit Ltd.), the University of Glasgow and Silsoe Research Institute.

The responsibilities for the different components of the work can be summarised as follows:

BPC Sutton Bridge Experimental Unit - provision of the stores, loading boxes and stores, operation of the stores and sampling of tubers from within boxes, study co-ordination and management;

Silsoe Research Institute - monitoring of the size distribution in the applied fog and the temperature differences between the air space above potatoes in a box and in the corridor;

University of Glasgow - measurement of CIPC deposits on sampled potatoes.

Chemical applications for the work were carried out by Sands Agricultural Services Ltd., Stored Crop Conservation Ltd and Superfog Ltd. using CIPC products provided by Luxan (UK) Ltd and Nufarm Whyte Agriculture Ltd.

Authors' note

This report covers a series of trials undertaken to investigate the effect of different factors on CIPC distribution in potato stores.

It should be appreciated that the individual trials were designed to assess the effects of these factors in isolation, so it is not appropriate to combine data from different experiments. Some data are limited and due account of this should be taken when considering the results.

Where clear effects are evident, these form the basis of the commercial recommendations in Section 5, whilst some other aspects requiring further data or commercial evaluation are the subject of on-going BPC-supported work at SBEU and Glasgow University.

3. THE EFFECT OF PARTICLE SIZE ON CIPC DISTRIBUTION

Year 1: Experiment 97/1, carried out on 23 April 1997
Year 2: Experiment 98/1a, carried out on 27 May 1998
Experiment 98/1b, carried out on 25 June 1998

The experiments on particle size were carried out to evaluate any direct effects of particle size which would, by influencing the particles' behaviour, potentially influence CIPC deposition and therefore potentially affect CIPC distribution in potato stores.

Opinion in the CIPC fogging industry suggested that variations in particle size could be obtained by altering burner temperature and an investigation of this formed the starting point for the trial. There was a view that generation of a fog with predominately small particles would offer better distribution of the chemical.

The objective was to measure particle size using a method developed at Silsoe Research Institute. This would be used to establish whether or not particle size can actually be varied by simple adjustment of the applicator and if the generation of a particular particle size spectrum can help to give an even distribution of the chemical in store.

Year 1

Experimental methods

The layout of the stores used for these experiments is shown in Figure 2.1. Boxes were stacked in three columns of four boxes forming a solid 'block', with gaps between boxes minimised. Boxes were solid-sided with slatted bases. The entire 'block' of boxes was stacked away from the plenum chamber ensuring that CIPC fog had access to boxes via pallet apertures at both ends of the block and via the surface boxes. Samples for deposit analysis were obtained from the top boxes in the middle column (third and fourth boxes from ground level). The walls of the sample box at level 3 were also covered in polythene film to ensure that CIPC fog could only enter by horizontal movement via pallet apertures, and vertical movements through the crop. The store was set up 6 days prior to chemical application, to allow conditions to stabilise.

All tuber samples (from a single sample box) were taken from a column of potatoes positioned centrally in a box (Briddon *et al*, 1998). This column was created by filling a box of potatoes with a piece of blanked-off drainage pipe located vertically in the middle of the box (Figure 2.2). When the box had been filled the pipe was unsealed and filled with a second batch of tubers using red or washed potatoes as appropriate. When this was full the pipe was withdrawn.

Sampling tubes were installed by the team from Silsoe Research Institute to enable samples of air laden with fog particles to be drawn from two levels within a treated store using methods described by Miller *et al*. (2000). which were instrumented to monitor temperature immediately above potatoes, of air in the pallet apertures and at an equivalent position within the free air of the corridor to the side of the boxes. The layout of the instrumented store is shown in Figure 2.3. Crop temperature was also measured using thermistor probes linked to SBEU's store control computer [Cornerstone Systems Ltd., Stone.]

Prior to fogging, all stores were subject to the same air flow and temperature treatments and conditions in each store were similar at the time of treatment. Stores were switched off before application, and remained off until all deposit samples had been obtained.

CIPC fog was introduced into each store via a low level port (500 mm above ground) in the store access door and, to reduce the back pressure on the applicator from the small experimental stores, this was initially allowed to escape from the store via an exhaust in the store roof. All ports were closed on completion of the application.

Fog was applied for 3 minutes to each store, with a chemical flow rate of 1 litre per minute. The applicator used was a *Superfog* machine, applying the formulation MSS CIPC 50 M containing 500g CIPC per litre methanol [Nufarm Whyte Agriculture Ltd., Doncaster]. To obtain differences in CIPC fog ‘quality’ in each store the applicator temperature setting was adjusted by the operator [D. Wagstaffe, Superfog Ltd., Stamford]. Burner temperatures of 400C, 460C (*Superfog* optimum) and 520C were employed. Some problems of leakage and co-ordination when the first store (store 36, 400C) was treated were noted. Store conditions at the time of application were 10C and 95% relative humidity.

24 hours after application, the potatoes forming the majority of the box contents were carefully removed by hand. Samples were then obtained by randomly taking five individual tubers from the surface of Box 4 and from each of the sampling positions in the central column of Box 3 in each store.

The samples were taken from:
<u>Box 4</u> ref 4T: Tubers on the surface (halved horizontally*).

<u>Box 3</u> ref 3T: Tubers on the surface (halved horizontally*).
ref 3M: Tubers at a depth of 300 mm (middle of box).
ref 3B: Tubers at a depth of 600 mm (bottom of box).

*Top tubers were halved horizontally *in situ* to allow deposition on the top and bottom surfaces of the tuber to be analysed separately.

In year 1, cv. Kerrs Pink tubers were used within a bulk of cv. Maris Piper. Washed and unwashed samples were assessed. In year 2, washed tubers were used within an unwashed bulk, both cv. Cara.

Samples were stored in closed polythene bags at 3.5 - 4C before despatch by courier to Glasgow University. At Glasgow, samples were frozen on receipt and CIPC deposits were subsequently assessed within one month of sampling by gas chromatography (GC) using the method described by Khan (1999).

Figure 2.1: Store stacking pattern for particle size experiments

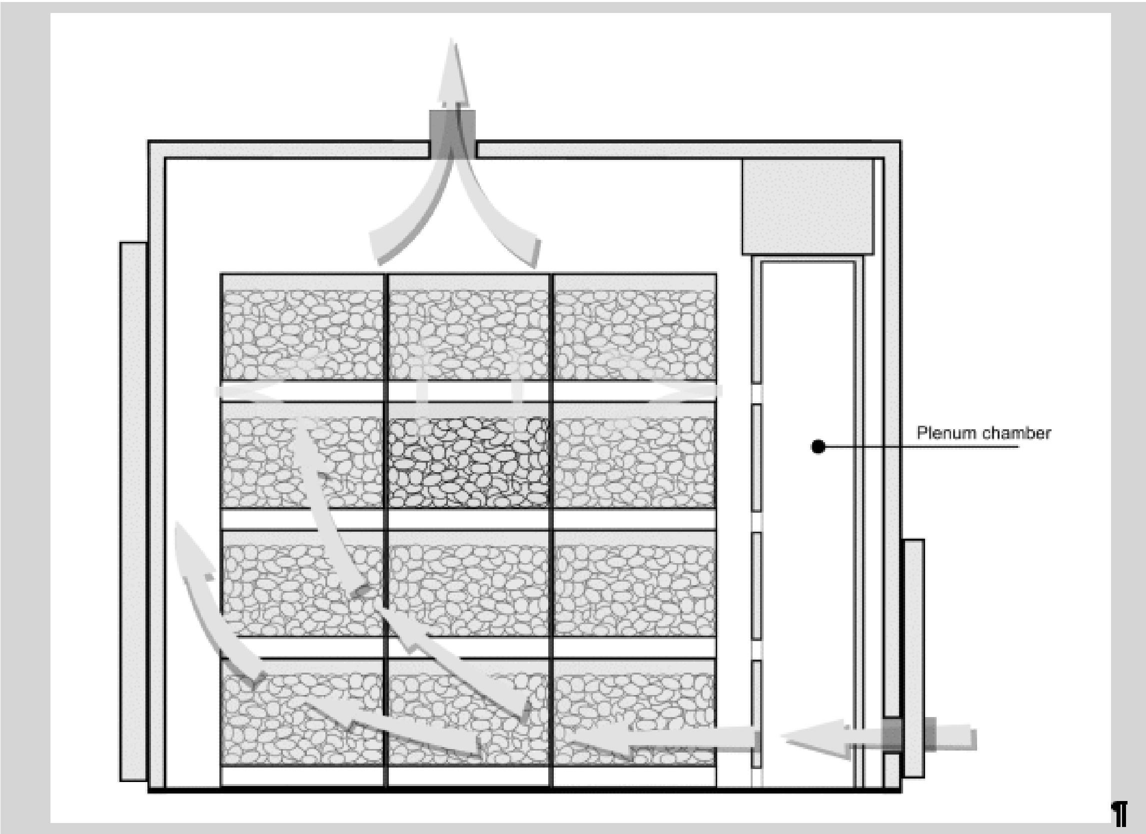


Figure 2.2 : Layout of column of sample tubers within a 1-tonne box (remaining tubers not shown for clarity)

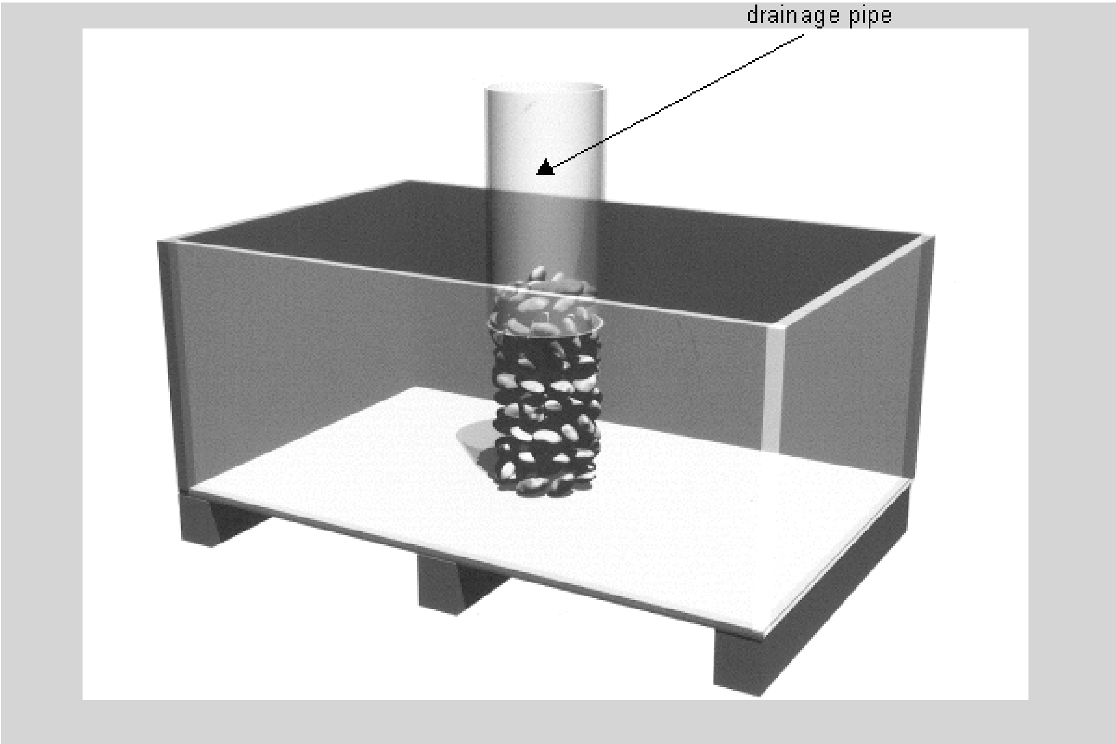
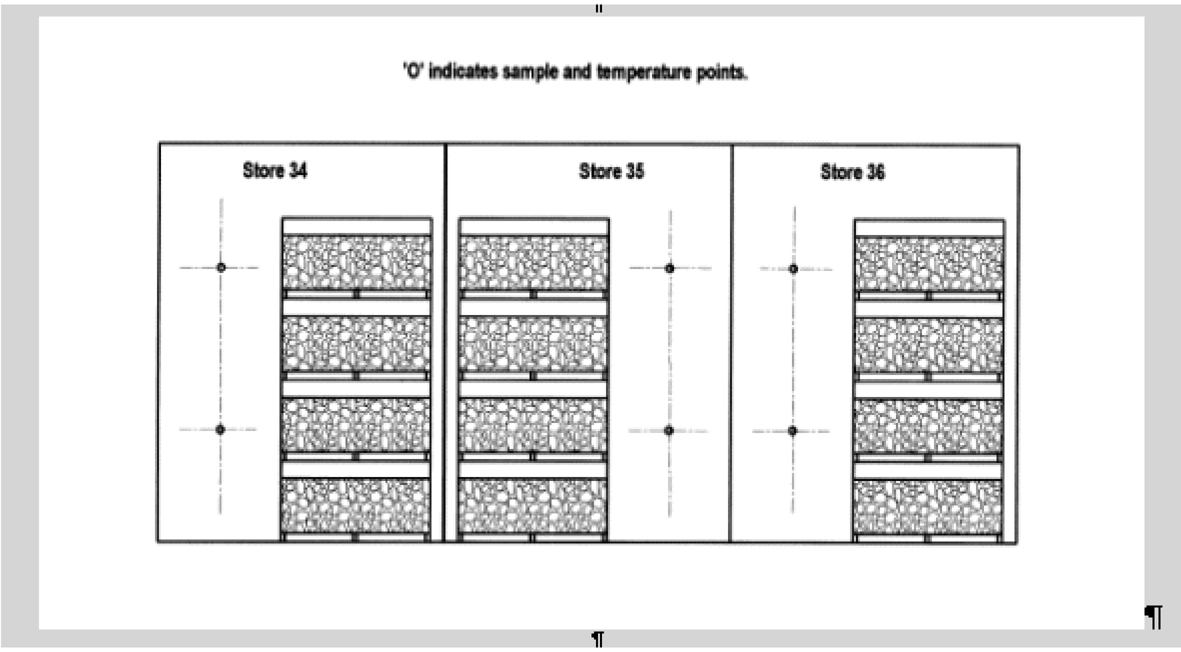


Figure 2.3: Layout of instrumented experimental stores



Year 1 results & observations

In the first year's work, it was found that the applied dose of CIPC formulation was considerably in excess of normal treatment levels and this led to very high levels of airborne particle concentration in the treated stores which influenced the accuracy with which size distributions could be measured. Due to these difficulties, reliable measurements of the airbome fog distribution could only be made after the stores were sealed at the end of the whole treatment process.

