Final Report

Evaluation of CIPC application and behaviour and their influence on the variability of CIPC residues in box stores: commercial stores

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1 Summary

Around 50% of potato stores in GB are box stores with the majority using the 'overhead throw' type of ventilation. CIPC applications in this type of store tend to result in variable residue distributions and relatively poor efficacy because air (and CIPC fog) are supplied to the general store void and not forced 'positively' through the crop. Store fans are currently not typically used for applications in such stores.

CIPC applications were made to a range of modified commercial 'overhead throw' stores and results compared with unmodified (control) stores. In addition, a positively ventilated ('suction wall') box store was assessed.

Control stores (c.1,700 tonnes), without modification and where CIPC fog was allowed to rise directly into the store headspace resulted in variable CIPC residue levels (Store A, CV% 122 and 158). Application of fog via a simple plenum (a covered walkway through the main block of boxes) improved residue distribution considerably in some stores (Store B, CV% 94 and 96), but not consistently (Store F, CV% 137) and sometimes there was little difference (stores E and F, CV% 110 and 115).

The use of fans, to create a positive pressure or negative pressure plenums, to increase recirculation of fog, also did not lead to consistent improvements in CIPC residue distribution or sprout control efficacy.

In two low-temperature stores, modifications to create positive and negative pressure plenums resulted in even but very high residue levels (Stores C and D). Further work here was discontinued and transferred to smaller scale experiments.

In contrast to the standard 'overhead throw' and modified 'overhead throw' stores, the positively ventilated 'suction wall' store resulted in the most even CIPC residue distributions (Store H, CV% 90 and 56) and good sprout control efficacy. Results comparable with those in bulk stores, using inverter controlled fans, were obtained. The 'suction wall' store type is dependent on the correct box type being used though, and when this was not the case store performance deteriorated (Store G, CV% 119).

In addressing CIPC efficacy in box stores, it is considered doubtful that simple modifications to ‘overhead throw’ stores can be totally effective, although some are certainly likely to enhance their performance significantly. Their prevalence in the GB industry will make this imperative. However, for full, effective and uniform distribution of CIPC and minimisation of residues, on the basis of these trials, positive ventilation is required.

The use of CIPC in ‘overhead throw’ stores results in residue distributions with an increased risk of exceeding the maximum residue level. Other approaches may prove effective, however, until these have been demonstrated, additional controls should be put in place to ensure the MRL is not exceeded and the future of CIPC is safeguarded.

2 Introduction

After a period of dormancy, sprout growth is initiated in stored potatoes. Unchecked, sprout growth gives rise to changes in stored potatoes that ultimately render the crop unacceptable. Such changes include increased weight loss, shrinkage, unacceptable appearance and deterioration in processing quality.

Suppression of potato sprout development during storage, especially at the warmer temperatures used for processing, is therefore critical. CIPC is the main active substance for the control of sprout growth, and in 2008 was used on around 47% of stored potatoes in Great Britain (Garthwaite *et al*. 2009[1]) and made up 94% of post-harvest treatments to stored potatoes. Difficulties have been experienced in ensuring all stored crops are consistently within the maximum residue level (MRL), and the use of CIPC is now covered in the UK by the Potato Industry CIPC Stewardship Group.

In bulk stores, significant reductions in CIPC usage can be obtained by enhancing the evenness of residue distributions. This results in more general, improved sprout control which allows application intervals to be extended. In bulk stores this was achieved, using low speed recirculation of fog. This and approaches aimed at preventing fog entering the store headspace have been tested in a range of box stores to determine whether the same benefits can be achieved. The aim is to distribute the applied CIPC fog evenly in a reduced volume throughout the crop, with slow recirculation where possible. The range of store types described below indicates how this was attempted at each site.

Commercial stores were used to assess modifications to both box stacking regimes and CIPC application practices. Most of the stores were in use for storage of processing crops at moderate temperatures, but two were low-temperature stores used for the packing industry. The majority of the stores had non-positive, ‘overhead throw’ (OHT) type ventilation systems. These were used to establish the value of

[1] Garthwaite, D.G., I. Barker, G. Parrish and L. Smith, 2009. Pesticide usage survey report 227. Potato stores in Great Britain. Food & Environment Research Agency, York, UK. http://www.fera.defra.gov.uk

modified box stacking and application of CIPC into a plenum chamber, assisted by various configurations of covers and/or low speed fan recirculation of CIPC fog. OHT stores are recognised as being problematic in terms of CIPC usage but they are the most common type of box store in Great Britain. In OHT stores, air displaced by the fan is ducted away from the air-handling unit and returns (to the low pressure area created by the displacement) around and between pallet boxes stacked in the store. In such stores air velocity within boxes is minimal. Distribution of CIPC in this store type is ‘driven’ by convection currents. Potatoes warm the air surrounding them increasing its buoyancy, and cause convection currents to rise up through the box. This air is replaced with cooler air (laden with CIPC fog at the time of its application) which enters blocks of boxes along the pallet apertures (Burfoot *et al* [2]). Sprout control in such stores is typically poorest in the middle of blocks (i.e at points furthest from the source of fog).