The measured size distributions for the three stores plotted in Figure 2.4 show relatively small differences in the treatments applied to the stores with volume median diameters of 11.3, 7.7 and 7.3µm for the three stores (numbered 34, 35 and 36 respectively). Close inspection of the data in Figure 2.4 shows that a high percentage of the measured particles in store 34 were assessed as being in the size range 10.0 to 25.0 µm (arrowed). This was probably due to a very high level of airborne particles in this store at the time of measurement (from the high dose of CIPC applied) resulting in the instrument recording the high concentrations of small particles as a single larger particle. The leakage during the treatment of store 36 (treated with a temperature setting of 400 C) resulted in a lower airbome concentration of fog particles and hence a more reliable measure of the particle size distribution.

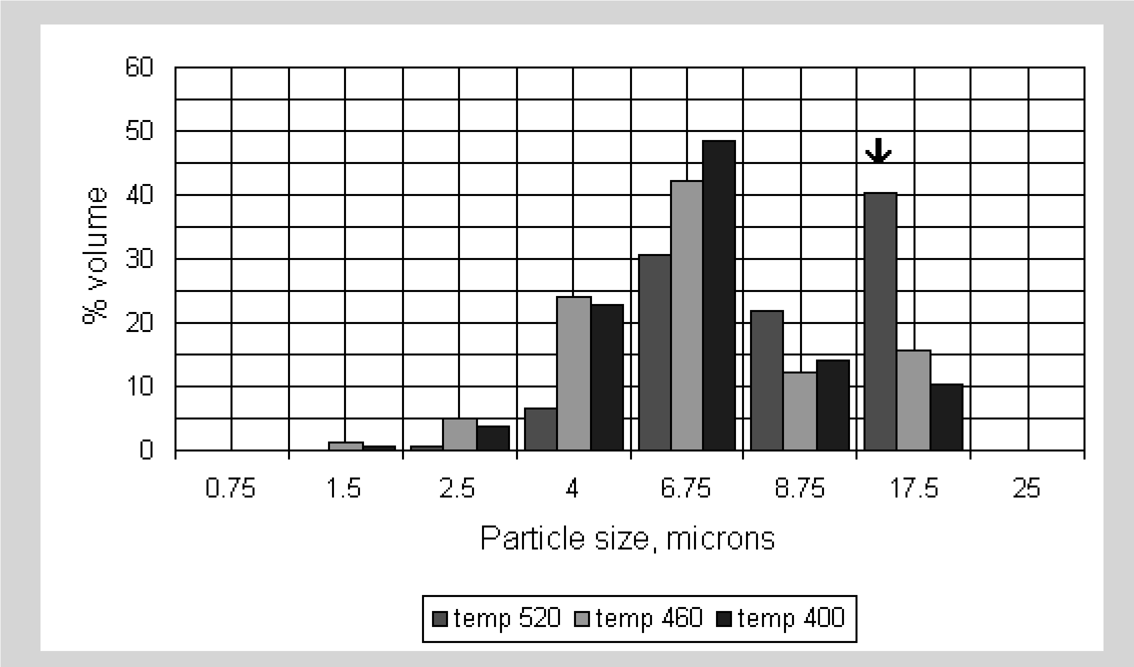
The similarity between the size distributions measured at the two lower fogger temperatures suggested that temperature was not the most effective way of changing the particle size distribution. However, other (unpublished) evidence suggested that also varying the flow rate of the liquid formulation through the fogger may be a better way to achieve a difference in the size distribution of the applied fog. This would then mean that treatment times would need to be varied to keep the applied dose to each store constant.
The CIPC deposit levels measured in the samples taken from Experiment 97/1 are summarised in Table 2.1. The results show that the levels of CIPC deposited in one store (store 36) are very different from those measured in the other two (stores 34 and 35). This is most likely, when considered with the particle size data, to be a result of the leakage of CIPC on application to this store rather than as a direct consequence of burner temperature or particle size. The similarity in deposits from stores 34 and 35 (on both unwashed tubers and after washing) suggest that particle sizes are similar in these two cases. This supports the measurements made by SRI and the case that, on this occasion, changing the temperature setting on the applicator did not make a significant difference to the particle size patterns or CIPC deposition.

Table 2.1: Deposits of CIPC* (% of mean deposit) in samples from Expt 97/1

	unwashed samples			washed samples		
store	36	35	34	36	35	34
burner temp.	400C	460C	520C	400C	460C	520C
top box: tuber top half	223	171	170	233	231	202
bottom half	64	53	46	32	17	12
middle box	53	98	100	81	79	86
bottom box	60	79	84	53	73	101

*Each data point is mean of 5 individual tuber analyses expressed as % of mean deposit for the treatment

Figure 2.4: Particle size spectra for 3 stores in Experiment 97/1



Year 2

<u>Methods & materials</u>

The second season's experiment was first attempted on 27 May 1998 (Expt 98/1a) but test applications and measurement of the particle sizes of the fog generated using three products — *MSS CIPC 50 M* and *Warefog 25* [both Nufarm Whyte Agriculture Ltd., Doncaster] and *Gro-Stop HN* [Luxan (UK) Ltd, Melton Mowbray] — when applied through a *Superfog* machine, showed that there was little effect on the particle size spectrum. This was despite the operator making some quite significant adjustments to the fogger (flow rates ranged from 0.25 - 2.0 l/min; burner temperature from 460C - 550C). Particle sizes were generally in the range 4-6 µm for most of the configurations tested and it was therefore decided not to proceed with the potato treatments given the narrow band of particle sizes available.

Further tests were undertaken during preparation work for the ventilation trial (Experiment 98/3, section 4) which indicated that a wider band of particle sizes (although not as wide as originally intended for this work) could be obtained using the *SAM Unifog* machine [Sands Agricultural Machinery Ltd, Stalham] operating with the *Gro-Stop HN* CIPC product. This combination was therefore used for a second attempt at the experiment (Expt. 98/1b) undertaken on 25 June 1998. The *Gro-Stop HN*, containing 300g/l chlorpropham in dichloromethane, was applied at 20 ml product/tonne to give a target dose of 6g CIPC per tonne of potatoes.

By adjusting the nozzle pressure (thereby varying product flow rate) and burner temperature, CIPC fogs of three 'qualities' were generated and these were each applied to different stores containing boxes stacked as in Year 1. The parameters for each treatment are given in Table 2.2.

Table 2.2: Application parameters for three particle size qualities (Experiment 98/1b)

store number	particle size treatment	nozzle pressure (bar)	burner temperature (C)	application time (s)
34	fine	1.5	400	20
35	medium	3.5	400	20
36	coarse	5.5	330	20

Year 2 results and observations

Following on from the problems encountered in the first year's work, where it proved difficult to influence particle size by varying burner temperature alone, the additional changes made in the second year to formulation and/or flow rates (nozzle pressures) still failed to affect particle size as much as had been anticipated.

The initial measurements undertaken in Experiment 98/1a on the *Superfog* machine showed that generation of an 'abnormal' fog was very difficult to achieve and this would indicate that, in commercial practice under normal operating conditions, obtaining a markedly different particle size spectrum between applications is unlikely to occur.

The particle sizes generated in the first tests (Expt 98/1a) are summarised in Table 2.3. There was no application of CIPC made to potatoes as the data from the various settings tested were not deemed sufficiently different to give appropriate particle size treatments to evaluate.

Table 2.3. Particle sizes (volume median diameter) of a range of CIPC fogging treatments using a *Superfog* applicator in Experiment 98/1a

product & dilution	flow rate (litre/min)	burner temp. (C)	particle VMD (µm)
MSS *CIPC 50 M* 100%	1.0	460	4.56
MSS *CIPC 50 M* 100%	1.0	550	4.58
MSS *CIPC 50 M* 100%	0.25	460	4.20
MSS *CIPC 50 M* 25%	1.0	460	3.85
MSS *CIPC 50 M* 100%	2.0	460	5.73
Whyte *Warefog 25* 100%	1.6	460	5.99
Whyte *Warefog 25* 25%	0.4	460	4.48
Luxan *Gro-Stop HN* 100%	0.6	460	5.28
Luxan *Gro-Stop HN* 100%	2.3	460	5.55
Luxan *Gro-Stop HN* 100%	2.4	550	2.79

Subsequent tests showed that some variation in particle size could be generated by the *SAM Unifog* machine. This was used to create CIPC fog of three ‘qualities’ in Experiment 98/1b, when CIPC applications to the potatoes were also made. The particle sizes generated are summarised in Figure 2.5 and the volume median diameter data for the fogs are given in Table 2.4.

Figure 2.5: Particle size spectra generated for the three 'qualities' of fog

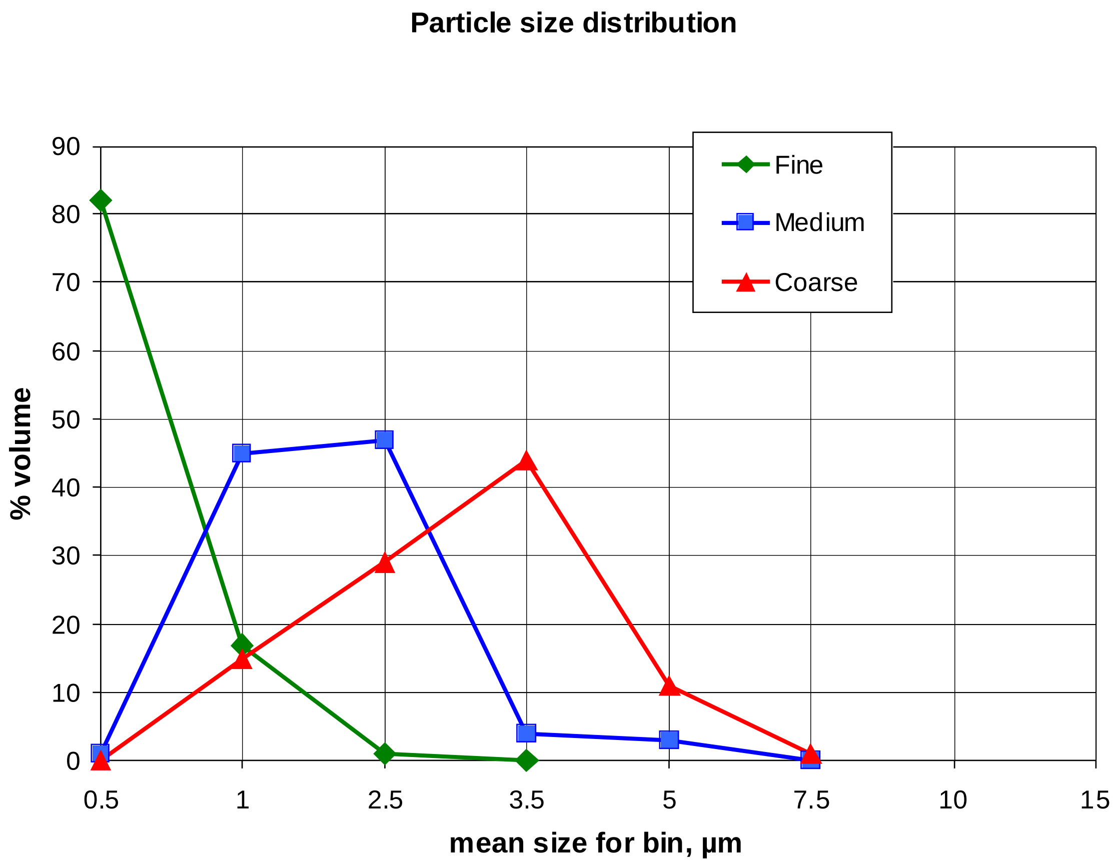


Table 2.4. Particle volume median diameter for a range of CIPC fogging treatments from a *SAM Unifog* applicator in Experiment 98/1b

product & dilution	nozzle pressure (bar)	burner temp. (C)	particle VMD (µm)
Luxan *Gro-Stop HN* 100% 'fine' treatment	1.5	400	1.17
Luxan *Gro-Stop HN* 100% 'medium' treatment	3.5	400	2.51
Luxan *Gro-Stop HN* 100% 'coarse' treatment	5.5	350	3.98

The deposits measured from the samples removed 24 hours after treatment are given in Table 8.1 (Appendix) and include separate figures for each half of the five tubers (top (t) and bottom (b)) taken from each of the sampling positions in the top of boxes 3 and 4, designated sample points 3T & 4T respectively.

Although the range of particle sizes obtained was not particularly great, differences in the pattern of deposition were evident. A fine particle size (0-3µm) resulted in poor attachment to tubers in the centre of the box. A medium particle size (c 1-4µm), i.e. within the normal operating range of the fogger, produced a quite uniform deposit with good penetration into the box. The comparatively larger particle spectrum (2-7 µm) resulted in a higher proportion of the CIPC being deposited on to the top surface of the top box and only moderate deposits penetrated to the lower levels of the other boxes within the stack from which samples were taken.

The proportion of fog deposited by sedimentation (measured by comparative amounts of the CIPC deposited on the top surface of the top tubers) increased as the particle size became larger (ratios of deposits in box 4T, top:bottom were Fine: 1.35:1; Medium: 2.26:1; Coarse: 2.57:1). This suggests that the larger particles are more prone to sedimentation, resulting in high levels on upper surfaces of tubers whilst smaller particles are more likely to 'condense' onto the entire tuber surface.

Discussion:

The results from the two year's trials suggest that there is no simple way, using any one applicator, in which to dramatically vary particle size of the thermal fog under normal operating conditions.

In the year 2 trial, both the fine and coarse fog treatments were generated at the limit of the fogger's capabilities, and it should be noted that this scenario is very unlikely to be repeated, even in error, under commercial operating conditions.

Evidence was also gathered which indicates that the coarse particle size led to more deposition on the surface of boxes and poorer penetration into the stored crop than with the fog generated in the mid-range. However, the size of particles in the coarse treatment was, in fact, not particularly large (<8 µm) in this experiment and, on the evidence of the earlier tests (Expt 98/1a), would be typical of the normal output from a *Superfog* machine.

Burfoot *et al* (1994), in forming a model of CIPC distribution, suggested that larger particles (*c* 10 µm) would provide a more erratic distribution of chemical than a fog with particles of mean size *c* 2 µm. However, the, albeit limited, data from this work suggests that the latter might be too small for the fog to be able to attach effectively within the boxes and a slightly larger range (*c* 3 – 7 µm) would appear to be deposited more effectively.

Nevertheless, an overriding factor in this study has been that the commercial applicators tested (and CIPC products) have generated a fog close to the above range and therefore the true effect of particle sizes outside this band has proved difficult to evaluate. Certainly, it can be concluded that particle size variation is not an issue which should be of great concern to those undertaking CIPC treatment providing properly-configured thermal fogging equipment is used.

These data have also been used in subsequent modelling studies reported by Xu & Burfoot (2000).

4. THE EFFECT OF TEMPERATURE GRADIENT ON CIPC DISTRIBUTION

Year 1: Experiment 97/2, carried out on 28 May 1997
Year 2: Experiment 98/2, carried out on 17 July 1998

The primary aim in this trial was to establish the effect of differing types of temperature gradient on CIPC deposition within a non-positively ventilated box store. This type of store is in common use in Great Britain.

Many such stores are ventilated overhead which can create a ‘negative’ gradient where potatoes at the top of the store can be cooler than those below. This can create problems with condensation and may therefore also affect CIPC distribution. Comparisons with minimal and positive gradients (warm top of store) were also planned.

The experiment was carried out in three 12-tonne capacity stores in two consecutive seasons.

Year 1

Experimental methods

For this experiment, each store contained four boxes in a single column stacked against the plenum chamber. The top box in each store was not filled, but was sealed across the base, allowing the pallet aperture to be used as a manifold controlling air movement (Figure 3.1).

Air distribution was manipulated in such a way as to give:

a) minimal gradient,

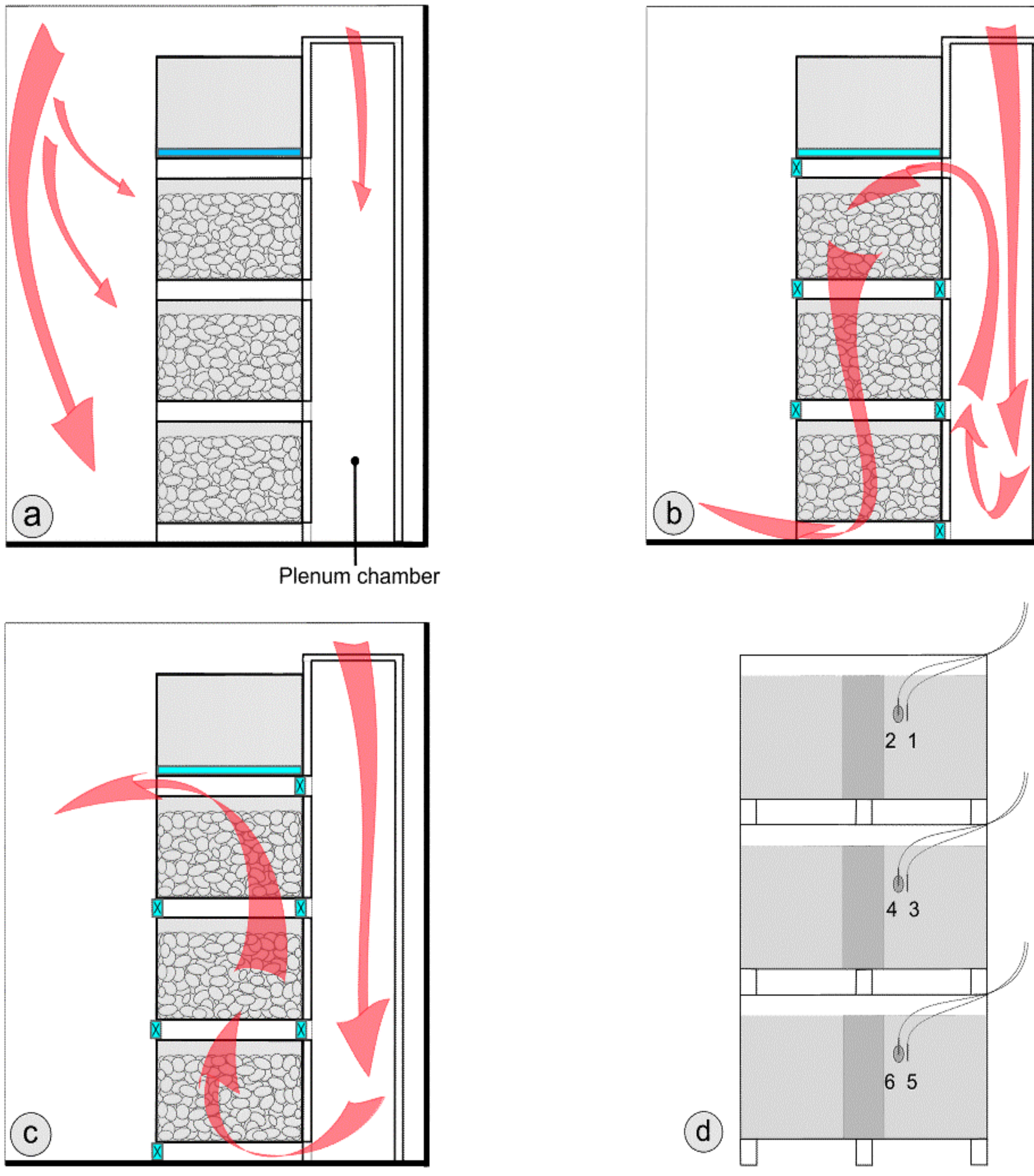
b) positive gradient (temperature increasing with height within stack) and

c) negative gradient (temperature decreasing with height within stack).

Air movements were controlled by selectively sealing pallet apertures with foam blocks. In this first year, heating was used to raise temperatures from 7C.

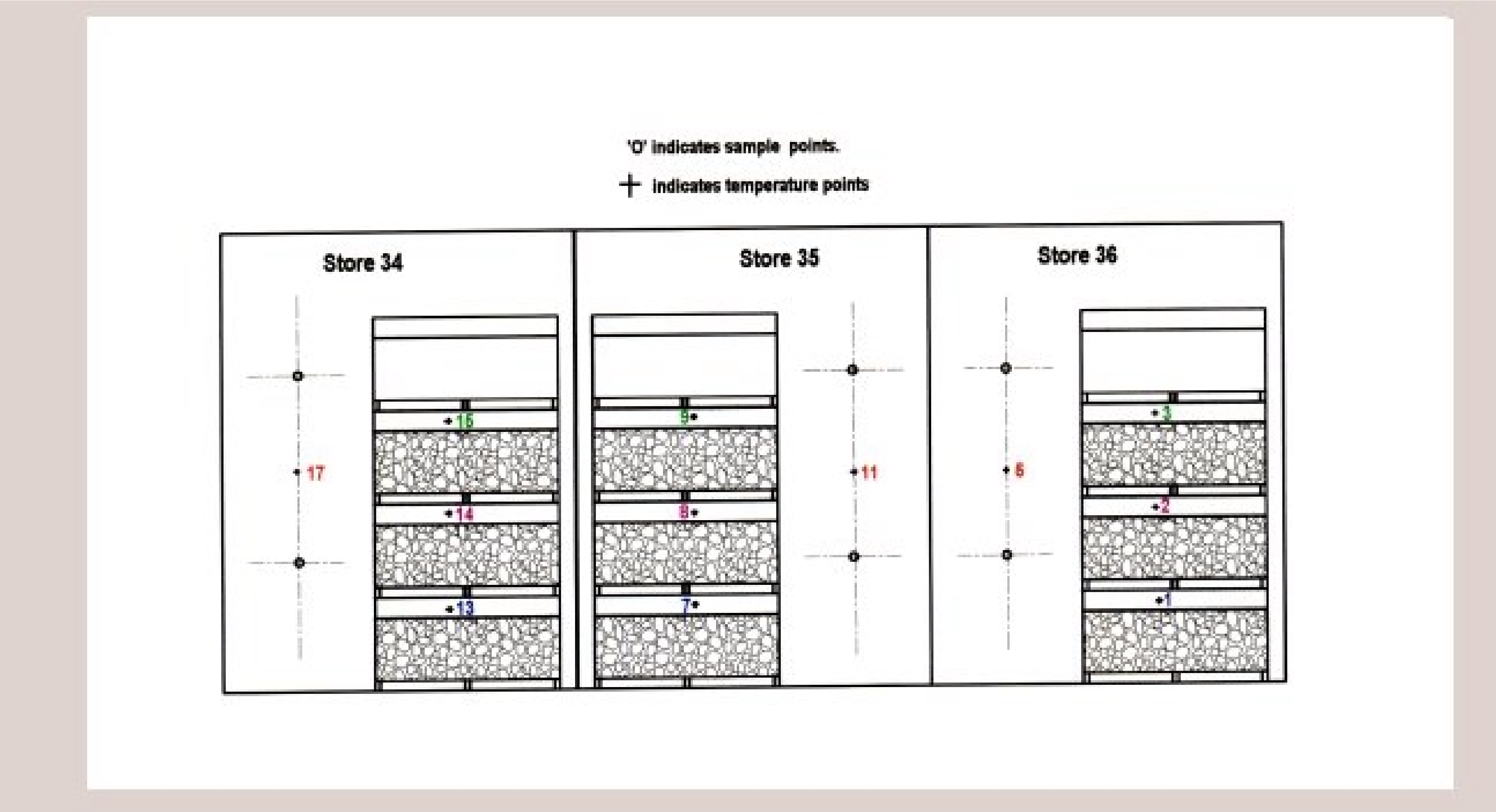
Prior to chemical application, the crop was maintained at a steady temperature and the relative humidity 95%. About four hours before chemical application, the heating or cooling system was switched on in the two stores where a temperature gradient needed to be established. When the desired temperature gradient had been established, stores were switched off, foam sealing blocks removed and CIPC was applied.

Figure 3.1: Air flow patterns used to obtain temperature gradients [a) uniform, b) top air delivery, c) bottom air delivery] and temperature probe locations (d)



Stores were instrumented by Silsoe Research Institute to monitor temperatures and measure the CIPC particle size spectra. The layout of the store instrumentation system is shown in Figure 3.2.

Figure 3.2: Layout of instrumented experimental stores for temperature gradient trials



For all three stores in the temperature gradient experiment, the formulation used was *MSS CIPC 50 M* [50% w/v chlorpropham in methanol; Nufarm Whyte Agriculture Ltd., Doncaster] which was applied using a *Superfog* machine [D. Wagstaffe, Superfog Ltd., Stamford]. A product flow rate of 1 litre per minute was used, at a burner temperature setting of 460C. CIPC fog was applied for 20 seconds to each store. As in the particle size experiments (Section 2), the fog was introduced at low level, and allowed to escape from an exhaust in the roof until application was complete. Stores remained switched off until all samples had been obtained, approximately 24 hours after application.

Applications were made as follows:

a) Store 34 - negative gradient (cold top/warm bottom);
b) Store 35 - minimal gradient;
c) Store 36 - positive gradient (cold bottom/warm top).

Tuber samples for deposit analysis were obtained from each box from a central, vertical column of potatoes, as in the particle size work (Section 2, Figure 2.3). Unwashed tubers were sampled in year 1 and two sets of assessments conducted, one on unwashed and a second on washed tubers. Samples were taken from the surface of boxes, and from depths of 300 mm and 600 mm after 24 hours. Surface tubers were halved horizontally *in situ.* Samples were stored at 3.5 - 4C prior to transfer to the University of Glasgow. CIPC deposits were analysed at Glasgow in August 1998 using a GC method (Khan, 1999).

Results

Minimal (<1C), positive and negative gradients were achieved (Table 3.1) although it was noted that the boxes receiving the heated air used in this year tended to be disproportionately warmer that others in the store. Consistency of temperature was also compromised between stores using heated air.

The measured size distributions in the fogs applied to the three stores treated in this experiment showed good agreement with mean particle size for all treatments in the range 4.6 to 7.4 µm. There was some tendency to measure higher concentrations of the smaller particle sizes at the lower sampling points which was not expected but may have been due to localised flow patterns in the access corridor as the fog was introduced.

The measured temperatures in each of the stores during application is shown in Figure 3.3. In the case of store 35 (minimal), temperatures during the period of control were very uniform. When the control system was turned off prior to fogging there was some tendency for higher temperatures to be measured in the top of the plenum chamber as expected. In both stores 34 and 36, the highest temperatures were measured in the top of the store (as expected) with the highest temperatures being recorded in store 36.

The CIPC deposit levels measured in the samples taken from this experiment are summarised in Table 3.1. The patterns of distribution were rather similar for stores 35 and 36 both in terms of deposition and residual CIPC after washing. The temperature gradients in these two stores were both positive (store 35 by natural convection and store 36 deliberately imposed) although the gradient in store 36 was greater. If any trend is evident, it is that there was less chemical deposited in the warmer top box of store 36 compared with that in store 35 where the temperature gradient was minimised.

Store 34 (negative gradient, cold at the top) was markedly different both in terms of straightforward deposition (unwashed) and residual attachment (as reflected in % retention after washing). It is likely that condensation and deposition of the chemical has occurred on the cold surfaces at the top of the upper boxes with little deposition taking place within the bottom box. The difference in the amount of CIPC which readily washed off in the top boxes of store 34 would suggest that the attachment of the majority of the CIPC to the tubers was slight under these conditions.