In addition, in this type of store, CIPC fog is typically introduced into an inspection corridor or a gap around the perimeter of the store. As it is introduced as a hot fog, it rises into the roof space and effectively fills the store from the top down and results in sedimentation of fog on to top boxes.

A box store with a ‘suction wall’ ventilation pattern was included in each year of the study. In this store type, boxes are stacked to create a plenum and displaced air returns to the fan sideways through boxes with slatted sides. This system was anticipated to result in relatively even residue distributions and scope for input reduction by virtue of its positive ventilation characteristic (i.e. it would behave as a bulk store).

Solid formulations of solvent-free CIPC (*MSS SproutNip* or *GroStop Solid*) were used in all of the modified stores, applied by a close-coupled fogger, to limit leakage by reducing input volume (McGowan *et al,* Potato Council project R265). With the exception of one store (store H), all applications were made using a close-coupled

[2] D. Burfoot, D. L. O. Smith, M. C. Butlerellis and W. Day. 1996. Modelling the distribution of isopropyl N-(3-chlorophenyl) carbamate [CIPC] in box potato stores. Potato Research Volume 39, Number 2, 241-251.

Unifog machine operated by Stored Crop Conservation Ltd. (SCC). Store H was treated using an innovative applicator based on a heat-exchange principle and operated by Potato Storage Treatments Ltd. (PST).

In terms of residue variability and sprout control efficacy, the ‘suction wall’ store used in years 2 and 3 was most effective resulting in a low level of residue variability and good sprout control efficacy. This store design employs positive ventilation and, therefore, it is unsurprising that results were most similar to those from bulk stores (McGowan *et al,* Potato Council project R265) where CIPC fog was recirculated through the bulk pile.

In ‘overhead throw’ box stores, commercial trials indicate that residue distribution may be improved (reduced variability) by carrying out applications of CIPC using a simple plenum. Although recommended to improve efficacy, the adoption of such systems is not thought likely to result in any major reductions in CIPC inputs. In order to reduce chemical inputs, it is likely that positive ventilation (bulk stores or ‘suction wall’ stores) are required. New box store installations should look to provide this, especially for storage for processing and should therefore be of a type that uses positive ventilation for optimal results.

3 Materials and methods

The aim of this work was to improve distribution of CIPC in box stores, especially ‘overhead throw’ type box stores which are popular within the GB potato industry but in which ventilation is non-positive. Over the four year period of this study, various methods were evaluated and compared with the industry standard practice of applying via a fogging port at ground level (or even under a partially open door), and allowing fog to enter the store head-space.

Modified treatments had a common approach, which involved leaving an access corridor (c. 600 mm wide) through the main block of boxes, perpendicular to the direction of airflow. This access corridor was covered, creating a plenum chamber, into which CIPC fog was then delivered.

3.1 Control Stores

(code: Cont)

In year 1 the control store was stacked and treated as per the grower's standard practice. Two solid blocks of boxes, stacked at 90 degrees to the fan discharge unit, either side of a central door to leave a central corridor which in turn was back-filled with 2 columns of boxes up to the door. CIPC was applied under the partially open roller door aiming the fog along the gap to the side of the back-fill boxes.

In year 2, the control store was modified. Box stacking was revised and incorporated a transverse alleyway, perpendicular to the direction of airflow, approximately half way along the store. To achieve this, boxes were orientated at 90 degrees to the original stacking pattern, such that all boxes now 'faced' the fan unit. Fog was applied directly into the alleyway, closer to the centre of the store.

Prior to the third year of the experiment the host grower completed a building project adjacent to the control store. This resulted in access to the new application port, in the side of the building, being lost. It was decided therefore not to assess a control store in the final season.