Table 3.1: Temperature gradients achieved in first year's trial (Expt 97/2)

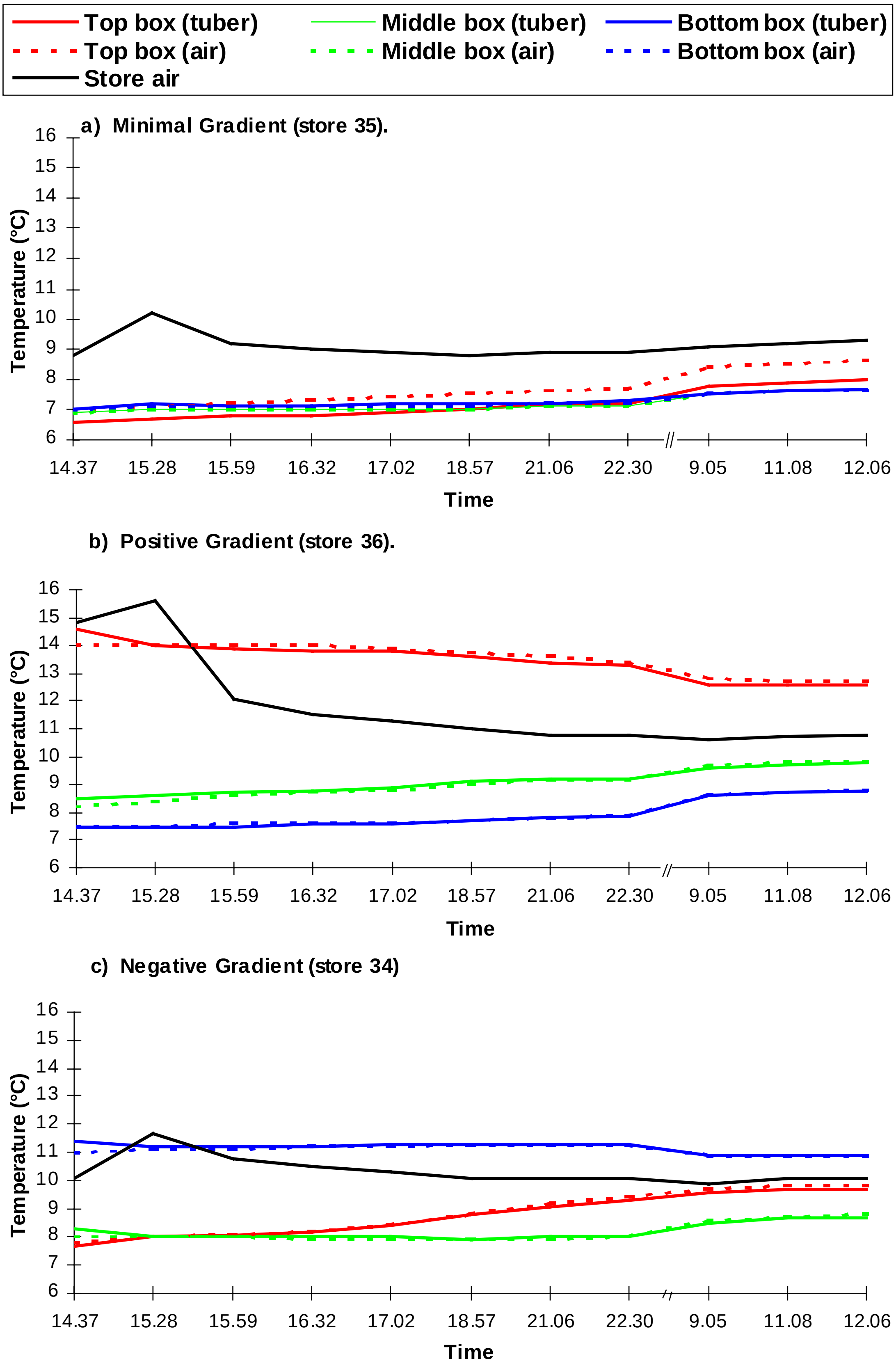
Time	Bottom 1	2	3	4	5	Top 6	Air
Store 34	**Positive**						
9.05	9.6	9.7	8.5	8.6	10.9	10.9	9.9
11.08	9.7	9.8	8.7	8.7	10.9	10.9	10.1
12.06	9.7	9.8	8.7	8.8	10.9	10.9	10.1
Store 35	**Minimal**						
9.06	7.8	8.4	7.5	7.5	7.5	7.5	9.1
11.09	7.9	8.5	7.6	7.6	7.6	7.6	9.2
12.06	8.0	8.6	7.6	7.6	7.7	7.6	9.3
Store 36	**Negative**						
9.06	12.6	12.8	9.6	9.7	8.6	8.6	10.6
11.09	12.6	12.7	9.7	9.8	8.7	8.7	10.7
12.07	12.6	12.7	9.8	9.8	8.8	8.8	10.8

Table 3.2: CIPC deposits in stores treated under differing temperature gradients (Expt 97/2)

Store		34	35	36	34	35	36
Temperature gradient		Negative**	Minimal	Positive*	Negative**	Minimal	Positive*
Box	Location within box	Deposit (as % of mean)[1]			% deposit retained after washing		
top	top[2]	165	188	92	30	55	66
	middle	36	97	25	45	61	100
	bottom	31	87	54	58	59	67
middle	top[2]	341	108	168	48	76	66
	middle	17	69	116	74	72	39
	bottom	22	79	93	79	70	60
bottom	top[2]	27	89	115	43	79	84
	middle	17	63	94	41	54	44
	bottom	11	35	67	85	77	67

**negative = cold at top of store; * positive = warm at top; [1] mean data from 5 replicate tubers expressed as % of mean deposit for each treatment
[2] mean data for top and bottom halves analysed separately (see Fig 3.6)

Figure 3.3 : Air temperatures measured after CIPC application in Expt 97/2.



The measurement conditions in this experiment were such that good quality estimates of the droplet size distributions applied to the stores were obtained. The deposit assessments also exhibit a good degree of consistency (once allowance for the variation between single tuber assessments is made). Many of the trends observed are consistent with earlier work carried out by the authors and others and the data can therefore be regarded as reliable.

Year 2

Experimental methods

For the second year of this experiment, the methods used were very similar to those employed in year 1. Again, each store contained four boxes in a single column stacked against the plenum chamber.

The method for establishing gradients was refined by changing to cooling crops from 10C using refrigeration to reduce the risk of any condensation forming on the potatoes which might interfere with CIPC deposition.

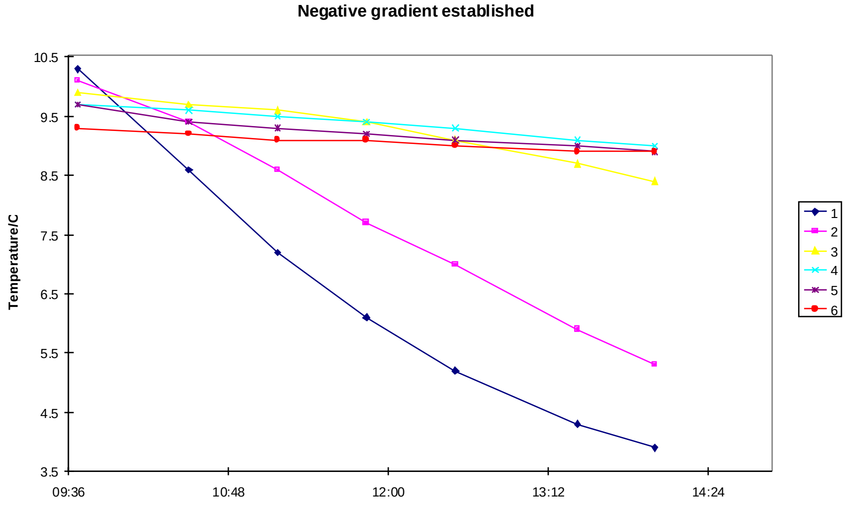
In year 2, only one set of CIPC deposit assessments were undertaken using *washed* tubers placed within the central column.

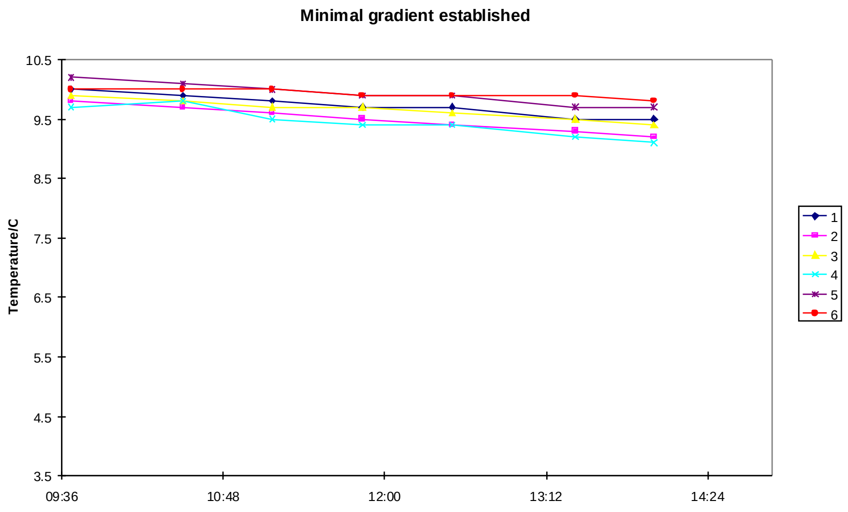
Results and observations

The temperature gradients established over a 4-5 h period prior to treatment in the second season’s work are shown in Figure 3.4. Negative, minimal (<1C) and positive gradients were attained in each store although it was noted that the negative gradient was not as even being skewed towards the upper box directly receiving the cooled air to establish the gradient. The particle size distributions of the fogs applied to the three stores in this experiment were quite uniform with a volume mean diameter range of 3.8 - 4.4 µm across the three treatments.

The trial produced a similar pattern of results to those obtained in Year 1. The data is summarised graphically in Figure 3.5 after normalisation to % of mean deposit. For all three treatments, similar overall mean levels of CIPC were deposited (c 22 mg/kg) but none resulted in particularly good patterns of CIPC deposition. Differences between treatments were less pronounced than in 1997 and, in general, the chemical was largely deposited on the upper surface of the tubers in the top of each box. The detailed deposit data also indicate that a high CIPC level was also evident in the lower level of the bottom box in the store with the positive temperature gradient (i.e. the stack which was comparatively cool at the base).

Figure 3.4: Temperature gradients established in Expt 98/2:





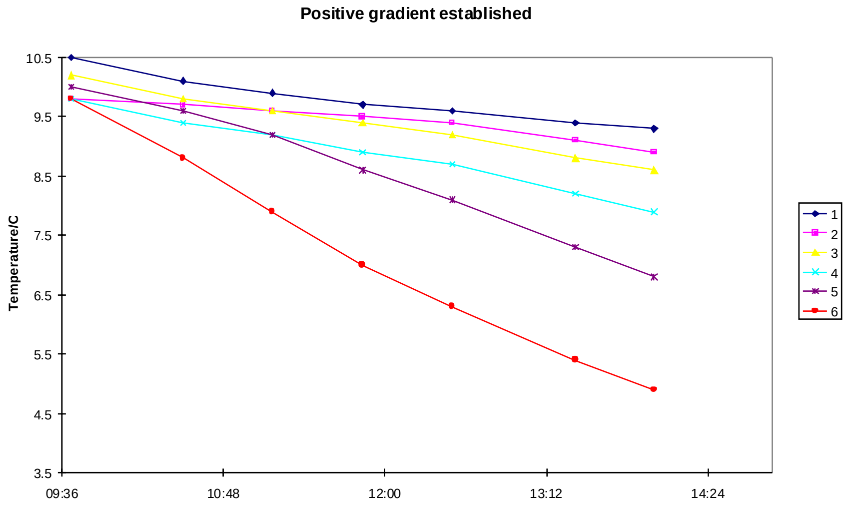
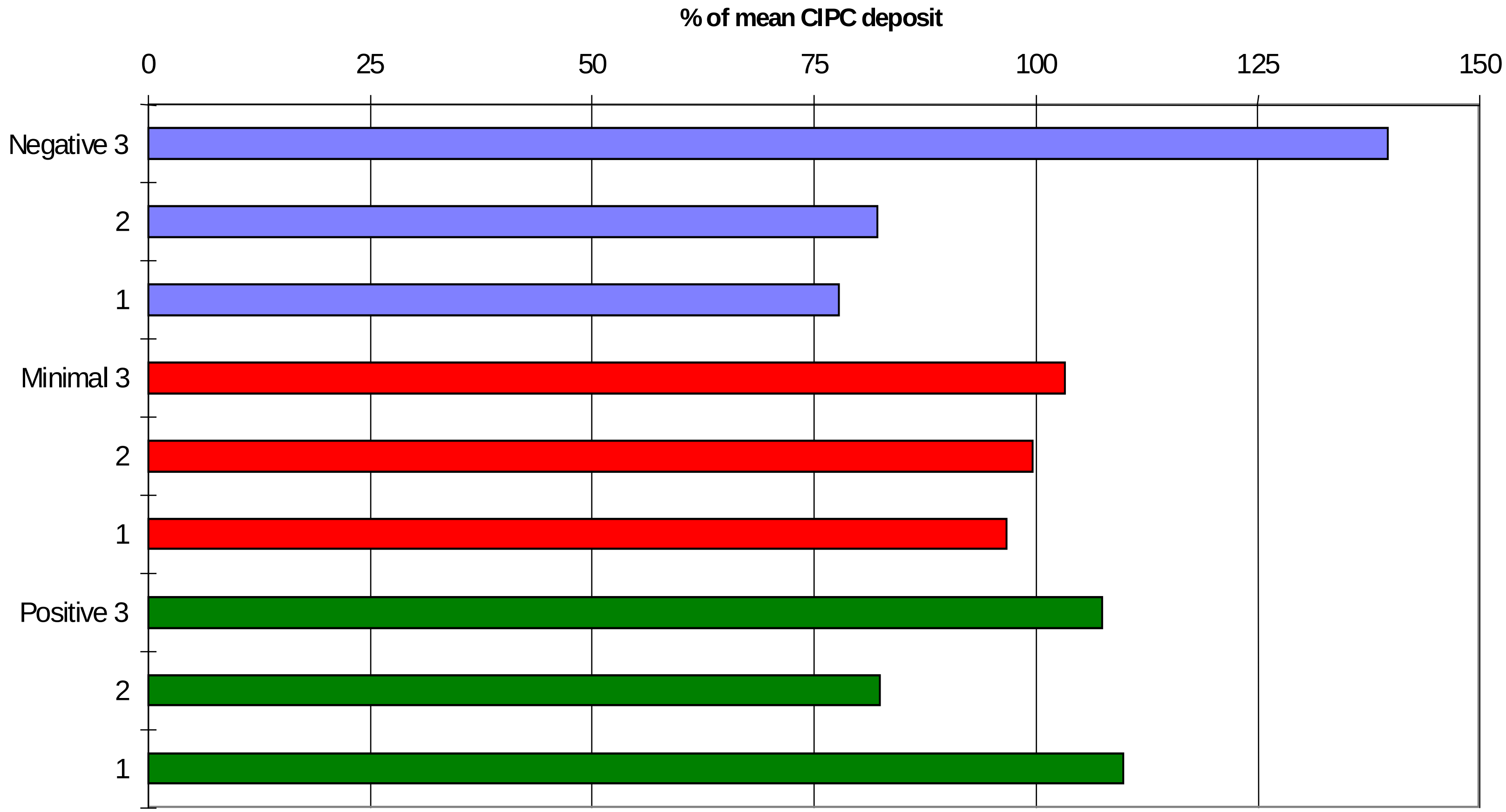


Figure 3.5: Normalised CIPC deposits by box position within sampled column for temperature gradients in Expt 98/2



Discussion

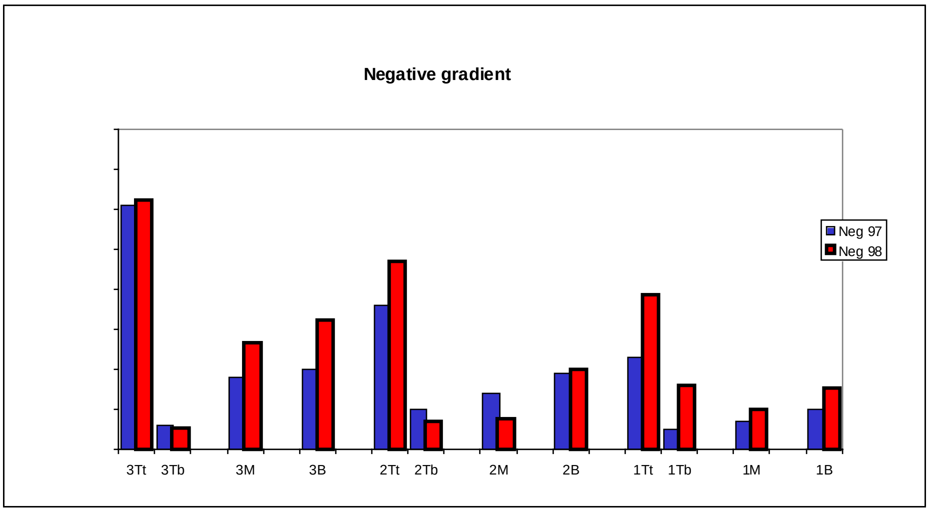
Graphs showing the comparative results, by position within box, for each of the treatments (Figure 3.6) show a very close correlation between the two years' work with just the positive gradient data exhibiting some minor differences. On the basis of the two years' studies, it appears the effect of temperature gradient is, like particle size, less marked or perhaps less direct, than was first thought. In all the gradients established within this study, the pattern and level of CIPC deposition *within* boxes was similar with large deposits on the upper surfaces of the top tubers and smaller amounts measured in the centre and bottom of the boxes. This supports the conclusion of the first year's work where it was suggested that CIPC flow and consequent deposition takes place mainly in a *downwards* direction from the top of the box.

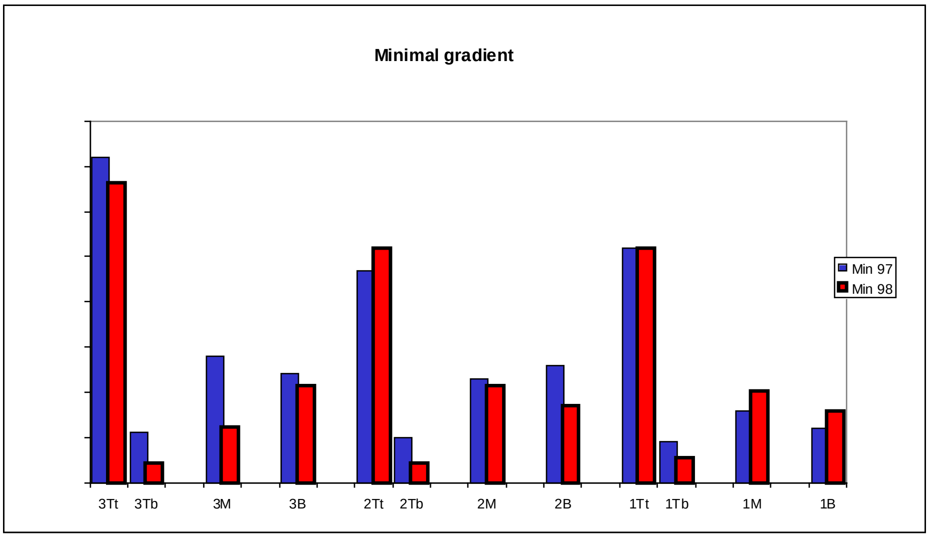
This observation may, however, only hold for the type of indirectly ventilated store where there is no means for the CIPC to access the boxes other than by dissipation through the pallet apertures or directly on to the top surface of the stack. Some of the work by Duncan & Boyd (1994) indicated that, where positive delivery of air (and hence CIPC) can be achieved via a plenum, more even distribution and attachment of the chemical (and therefore sprout control) had been noted.

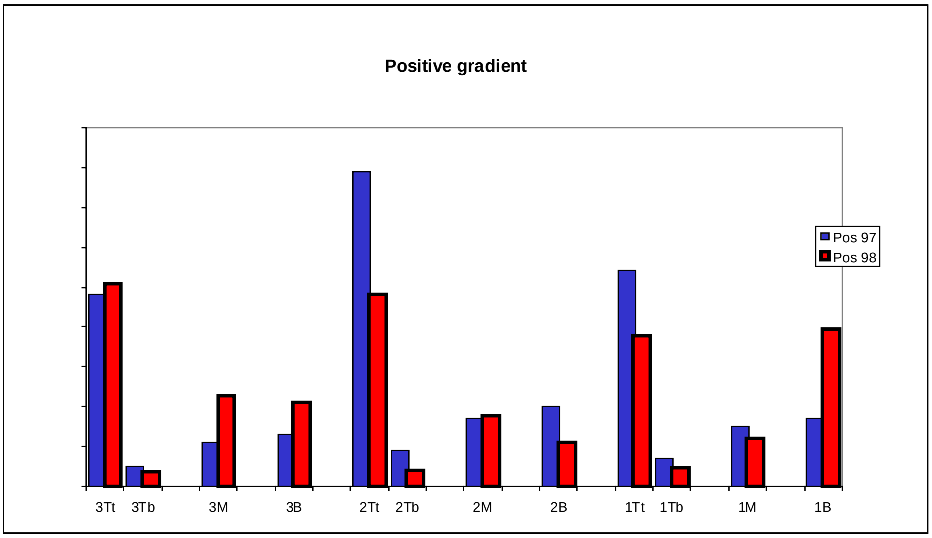
Between boxes, deposits varied according to the type of gradient. Deposits in the top boxes were reduced comparatively where a natural, positive gradient existed although this resulted in a higher concentration of CIPC in the bottom box. The most even distribution resulted from the store with a minimal temperature gradient.

Where hot fog has access to the store roof space it can quickly come into contact with cooler potatoes and begin to condense out on the surface of the stack. But a factor which may also be of particular relevance, as a consequence of any temperature gradient, is condensation of water within the crop. Work by Pringle (1996) and others has demonstrated how easily thin films of moisture can form within potatoes where there is even just quite a small gradient in temperature. If such a film were present when CIPC was applied, this might lead to rapid deposition of the chemical as it comes into contact with any affected tubers. Certainly, dramatic differences in temperature have been shown to influence CIPC deposition and, even if the effect is an indirect one, it is wise to conclude that – as is the case for other store management factors – large temperature gradients should be avoided if even CIPC distribution is to be attained. Measures to prevent the fog from rising directly up into the roof of a store might also be beneficial, such as the use of covers over the treatment area effectively creating a plenum which will force a proportion of the fog straight into the pallet apertures.

Figure 3.6 : Graph showing the comparative patterns of CIPC deposit for the two years' trials for box position and position within box







Key: 1,2,3 = box position (1 = floor); *n*Tt= top half of tubers at top of box *n*, Tb= bottom half of tubers at top of box, M=middle of box, B= bottom of box etc.

5. THE EFFECT OF VENTILATION ON CIPC DISTRIBUTION

Experiment 98/3 carried out on 11 June 1998
Experiment 99/3 carried out on 4 August 1999

This trial series was aimed at investigating the effects of ventilation treatments on CIPC distribution. As CIPC is delivered into the store as an airborne fog it is dependent largely on passive air movements (from differences in temperature) and the energy of the application process itself to be able to penetrate the potatoes. There is potential to utilise the store's ventilation system to assist in this process.

However, this technique has not been widely adopted by the industry, mainly because of a fear of fire or explosion associated with the low flashpoint of one of the main CIPC formulation solvents (methanol). There are nevertheless non-flammable solvents (eg dichloromethane and pyrollidone) now available which offer potential for use of ventilation and the effect of its use on distribution of the chemical was investigated.

Year 1

Experimental methods

The trial was carried out in three 12-tonne capacity stores at SBEU. Each of these contained three columns of four boxes stacked away from the plenum chamber. All the boxes were filled with potatoes, with a central column of different tubers incorporated into each of the middle column of boxes (as described earlier in Section 2, see Figure 2.2).

Stores were instrumented using the SBEU stores' probe systems [Cornerstone Systems Ltd., Stone] to measure tuber temperature and these were supplemented by Silsoe Research Institute to monitor air temperatures and measure CIPC particle sizes. The layout of the store instrumentation for these experiments is as shown in Figure 2.3.

The ventilation treatments were:

a) no ventilation
b) 'full' ventilation, i.e. recirculative ventilation, for 15 min prior to and 1 hour immediately after application (ventilation was turned off during application itself)
c) intermittent recirculative ventilation for 5 min immediately after application then 5 min every hour for 4 h.

Both ventilation treatments were applied using the integral store fan.

The CIPC formulation used was *Gro-Stop HN* applied using a *Unifog* machine by Sands Agricultural Services Ltd. *Gro-Stop HN* is a liquid hot fogging concentrate containing 300g per litre chlorpropham in dichloromethane. This non-flammable formulation has a label recommendation for ventilation to be used to assist application.

For the application, a nozzle pressure of 3.5 bar was used, with the burner temperature setting on the applicator at 400C. Fog was applied for 30 seconds to each store. The CIPC fog was introduced at low level through a port in the store door and, to prevent undue back pressure on the application system in the small 12t experimental stores, was allowed to escape from an exhaust in the roof until application was complete. Apart from the specific ventilation treatments applied, stores remained switched off until all samples had been obtained.

Tuber samples for deposit analysis were obtained, from each box, from a central, vertical column of untreated and washed potatoes (using the techniques described in Section 2), 24 hours after application. Samples were taken from the surface of boxes, and from depths of 300 mm and 600 mm. Surface tubers were halved horizontally *in situ*. Samples were stored at 3.5 - 4C prior to despatch and were sent to Glasgow by overnight courier within 7 days of application. CIPC deposits were again analysed by the University of Glasgow using a gas chromatographic technique (Khan, 1999).

Results & observations

CIPC deposits measured on samples taken after application of the various ventilation treatments are detailed in Appendix Tables 8.2, 8.3 & 8.4 for Stores 35 (no ventilation), 34 (full recirculative ventilation treatment) and 36 (intermittent ventilation treatment) respectively.

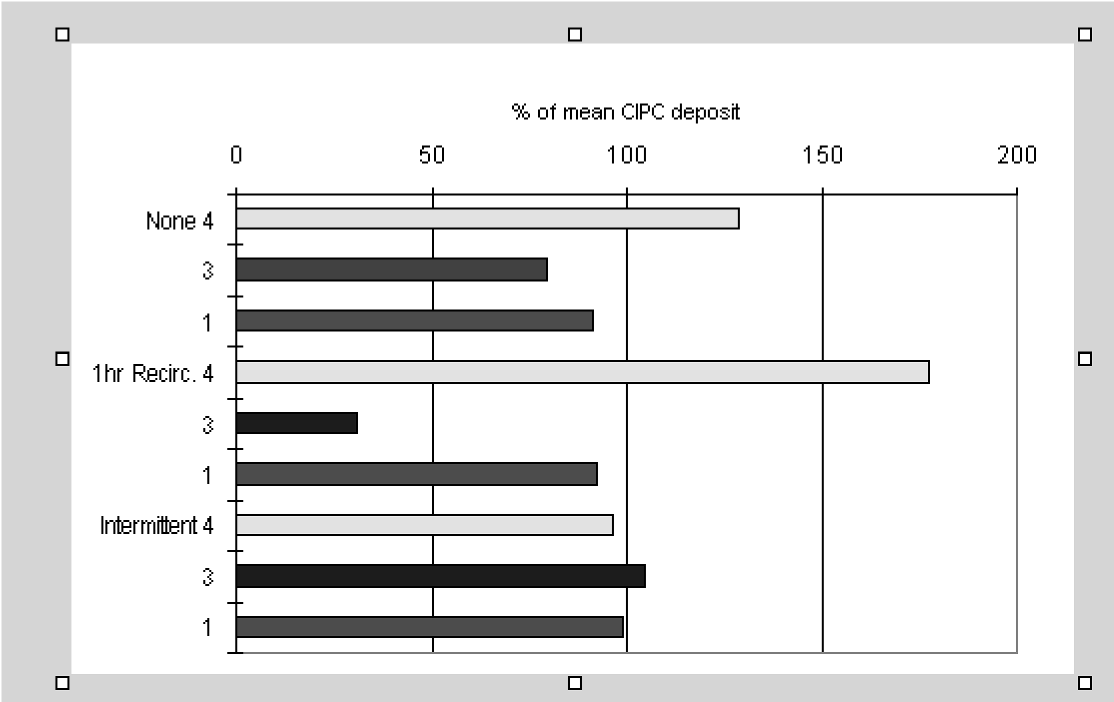
This data is summarised by box position within the sample column (1=base, 4=top) in Figure 4.1. Compared with the unventilated control which gave good but slightly uneven deposits of CIPC, the data illustrates that, in this particular experiment, continuous ventilation for one hour after application resulted in an undesirable distribution of the chemical which was heavily biased to the top part of the upper box. Use of ventilation for just 5 minutes per hour for 4 hours after application gave a more even deposit overall than the unventilated control.

Year 2

Experimental methods

The experiment was repeated in 1999 using the same methods as employed in Year 1 (Section 4.1.1). However, the fogger burner temperature used for the 1999 trial was slightly lower at 350C and boxes were stacked 3 high in the second year.

Figure 4.1 : Summary of normalised CIPC deposits by box position within sample column for three ventilation regimes used during CIPC application (Expt 98/3)



For the second season, the ventilation treatments were modified slightly to:

a) no ventilation
b) intermittent recirculative ventilation: recirculation for 5 min immediately after application then 5 min every hour for 4 h using the integral store fan.
c) intermittent recirculative ventilation: recirculation for 5 min immediately after application then 5 min every hour for 4 h using an auxiliary fan mounted at low level in the store adjacent to the access corridor
d) recirculative ventilation for 20 minutes immediately after application using an auxiliary fan mounted at low level in the store adjacent to the access corridor.