3.2 Modified treatments

Passive Plenum Stores (code: PaP)

In each season one commercial store was set up with a "passive plenum" arrangement. Box stacking in these stores was modified to incorporate a 600mm – 800mm transverse gap mid-way along the stack, thus splitting the store into 2 blocks. This gap was covered by means of a PVC tarpaulin sheet to form a plenum chamber into which the CIPC was applied. From the plenum, fog was free to percolate along the box pallet apertures and ultimately to the roof space.

Fan Assist (code: Fa)

A development of the passive plenum was to include a low speed fan at the point of CIPC application. The application was made into a mixing box and fed a PVC, perforated tube. This was designed to distribute the air/fog mix evenly along the plenum. The tube was lightweight and collapsible to aid store access. Air flow from the fan was sufficient to inflate the tube over the length of the plenum.

Positive Plenum Stores (code: PoP)

This arrangement was similar to the Passive Plenum but incorporating low speed fans positioned to draw fog from the store head-space and re-introduce this back into the plenum. Fans were run during application with this pattern of recirculation.

Figure 1. Recirculation fans mounted on a plenum drawing air from the store headspace into the plenum in *positive pressure plenum* treatment.

Negative Plenum Stores (code: NP)

In Negative Plenum treatments, low-speed fans were used to draw fog out of the plenum and deliver it to pallet apertures of boxes at the extreme ends of the store, via PVC ducts, where it could be drawn back to the plenum. Using this pattern, recirculation was only enabled after the CIPC application had been completed.

Figure 2. Fans being used to extract fog from a plenum in *negative pressure plenum* pattern of application.

Covers (code: Co)

As the study developed some set-ups were modified to include a PVC cover over top boxes. In the second year 2/3 of the crop either side of the central plenum were covered and in the final year the main blocks were entirely covered. Covers were put in place immediately before, and removed as soon as possible after application (typically 3-4 hours, once the fog had cleared).

Suction wall stores (code: SW)

Suction wall ventilation (originally marketed as the Pirie *Aspire* system) is an established technique for positively ventilating box potato stores. The boxes. are stacked in pairs of rows with a central passage way, which is covered by a tarpaulin. Air is extracted from under the tarpaulin and discharged into the headspace, drawing air sideways through slatted-ended boxes. Although recognised as an effective method of storage, the system has not been widely adopted because costs of storage are increased as, for a given 'footprint' fewer boxes can be stored due to the requirement for additional void areas for recirculating air. Both stores used were fitted with inverters (variable frequency drives). Fog was recirculated during and after application, until chemical had deposited. A summary of the treatments in each store is shown in Table 1.

Table 1. Treatments used in stores.

Store	Year	Tonnes	Set-up code	Treatments/applicator
A	1 & 2	1700	Cont	*ProLong* SCC.
B	1	1700	PaP.	*MSS Sprout Nip* SCC
B	2	1700	PaP. Fa. Co	*MSS Sprout Nip* SCC
B	3	1700	PoP. Fa. Co	*MSS Sprout Nip* SCC
C	1	450	PoP	*GroStop Solid* SCC
D	1	450	NP	*GroStop Solid* SCC
E	2	1260	NP	*MSS Sprout Nip* SCC
E	3	1260	PaP. Fa.	*MSS Sprout Nip* SCC
E	4	1145	PaP.[1]	*MSS Sprout Nip* SCC
F	2	1260	PoP. Fa $^{2}/_{3}$Co.	*MSS Sprout Nip* SCC
F	3	1260	PaP. Fa. Co	*MSS Sprout Nip* SCC
F	4	1145	PaP. Co[1]	*MSS Sprout Nip* SCC
G	1	1100	SW	*MSS Sprout Nip* SCC
H	2 & 3	1300	SW	*GroStop Solid* PST

SCC – Stored Crop Conservation, PST – Potato Storage Treatments
[1]Initial treatment in each store was made using fan assistance (FA) however due excessive heat build-up this was not used during subsequent applications.

3.3 Application equipment

Applications in the control store (A) were carried out by Stored Crop Conservation using their standard machine (*Unifog*) to apply *MSS ProLong* (UPL) at a rate of 28ml per tonne of potatoes. Applications to store H were completed by Potato Storage Treatments using a *PurO$_2$* machine to apply *GroStop Solid* (Certis) at a rate of 12g/t. Applications to stores C & D were made by Stored Crop Conservation using *Unifog* equipment, modified by addition of a melter stage to apply *GroStop Solid* at a rate of 12g/t. Application to stores B, E, F & G were undertaken by Stored Crop Conservation, again using a *Unifog* machine modified by addition of a melter stage, to apply *MSS Sprout Nip* at a rate of 14g/t.

Fans

With the exception of the negative plenum (NP) treatments, wherever fans were used these were of an axial type (*Multifan*, Vostermans Ventilation BV – model TB4E50, operated at 258 rpm and displacing air at 0.45m^3/s or 1611m^3/hr).

For 'fan assist' applications (Fa), just one fan was used; For positive plenum applications (PoP) in store C, three fans were used. For positive plenum applications in stores B & F, a total of six fans were used.

The fans used for the negative plenum (NP) work were supplied by Fläkt Woods (model JM71, fitted with speed controllers). Speed was adjusted to deliver approximately 1.32 m^3/s (4744 m^3/h) each.

3.4 Application dates and intervals

CIPC treatments over the four storage seasons are shown in Table 2.

Table 2. CIPC application dates and intervals

Store	Year	Full	Days	1st	Days	2nd	Days	3rd	Days	4th
A	08/09	18 Oct	10	28 Oct	45	12 Dec	66	16 Feb	-	-
A	09/10	1 Oct	6	7 Oct	41	17 Nov	57	13 Jan	63	17 Mar
B	08/09	28 Sep	19	17 Oct	56	12 Dec	66	16 Feb	-	-
B	09/10	20Oct	7	27 Oct	36	2 Dec	65	5 Feb	-	-
B	10/11	5 Oct	10	15 Oct	61	15 Dec	63	16 Feb	58	15 Apr
C	08/09	24 Sep	57	10 Dec	83	3 Mar	-	-	-	-
D	08/09	25 Sep	56	10 Dec	83	3 Mar	58	30 Apr	-	-
E	09/10	20 Oct	24	13 Nov	63	14 Jan	49	4 Mar	67	10 May
E	10/11	8 Nov	18	26 Nov	34	30 Dec	49	17 Feb	46	4 Apr
E	11/12	15 Oct	20	4 Nov	47	21 Dec	78	8 Mar	45	20 Apr
F	09/10	27 Oct	17	13 Nov	63	14 Jan	49	4 Mar	67	10 May
F	10/11	2 Nov	34	6 Dec	43	18 Jan	-	-	-	-
F	11/12	21 Oct	14	4 Nov	47	21 Dec	78	8 Mar	-	-
G	08/09	7 Nov	14	21 Nov	123	24 Mar	-	-	-	-
H	09/10	8 Nov	23	1 Dec	51	21 Jan	78	9 Apr	35	14 May
H	10/11	10 Nov	22	2 Dec	50	21 Jan	-	-	-	-

Stores A & B were used for crisping varieties, predominantly Saturna at *c.* 8.5 C.
Stores C & D were used to store pre-packing potatoes, M. Piper & Desiree at *c.* 3.0 C.
Stores E, F, & H were used for processing, predominantly Markies at *c.* 8.0 C.
Store G was used to store Russet Burbank for processing at *c.* 7.0 C.