All other aspects of the methodology employed were the same as in Year 1.

Results & observations

CIPC deposit measurement data for Year 2 are given in Appendix Tables 8.5-8.8 for treatments (a) through to (d) respectively. The results are summarised by box position (1=base, 3=top) within the sample column in Figure 4.2 with a more detailed breakdown by position within box (T=top; M=middle, B=bottom) shown in Figure 4.3.

In the second year, the intermittent ventilation using the integral store fan (as used in 1998) did not result in as even a pattern of deposit as in year 1 with a higher proportion of the CIPC deposited in the top box.

The use of intermittent recirculative ventilation with an auxiliary fan *at low level in the store* reduced characteristic bias towards deposition on the top of the top box such that this was the only treatment where the maximum deposit was not on the top box. Continuous recirculation for 20 minutes after fogging with a similarly located fan did not benefit overall CIPC distribution.

Discussion

CIPC distribution without recirculative treatments resulted in a familiar pattern with the highest proportion of CIPC present on the top surface of the top boxes but with a reasonable percentage of the CIPC (>70% of mean deposit) being deposited in the lower levels of the boxes.

The application of recirculative ventilation treatments after application modified this pattern.

The use of a 60 minute continuous air recirculation period immediately after application resulted in a re-distribution of CIPC such that the concentration of the top box was very high, compared with the control, and the concentration in the middle box was very low.

The use of continuous ventilation in year 2 (20 minutes with the auxiliary fan placed at low level) also resulted in an increase in CIPC deposits on the top tubers, but differences between this treatment and the control were slight.

Use of the ventilation system intermittently resulted in an inconsistent effect. In year 1, using the integral store fan, very even distribution of CIPC was obtained throughout the column of boxes. However, in year 2, the same treatment resulted in a high level of CIPC in the top box, which was relatively evenly distributed throughout that box. A similar treatment (4 x 5 minutes) using a low level axial fan resulted in a general reduction in the CIPC deposited on tubers in the top box such that levels were lower than on tubers sampled from the boxes lower down the stack.

This suggests that redistributing the fog to minimise its natural tendency to (initially) rise to the top of the store and then sediment out can improve evenness of chemical distribution.

Figure 4.2 : Normalised CIPC deposit data by box position within sample column for four ventilation regimes employed during CIPC application (Experiment 99/3)

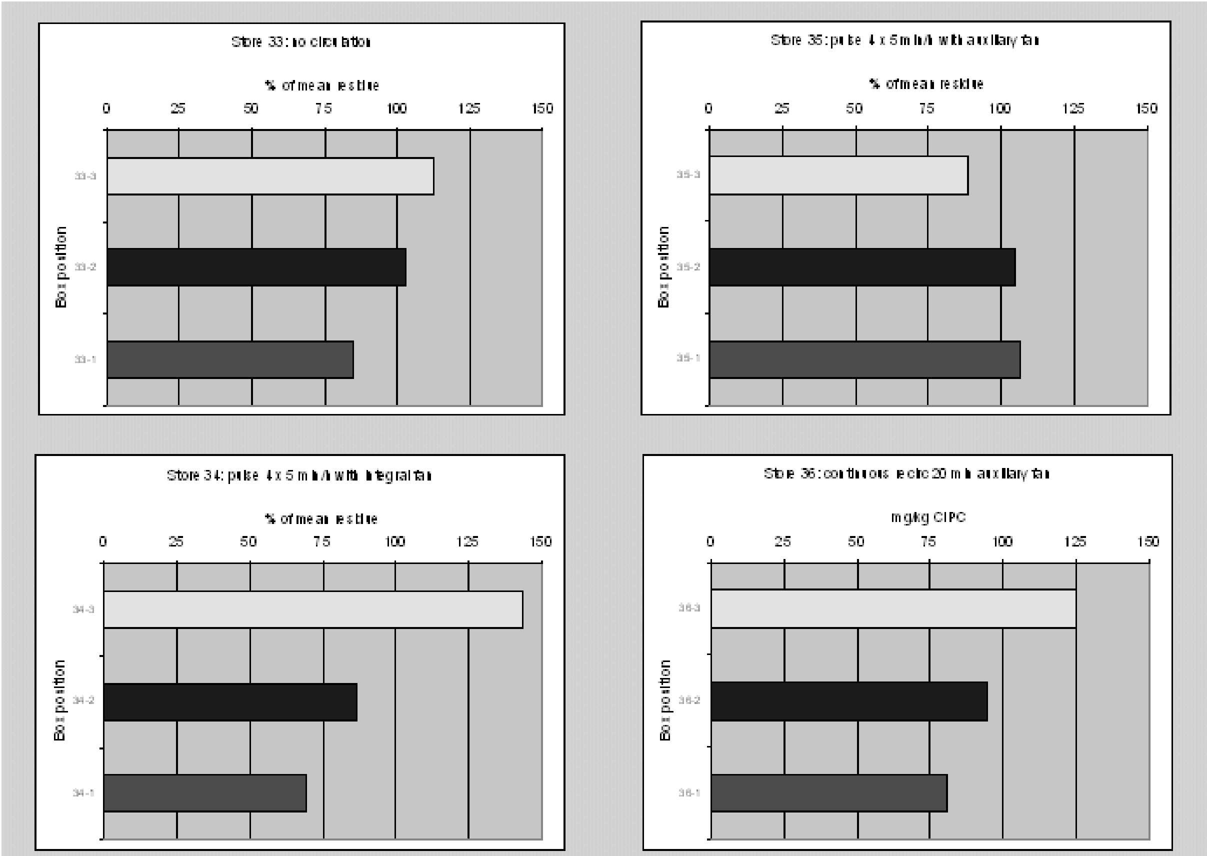
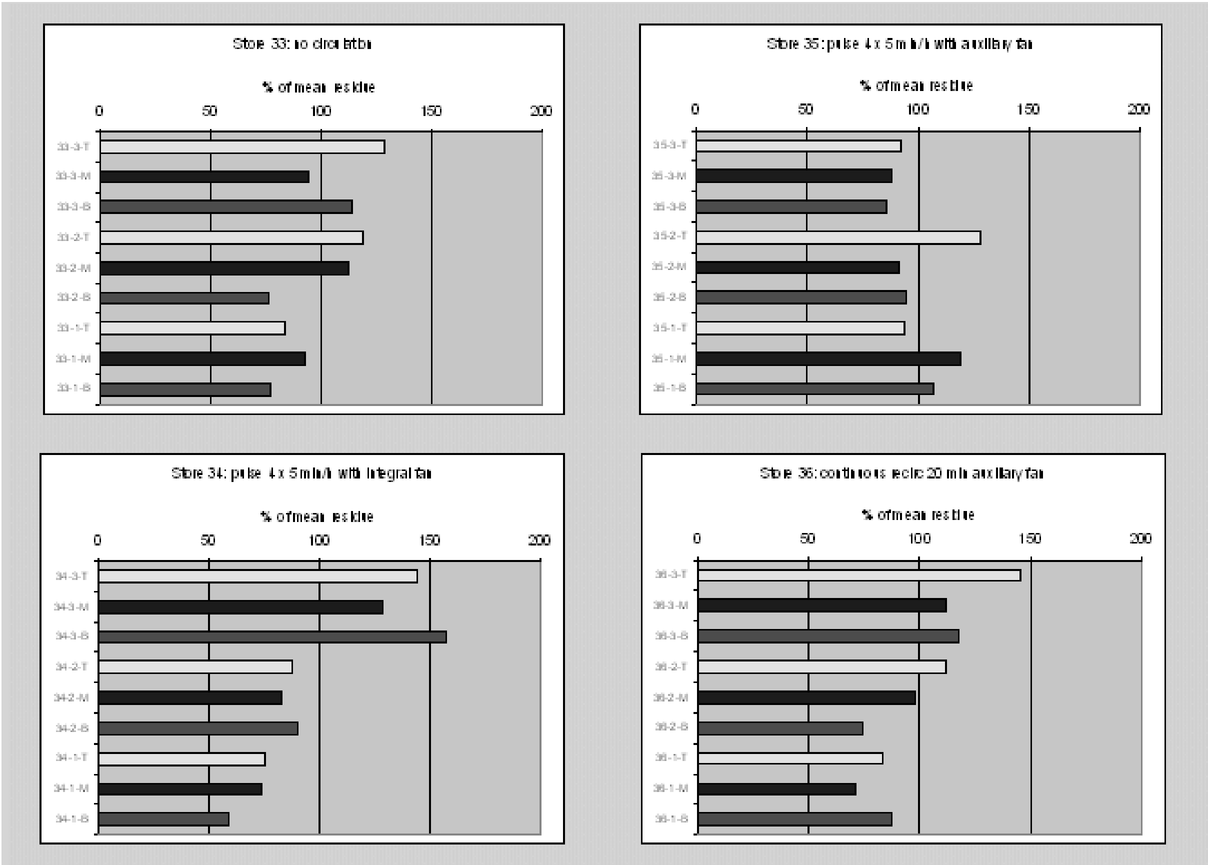


Figure 4.3: Normalised CIPC deposit data in detail by position within box within sample column for four ventilation regimes employed during CIPC application (Experiment 99/3)



However, the use of any form of ventilation to re-distribute CIPC within a store is questionable if this involves discharging the chemical over the top of the stack. This may, on the evidence of this work, heighten the risk of concentrating the chemical in the air paths, and the roof space in particular, increasing sedimentation on the top surfaces of the crop. Nevertheless, where some form of positive delivery of air, and therefore CIPC, is possible the technique could have considerable benefits in getting the chemical into contact with the potatoes, although these would need to be evaluated in a future experiment.

It is important to point out, despite these findings, that **an element of caution is still necessary** as, although ventilation may offer advantages for distribution if correctly applied, it is the collective view of the authors that the adoption of practices to take advantage of some of the trends shown by this work (eg generation of a finer fog and more extensive use of ventilation systems to re-distribute the CIPC) could also have detrimental implications for store safety which warrant further investigation.

Initial work by Duncan (1999) has indicated that there may possibly be an increased risk of explosion where some source of ignition is present with fine particles of CIPC fog. Under some circumstances, the switching of ventilation systems may provide a spark which is sufficient to initiate the reactions. It is important to stress that sufficient data to fully substantiate this hypothesis have yet to be gathered but, until these become available, it would be prudent to err on the side of caution.

If any changes to normal procedures are to be adopted, these should be agreed with the application contractor and the agrochemical manufacturer involved beforehand. Label recommendations must of course be adhered to in order to comply with legislation governing the use of chemicals.

6. SUMMARY DISCUSSION, CONCLUSIONS AND COMMERCIAL RECOMMENDATIONS FROM THE TRIALS SERIES

The work on particle size found that varying this particular attribute of the CIPC fog was actually more difficult than first thought. Contrary to the suspicions of some in the industry, variation of burner temperature alone was insufficient to give a significant change in the particle size of the fog. Even when flow rate was adjusted, there was little change to the particle size spectrum although some variation was achieved with a particular formulation which suggests that the carrier may also have some role in affecting the particle size of the fog.

The rate at which the fog disperses and becomes deposited on the crop (or the store fabric) does appear to be affected by particle size. Very fine particles (<2µm) remain mobile for a longer period of time and other work (Briddon & Jina, 2000) suggests these may ultimately be lost from the store. However, the finest particles do make up an almost insignificant proportion of the total CIPC applied. Nevertheless, an increase in the proportion of fine particles, providing they are not *too* fine, may still be beneficial in that the finer particles remain mobile in the store air and therefore may have a greater propensity to attach to tuber skin rather than merely sedimenting out on top surfaces. The more CIPC that can be encouraged to attach in this way, the more even the distribution of the chemical is likely to become.

Temperature gradients have been shown to be detrimental to the pattern of CIPC deposition. Wherever a gradient exists, this might be expected to lead to a differential level of CIPC deposition. The exact effect the gradient has on deposition will vary according to the temperature of the crop in relation to the fog and the effects any gradient has on localised air movement in the store. One strong effect which the work has shown is that a gradient where there are relatively cold potatoes at the top of a store will result in significant levels of loosely-attached CIPC sediment falling out on the top surface of the top boxes. This has particular implications for the efficacy of the sprout suppressant, as this chemical is not reaching its intended target.

Uniform temperature gradients are therefore important for good CIPC deposition but the factors triggering this sedimentation of the chemical require further investigation. Whilst a cold layer of potatoes at the top of the store may lead to poor penetration of the warm CIPC into the boxes lower down in the store, it is perhaps unlikely the effect is solely temperature-related and other factors, such as formulation of the product, may be influential in the deposition process.

Use of ventilation when applying CIPC may be a way of circumventing some of these effects but this work suggests that continuous ventilation may result in diversion of CIPC from the target to other parts of the store, or even loss of the chemical from it. Short periods of ventilation to maintain the fog's mobility and perhaps counteract any sedimentation showed the best results in terms of evenness of CIPC deposit. However, more work is needed to confirm these findings.

In summary, it can be concluded from this series of trials:

Effect of particle size

- Particle size is very difficult to vary when a fogger is used within its normal operating range.

- The use of very fine particles results in a reduction of the importance of sedimentation and offers potential for improved efficiency of chemical use which might help meet future maximum residue limits.

- The dissipation rate of CIPC fog is dependent on particle size.

Effect of temperature gradient

- The maintenance of an even temperature gradient in stores helps to achieve a uniform distribution of CIPC within boxes.

- However, the significance of this factor may be diminished by sedimentation effects which can distort the distribution of CIPC and are less directly influenced by temperature.

Effect of ventilation

- Short periods of ventilation with an auxiliary fan at low level in the store resulted in a more even pattern of CIPC distribution through the stack.

It is therefore recommended that the following steps are taken in commercial stores to optimise CIPC use, pending further results from new studies now initiated by BPC at Sutton Bridge Experimental Unit and Glasgow University:

- Use a good chemical applicator operated by a specialist contractor. A machine which provides a relatively fine particle size will provide the best chance of achieving uniform distribution (all other factors being equal).

- Minimise temperature gradients within a store before application by turning off temperature control equipment (especially refrigeration) and recirculating air to even out any temperature differences.