4 Results

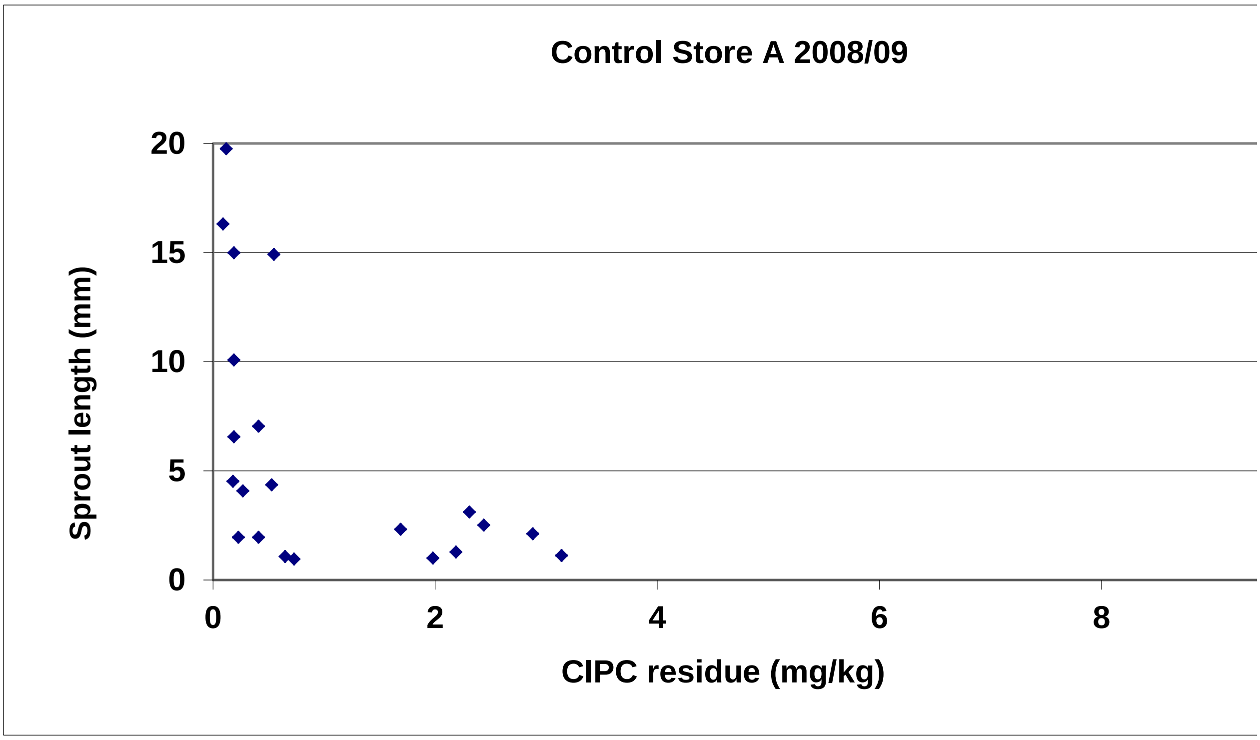
4.1 Control stores

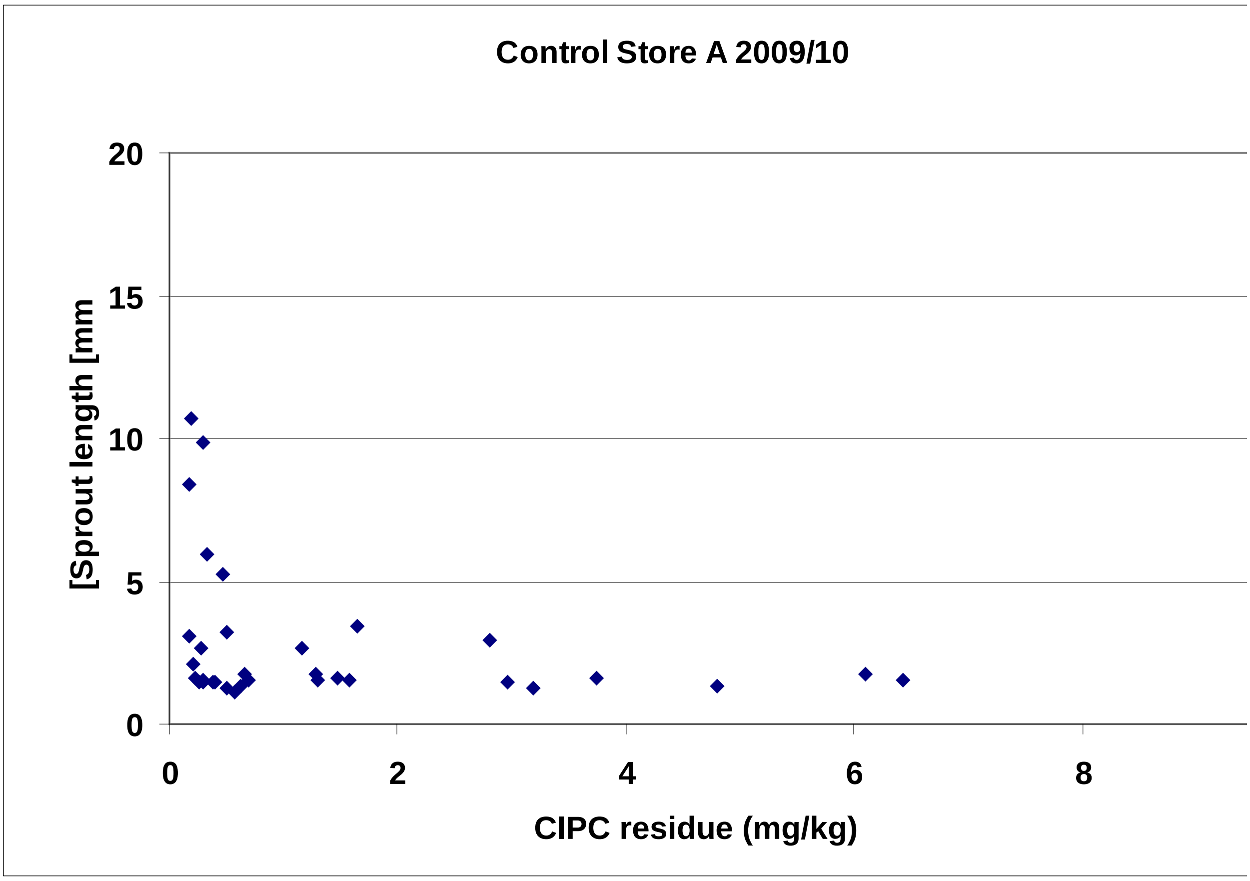
Results of the CIPC residue concentration measurements and maximum sprout length assessments for the control stores in each of two seasons are shown in Figure 3 (below).