- Take steps to minimise sedimentation of CIPC by delivering it into the boxes as directly as possible, ideally via the pallet apertures using a plenum chamber if one is available. Alternatively, investigate ways of creating an artificial plenum within a space ventilated box store.

- Consider the possibility of using, <u>but only if permitted by the product label</u>, short periods of ventilation to assist the distribution of the chemical around the store. There may be benefits to continuing to use these for up to six hours after application to maintain the mobility of finer particles of the CIPC.

- Do not over-ventilate as this may result in loss of CIPC or concentrate CIPC deposits within certain parts of the store. Use of a high ventilation rate can result in impaction of CIPC onto metal surfaces (eg fan blades, grilles) so use of a low volume auxiliary fan, perhaps with an airflow as low as 0.005 m^3/s/t, may be preferable to minimise any detrimental effects to the store cooling system.
- Be aware that ventilation of CIPC should only be used if electrical switch gear controlling the fans is of a type which is spark-free. Passing CIPC through ductwork and fridge coils can also be detrimental to these components and may invalidate warranties. It may be worthwhile investigating methods of providing independent circulation of the fog.
- Any changes to normal procedures should be agreed with the contractor and agrochemical manufacturer involved beforehand.

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Mr Jon Power of Silsoe Research Institute
Mr Waqar Khan and Mr Satar Kraish of The University of Glasgow.
Staff of BPC Sutton Bridge Experimental Unit

8. REFERENCES

Anon. (1994). *Chemicals for treatment of seed and ware potatoes.* Potato Marketing Board advisory leaflet. Potato Marketing Board, Oxford. 8pp.

Briddon, A., Cunnington, A.C., Miller, P.C.H., Lane, A.G., Duncan, H.J. & Khan, W. (1998). *Optimisation of CIPC application and distribution in stored potatoes.* Report to the British Potato Council by Sutton Bridge Experimental Unit Ltd., Silsoe Research Institute and the University of Glasgow. Sutton Bridge Experimental Unit Ltd. Year 1 interim project report, S104, February 1998.

Briddon, A., Cunnington, A.C., Miller, P.C.H., Lane, A.G., Duncan, H.J. & Kraish, A.S.F. (1999). *Optimisation of CIPC application and distribution in stored potatoes: 2.* Report to the British Potato Council by Sutton Bridge Experimental Unit Ltd., Silsoe Research Institute and the University of Glasgow. Sutton Bridge Experimental Unit Ltd. Year 2 interim project report, S104, April 1999.

Briddon, A. & Jina, A. (2000). *The deposition of thermal fog applied CIPC on stored potatoes.* Paper in preparation.

Burfoot, D., Smith D.L.O. & Butler-Ellis, M.C. (1994). *Air flow and modelling to improve the uniformity of CIPC distribution.* Report to the Potato Marketing Board. Silsoe Research Institute contract report CR/626/95/8716.

Burfoot, D., Smith, D.L.O., Butler-Ellis, M.C. & Day, W. (1996). Modelling the distribution of isopropyl N-(3-chlorophenyl) carbamate (CIPC) in box potato stores. *Potato Research* **39**: 241-251.

Duncan, H.J. & Boyd, I.M.G. (1994). *Optimising the use of CIPC for sprout control of ware potatoes.* Potato Marketing Board, project report 807/145.

Duncan, H.J (1999). Explosion and combustion processes associated with the fogging of stored potatoes. *Potato Research* **42**: 25-30.

Khan, W (1999). PhD Thesis: The distribution and behaviour of chlorpropham with tuber components in commercial potato stores. Department of Chemistry, University of Glasgow, January 1999.

Miller, P.C.H., Lane, A.G. & Butler-Ellis, M.C. (1997(a)). The measurement of particle sole distributions in fogged treatments applied to stored crops*. Crop Protection and Food Quality: Meeting Customer Needs*. British Crop Protection Council. 383-388.

Miller, P.C.H., Lane, A.G. & Power, J.D. (1997(b)). *Measurements of the particle size distributions in fogging treatments used in potato stores*. Silsoe Research Institute contract report CR/766/97/1500.

Miller, P.C.H., Briddon, A., Cunnington, A.C., Duncan, H.J., Khan, W. & Lane, A.G. (2000) *Application of sprout suppressant chemicals to stored potatoes using fogging treatments.* Paper submitted to *Crop Protection*.

Pringle, R.T. (1996) Storage of seed potatoes in pallet boxes. 2. Causes of tuber surface wetting. *Potato Research* **39**: 223-240.

Storey, R.M.J. & Briddon, A. (1996) Effective use of CIPC in potato stores. In: *Abstracts of 13th Triennial Conference of EAPR, Veldhoven, Netherlands, 14-19 July 1996*. European Association for Potato Research. 580-581.

Xu, Y. & Burfoot, D., (2000). Modelling the application of chemicals in box potato stores. *Pest Management Science* **56**: 111-119.

9. APPENDIX

Table 8.1: Deposits of CIPC(mg/kg) in samples taken from 3 treatments in Expt 98/1b

store/trmt/	sample point	half tuber	tuber	position means/SD	sample	point	half tuber	tuber mean	position mean	box mean	treatment mean
St 34: 'fine' fog											
4T	1t	1.27			3T	1t	0.85				
	1b	0.96	1.12			1b	0.34	0.60			
	2t	1.07				2t	0.26				
	2b	1.09	1.08			2b	0.22	0.24			
	3t	1.75				3t	0.69				
	3b	1.27	1.51	**t 1.40**		3b	0.28	0.49	**t 0.47**		
	4t	1.45		SD 0.25		4t	0.29		SD 0.28		
	4b	1.05	1.25	**b 1.04**		4b	0.26	0.28	**b 0.30**		
	5t	1.47		SD 0.16		5t	0.25		SD 0.07		
	5b	0.83	1.15	**1.22**		5b	0.41	0.33	**0.39**		
					3M	1		0.22			
						2		0.34			
						3		0.17			
						4		0.20	**0.19**		
						5		0.03	SD 0.11		
					3B	1		0.22			
						2		0.70			
						3		0.39			
						4		0.52	**0.43**		
						5		0.32	SD 0.19	**0.34**	**0.56**
St 35: 'medium' fog											
4T	1t	5.95			3T	1t	3.49				
	1b	1.14	3.55			1b	1.27	2.38			
	2t	5.84				2t	3.6				
	2b	1.98	3.91			2b	2.36	2.98			
	3t	2.74				3t	3.23				
	3b	2.78	2.76	**t 4.68**		3b	1.61	2.42	**t 3.84**		
	4t	4.82		SD 1.34		4t	3.97		SD 0.65		
	4b	2.14	3.48	**b 2.07**		4b	1.68	2.83	**b 1.71**		
	5t	4.03		SD 0.60		5t	4.89		SD 0.40		
	5b	2.33	3.18	**3.38**		5b	1.63	3.26	**2.77**		
					3M	1		1.30			
						2		3.11			
						3		2.41			
						4		2.52	**2.15**		
						5		1.42	SD 0.77		
					3B	1		3.13			
						2		3.77			
						3		2.48			
						4		2.87	**2.90**		
						5		2.25	SD 0.59	**2.61**	**2.80**
St 36: 'coarse' fog											
4T	1t	4.37			3T	1t	1.66				
	1b	1.58	2.98			1b	0.43	1.05			
	2t	4.87				2t	1.46				
	2b	1.69	3.28			2b	0.59	1.03			
	3t	2.18				3t	1.07				
	3b	1.66	1.92	**t 4.27**		3b	0.94	1.01	**t 1.45**		
	4t	4.23		SD1.31		4t	1.58		SD 0.23		
	4b	2.11	3.17	**b 1.66**		4b	0.95	1.27	**b 0.72**		
	5t	5.71		SD 0.30		5t	1.49		SD 0.22		
	5b	1.26	3.49	**2.97**		5b	0.67	1.08	**1.08**		
					3M	1		1.19			
						2		0.74			
						3		1.19			
						4		0.92	**0.84**		
						5		0.17	SD 0.42		
					3B	1		0.36			
						2		1.06			
						3		0.00			
						4		0.99	**0.71**		
						5		1.13	SD 0.35	**0.88**	**1.40**

t = top half of tuber; b= bottom half; 4T= top of 4th (ie top) box; 3T= top of 3rd box; M= middle; B= bottom; SD=std deviation

Table 8.2: Deposits of CIPC(mg/kg) in samples from no ventilation treatment in Store 35 for ventilation Expt 98/3

store/trmt/	sample point	half tuber	half tuber	mean	tuber	position mean	box mean	treatment mean
4T	tuber 1t	4.04						
	1b	3.74			3.89			
	2t	6.63						
	2b	1.56			4.10			
	3t	9.11						
	3b	1.95			5.53			
	4t	5.40	top half (box 1)					
	4b	3.44		**7.7**	4.42			
	5t	13.47	bottom half					
	5b	3.11		**2.8**	8.29	**5.3**		
4M	tuber 1				4.70			
	2				8.39			
	3				2.50			
	4				7.33			
	5				3.72	**5.3**		
4B	tuber 1				3.28			
	2				7.74			
	3				1.42			
	4				4.46			
	5				7.08	**4.8**	**5.1**	
3T	tuber 1t	5.30						
	1b	2.01			3.66			
	2t	7.00						
	2b	1.78			4.39			
	3t	4.15						
	3b	2.86			3.51			
	4t	4.62	top half (box 3)					
	4b	2.02		**5.0**	3.32			
	5t	3.69	bottom half					
	5b	1.56		**2.1**	2.63	**3.5**		
3M	tuber 1				3.74			
	2				2.27			
	3				2.45			
	4				3.18			
	5				2.58	**2.8**		
3B	tuber 1				1.56			
	2				3.24			
	3				4.29			
	4				4.56			
	5				2.14	**3.2**	**3.2**	
1T	tuber 1t	3.70						
	1b	1.72			2.71			
	2t	3.62						
	2b	3.35			3.49			
	3t	3.19						
	3b	2.14			2.67			
	4t	5.79	top half (box 1)					
	4b	1.60		**3.9**	3.69			
	5t	3.10	bottom half					
	5b	1.08		**2.0**	2.09	**2.9**		
1M	tuber 1				2.14			
	2				3.65			
	3				5.00			
	4				5.26			
	5				6.01	**4.4**		
1B	tuber 1				0.84			
	2				3.92			
	3				3.61			
	4				4.27			
	5				5.25	**3.6**	**5.1**	**4.0**

Table 8.3: Deposits of CIPC(mg/kg) in samples from 'full' ventilation treatment in Store 34 for ventilation Expt 98/3

store/trmt/	sample point	half tuber	half tuber mean	tuber	position mean	box mean	treatment mean
4T	tuber 1t	11.11					
	1b	1.03		6.07			
	2t	14.59					
	2b	1.59		8.09			
	3t	11.13					
	3b	3.11		7.12			
	4t	7.79	top half (box 1)				
	4b	1.32	**10.4**	4.56			
	5t	7.58	bottom half				
	5b	4.53	**2.3**	6.06	**6.4**		
4M	tuber 1			1.17			
	2			0.62			
	3			0.81			
	4			0.86			
	5			0.81	**0.9**		
4B	tuber 1			0.84			
	2			0.58			
	3			0.48			
	4			0.63			
	5			0.40	**0.6**	**2.6**	
3T	tuber 1t	0.82					
	1b	0.34		0.58			
	2t	0.77					
	2b	0.50		0.64			
	3t	1.14					
	3b	0.75		0.95			
	4t	0.72	top half (box 3)				
	4b	0.73	**0.8**	0.73			
	5t	0.41	bottom half				
	5b	0.50	**0.6**	0.46	**0.7**		
3M	tuber 1			0.45			
	2			0.34			
	3			0.40			
	4			0.23			
	5			0.19	**0.3**		
3B	tuber 1			0.30			
	2			0.59			
	3			0.03			
	4			0.59			
	5			0.28	**0.4**	**0.5**	
1T	tuber 1t	1.57					
	1b	0.77		1.17			
	2t	2.83					
	2b	0.73		1.78			
	3t	1.82					
	3b	1.30		1.56			
	4t	2.14	top half (box 4)				
	4b	1.01	**2.2**	1.58			
	5t	2.50	bottom half				
	5b	1.08	**1.0**	1.59	**1.5**		
1M	tuber 1			1.23			
	2			0.88			
	3			1.19			
	4			1.59			
	5			1.09	**1.2**		
1B	tuber 1			0.79			
	2			0.58			
	3			1.24			
	4			0.81			
	5			2.99	**1.3**	**1.3**	**1.5**

Table 8.4: Deposits of CIPC(mg/kg) in samples from intermittent ventilation treatment in Store 36 for ventilation Expt 98/3

store/trmt/	sample point	half tuber	half tuber	mean	tuber	position mean	box mean	treatment mean
4T	tuber 1t	5.39						
	1b	1.46			3.43			
	2t	2.06						
	2b	1.37			1.72			
	3t	1.41						
	3b	1.30			1.36			
	4t	3.51	top half (box 1)					
	4b	1.76		**2.9**	2.64			
	5t	2.32	bottom half					
	5b	1.95		**1.6**	2.14	**2.3**		
4M	tuber 1				2.77			
	2				3.13			
	3				2.44			
	4				2.53			
	5				2.44	**2.7**		
4B	tuber 1				1.40			
	2				2.37			
	3				0.83			
	4				1.50			
	5				1.56	**1.5**	**2.2**	
3T	tuber 1t	5.85						
	1b	1.30			3.58			
	2t	3.87						
	2b	1.09			2.48			
	3t	1.33						
	3b	1.46			1.40			
	4t	3.91	top half (box 3)					
	4b	1.59		**3.8**	2.75			
	5t	4.06	bottom half					
	5b	0.96		**1.3**	2.51	**2.5**		
3M	tuber 1				1.30			
	2				2.49			
	3				5.03			
	4				1.32			
	5				1.20	**2.3**		
3B	tuber 1				4.00			
	2				0.85			
	3				1.21			
	4				3.07			
	5				1.77	**2.2**	**2.3**	
1T	tuber 1t	3.23						
	1b	2.10			2.67			
	2t	2.79						
	2b	1.04			1.92			
	3t	1.26						
	3b	1.75			1.51			
	4t	3.79	top half (box 4)					
	4b	2.02		**3.1**	2.91			
	5t	4.56	bottom half					
	5b	1.98		**1.8**	3.27	**2.5**		
1M	tuber 1				1.82			
	2				1.98			
	3				3.00			
	4				2.74			
	5				0.84	**2.1**		
1B	tuber 1				1.46			
	2				0.95			
	3				3.00			
	4				2.61			
	5				2.26	**2.1**	**2.2**	**2.2**

Table 8.5: Expt 99/3: Data for store 33-Control (no recirculation)
Application 4/8/99 Sampling 5/8/99

Sample Number	Store	Box Position	Tuber	Sample Point	Half/Whole	CIPC deposit mg / kg	Mean		SD
1	33	1	1	Top	Top	7.62	7.64		1.75
2	33	1	1	Top	Bottom	1.48	1.04		1.58
3	33	1	2	Top	Top	9.91		4.34	
4	33	1	2	Top	Bottom	1.83			
5	33	1	3	Top	Top	7.35			
6	33	1	3	Top	Bottom	1.65			
7	33	1	4	Top	Top	5.06			
8	33	1	4	Top	Bottom	2.18			
9	33	1	5	Top	Top	8.28			
10	33	1	5	Top	Bottom	5.27			
11	33	1	1	Middle	Whole	5.8	4.82		1.64
12	33	1	2	Middle	Whole	4.62			
13	33	1	3	Middle	Whole	6.74			
14	33	1	4	Middle	Whole	4.55			
15	33	1	5	Middle	Whole	2.38			
16	33	1	1	Bottom	Whole	4.1	4.01		0.70
17	33	1	2	Bottom	Whole	4.1			
18	33	1	3	Bottom	Whole	4			
19	33	1	4	Bottom	Whole	2.94			
20	33	1	5	Bottom	Whole	4.9			
21	33	2	1	Top	Top	8.01	9.63		4.79
22	33	2	1	Top	Bottom	1.85	2.67		1.15
23	33	2	2	Top	Top	10.6		6.15	
24	33	2	2	Top	Bottom	2.19			
25	33	2	3	Top	Top	17.2			
26	33	2	3	Top	Bottom	4.63			
27	33	2	4	Top	Top	4.31			
28	33	2	4	Top	Bottom	2.71			
29	33	2	5	Top	Top	8.03			
30	33	2	5	Top	Bottom	1.96			
31	33	2	1	Middle	Whole	7.88	5.82		1.33
32	33	2	2	Middle	Whole	4.58			
33	33	2	3	Middle	Whole	5.48			
34	33	2	4	Middle	Whole	6.31			
35	33	2	5	Middle	Whole	4.86			
36	33	2	1	Bottom	Whole	3.64	3.95		0.49
37	33	2	2	Bottom	Whole	4.75			
38	33	2	3	Bottom	Whole	4.08			
39	33	2	4	Bottom	Whole	3.53			
40	33	2	5	Bottom	Whole	3.77			
41	33	3	1	Top	Top	9.28	11.02		1.49
42	33	3	1	Top	Bottom	1.98	2.35		0.45
43	33	3	2	Top	Top	9.62		6.68	
44	33	3	2	Top	Bottom	2.14			
45	33	3	3	Top	Top	12.52			
46	33	3	3	Top	Bottom	3.01			
47	33	3	4	Top	Top	11.48			
48	33	3	4	Top	Bottom	2.6			
49	33	3	5	Top	Top	12.2			
50	33	3	5	Top	Bottom	2			
51	33	3	1	Middle	Whole	5.7	4.87		1.38
52	33	3	2	Middle	Whole	4.1			
53	33	3	3	Middle	Whole	6.9			
54	33	3	4	Middle	Whole	3.94			
55	33	3	5	Middle	Whole	3.7			
56	33	3	1	Bottom	Whole	6.6	5.91		0.67
57	33	3	2	Bottom	Whole	5.7			
58	33	3	3	Bottom	Whole	6.41			
59	33	3	4	Bottom	Whole	4.9			
60	33	3	5	Bottom	Whole	5.93			

Table 8.6: Expt 99/3: Data for store 34 – Intermittent recirculation with integral fan (5mins/hr.for 4hrs.)

Application 4/8/99 Sampling 5/8/99

Sample Number	Store	Box Position	Tuber	Sample Point	Half/Whole	CIPC Deposits mg / kg	Mean		SD
61	34	1	1	Top	Top	2.44	3.13		1.16
62	34	1	1	Top	Bottom	1.11	1.54		0.34
63	34	1	2	Top	Top	3.9		2.34	
64	34	1	2	Top	Bottom	1.67			
65	34	1	3	Top	Top	2.31			
66	34	1	3	Top	Bottom	1.58			
67	34	1	4	Top	Top	4.81			
68	34	1	4	Top	Bottom	2			
69	34	1	5	Top	Top	2.2			
70	34	1	5	Top	Bottom	1.35			
71	34	1	1	Middle	Whole	2.4	2.29		0.28
72	34	1	2	Middle	Whole	2.1			
73	34	1	3	Middle	Whole	2			
74	34	1	4	Middle	Whole	2.24			
75	34	1	5	Middle	Whole	2.71			
76	34	1	1	Bottom	Whole	1.47	1.83		0.24
77	34	1	2	Bottom	Whole	1.7			
78	34	1	3	Bottom	Whole	2			
79	34	1	4	Bottom	Whole	2			
80	34	1	5	Bottom	Whole	1.96			
81	34	2	1	Top	Top	3.82	3.49		0.81
82	34	2	1	Top	Bottom	1.23	1.94		0.63
83	34	2	2	Top	Top	3.85		2.71	
84	*34*	2	2	Top	Bottom	2.83			
85	34	2	3	Top	Top	4.22			
86	34	2	3	Top	Bottom	1.73			
87	34	2	4	Top	Top	3.41			
88	34	2	4	Top	Bottom	2.3			
89	34	2	5	Top	Top	2.14			
90	34	2	5	Top	Bottom	1.59			
91	34	2	1	Middle	Whole	3.82	2.57		0.89
92	34	2	2	Middle	Whole	2.64			
93	34	2	3	Middle	Whole	2.93			
94	34	2	4	Middle	Whole	1.74			
95	34	2	5	Middle	Whole	1.7			
96	34	2	1	Bottom	Whole	4.45	2.80		1.05
97	34	2	2	Bottom	Whole	2.41			
98	34	2	3	Bottom	Whole	2.82			
99	34	2	4	Bottom	Whole	1.57			
100	34	2	5	Bottom	Whole	2.73			
101	34	3	1	Top	Top	6.51	6.25		1.56
102	34	3	1	Top	Bottom	3.3	2.70		0.92
103	34	3	2	Top	Top	8.36		4.48	
104	34	3	2	Top	Bottom	2			
105	34	3	3	Top	Top	4.42			
106	34	3	3	Top	Bottom	1.51			
107	34	3	4	Top	Top	6.92			
108	34	3	4	Top	Bottom	3			
109	34	3	5	Top	Top	5.06			
110	34	3	5	Top	Bottom	3.7			
111	34	3	1	Middle	Whole	4.82	3.99		0.72
112	4	3	2	Middle	Whole	3.8			
113	34	3	3	Middle	Whole	3.9			
114	34	3	4	Middle	Whole	2.95			
115	34	3	5	Middle	Whole	4.5			
116	34	3	1	Bottom	Whole	3.94	4.87		5.36
117	34	3	2	Bottom	Whole	2.56			
118	34	3	3	Bottom	Whole	14.32			
119	34	3	4	Bottom	Whole	1.87			
120	34	3	5	Bottom	Whole	1.67			

Table 8.7: Expt 99/3: Data for store 35 – Intermittent recirculation with auxiliary fan (5mins/hr. for 4hrs.)
Application 4/8/99 Sampling 5/8/99

Sample	Box	Sample	CIPC Deposits	Mean	SD

Number	Store	Position	Tuber	Point	Half/Whole	mg / kg			
121	35	1	1	Top	Top	4.3	5.03		1.11
122	35	1	1	Top	Bottom	1.24	1.51		0.80
123	35	1	2	Top	Top	5.03		3.27	
124	35	1	2	Top	Bottom	1.4			
125	35	1	3	Top	Top	6.85			
126	35	1	3	Top	Bottom	0.76			
127	35	1	4	Top	Top	4.01			
128	35	1	4	Top	Bottom	1.28			
129	35	1	5	Top	Top	4.97			
130	35	1	5	Top	Bottom	2.87			
131	35	1	1	Middle	Whole	5.7	4.16		1.38
132	35	1	2	Middle	Whole	3.06			
133	35	1	3	Middle	Whole	4.6			
134	35	1	4	Middle	Whole	5.04			
135	35	1	5	Middle	Whole	2.4			
136	35	1	1	Bottom	Whole	3.01	3.72		0.50
137	35	1	2	Bottom	Whole	4			
138	35	1	3	Bottom	Whole	3.5			
139	35	1	4	Bottom	Whole	3.91			
140	35	1	5	Bottom	Whole	4.2			
141	35	2	1	Top	Top	7.32	7.51		1.15
142	35	2	1	Top	Bottom	1.1	1.45		0.58
143	35	2	2	Top	Top	8.8		4.48	
144	35	2	2	Top	Bottom	2.21			
145	35	2	3	Top	Top	8			
146	35	2	3	Top	Bottom	1.7			
147	35	2	4	Top	Top	7.72			
148	35	2	4	Top	Bottom	1.54			
149	35	2	5	Top	Top	5.7			
150	35	2	5	Top	Bottom	0.7			
151	35	2	1	Middle	Whole	1.76	3.18		0.89
152	35	2	2	Middle	Whole	3.3			
153	35	2	3	Middle	Whole	3.36			
154	35	2	4	Middle	Whole	3.28			
155	35	2	5	Middle	Whole	4.21			
156	35	2	1	Bottom	Whole	3.24	3.3		0.27
157	35	2	2	Bottom	Whole	3.25			
158	35	2	3	Bottom	Whole	3.04			
159	35	2	4	Bottom	Whole	3.75			
160	35	2	5	Bottom	Whole	3.22			
161	35	3	1	Top	Top	5.33	5.13		1.76
162	35	3	1	Top	Bottom	1.05	1.27		0.30
163	35	3	2	Top	Top	6.92		3.20	
164	35	3	2	Top	Bottom	1.44			
165	35	3	3	Top	Top	6.04			
166	35	3	3	Top	Bottom	1.72			
167	35	3	4	Top	Top	5.1			
168	35	3	4	Top	Bottom	1			
169	35	3	5	Top	Top	2.24			
170	35	3	5	Top	Bottom	1.16			
171	35	3	1	Middle	Whole	0.49	3.06		1.78
172	35	3	2	Middle	Whole	3.48			
173	35	3	3	Middle	Whole	3.16			
174	35	3	4	Middle	Whole	2.72			
175	35	3	5	Middle	Whole	5.45			
176	35	3	1	Bottom	Whole	2.62	2.99		1.04
177	35	3	2	Bottom	Whole	4.38			
178	35	3	3	Bottom	Whole	1.75			
179	35	3	4	Bottom	Whole	2.5			
180	35	3	5	Bottom	Whole	3.7			

Table 8.8: Expt 99/3: Data for store 36 - recirculation for 20mins. with auxiliary fan
Application 4/8/99 Sampling 5/8/99

Sample Number	Store	Box Position	Tuber	Sample Point	Half/Whole	CIPC Deposits mg / kg	Mean		SD
181	36	1	1	Top	Top	5.3	5.10		1.35
182	36	1	1	Top	Bottom	1.5	1.69		0.62
183	36	1	2	Top	Top	5.03		3.40	
184	36	1	2	Top	Bottom	1.7			
185	36	1	3	Top	Top	6.51			
186	36	1	3	Top	Bottom	1.3			
187	36	1	4	Top	Top	5.75			
188	36	1	4	Top	Bottom	2.75			
189	36	1	5	Top	Top	2.91			
190	36	1	5	Top	Bottom	1.2			
191	36	1	1	Middle	Whole	3.16	2.88		1.01
192	36	1	2	Middle	Whole	2.71			
193	36	1	3	Middle	Whole	1.83			
194	36	1	4	Middle	Whole	4.45			
195	36	1	5	Middle	Whole	2.26			
196	36	1	1	Bottom	Whole	5.12	3.54		1.22
197	36	1	2	Bottom	Whole	3.1			
198	36	1	3	Bottom	Whole	2.61			
199	36	1	4	Bottom	Whole	2.35			
200	36	1	5	Bottom	Whole	4.54			
201	36	2	1	Top	Top	6.34	6.45		1.75
202	36	2	1	Top	Bottom	3.32	2.63		0.92
203	36	2	2	Top	Top	8.7		4.54	
204	36	2	2	Top	Bottom	1.6			
205	36	2	3	Top	Top	5.4			
206	36	2	3	Top	Bottom	2.4			
207	36	2	4	Top	Top	4.26			
208	36	2	4	Top	Bottom	2			
209	36	2	5	Top	Top	7.56			
210	36	2	5	Top	Bottom	3.82			
211	36	2	1	Middle	Whole	3.3	4.00		0.99
212	36	2	2	Middle	Whole	4.33			
213	36	2	3	Middle	Whole	5.6			
214	36	2	4	Middle	Whole	3.5			
215	36	2	5	Middle	Whole	3.28			
216	36	2	1	Bottom	Whole	2.62	3.01		1.27
217	36	2	2	Bottom	Whole	4.8			
218	36	2	3	Bottom	Whole	1.8			
219	36	2	4	Bottom	Whole	2			
220	36	2	5	Bottom	Whole	3.82			
221	36	3	1	Top	Top	8.08	9.12		2.21
222	36	3	1	Top	Bottom	1.4	2.72		1.24
223	36	3	2	Top	Top	12.44		5.92	
224	36	3	2	Top	Bottom	3.6			
225	36	3	3	Top	Top	10.26			
226	36	3	3	Top	Bottom	2.13			
227	36	3	4	Top	Top	7.81			
228	36	3	4	Top	Bottom	2.05			
229	36	3	5	Top	Top	7			
230	36	3	5	Top	Bottom	4.4			
231	36	3	1	Middle	Whole	7.15	4.53		1.84
232	36	3	2	Middle	Whole	5.61			
233	36	3	3	Middle	Whole	3.1			
234	36	3	4	Middle	Whole	4.1			
235	36	3	5	Middle	Whole	2.7			
236	36	3	1	Bottom	Whole	4.12	4.78		0.80
237	36	3	2	Bottom	Whole	4.43			
238	36	3	3	Bottom	Whole	5.93			
239	36	3	4	Bottom	Whole	5.3			
240	36	3	5	Bottom	Whole	4.14			