In the 2008/09 season boxes were stacked in multiple blocks across the direction of airflow, a stacking pattern suited for ease of handling.

In 2009/10, boxes were stacked as two large blocks, with pallet apertures aligned with the direction of airflow. The latter stacking pattern maximises the volume of air passing through pallet apertures and is considered to be best practice.

Control stores





Store	Year	Mean sprouting (mm)	SD	Mean CIPC residue (mg/kg)	SD	CV%
A	2008/09	14..9	20.96	0.8	0.99	122
A	2009/10	4.3	9.77	2.0	3.16	158

Fig. 3 CIPC residue concentration and maximum sprout length for control stores

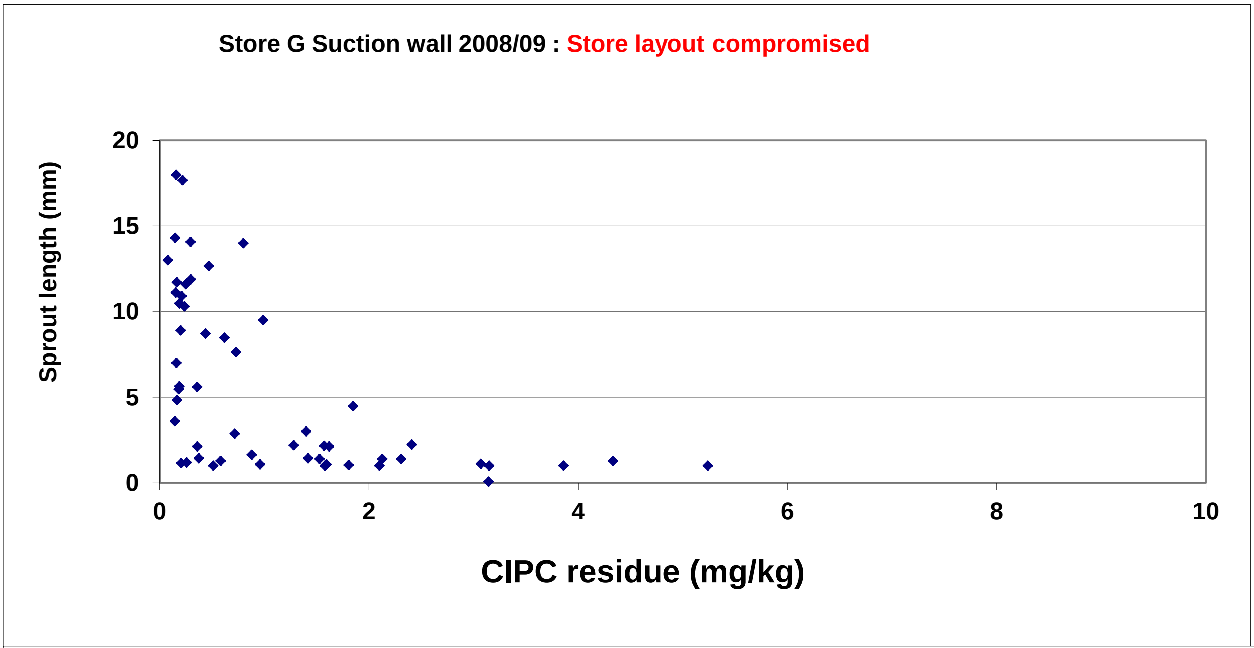
Sprout control efficacy was poor in 2008/09 (mean maximum sprout length 15.2mm) compared with that of 2009/10 (4.3mm). Although an additional application was carried out in 2009/10 (inputs increased 25%, 56g/tonne c.f. 42 g/tonne), the overall mean residue level was over 100% higher (1.72 mg/kg c.f. 0.81 mg/kg).

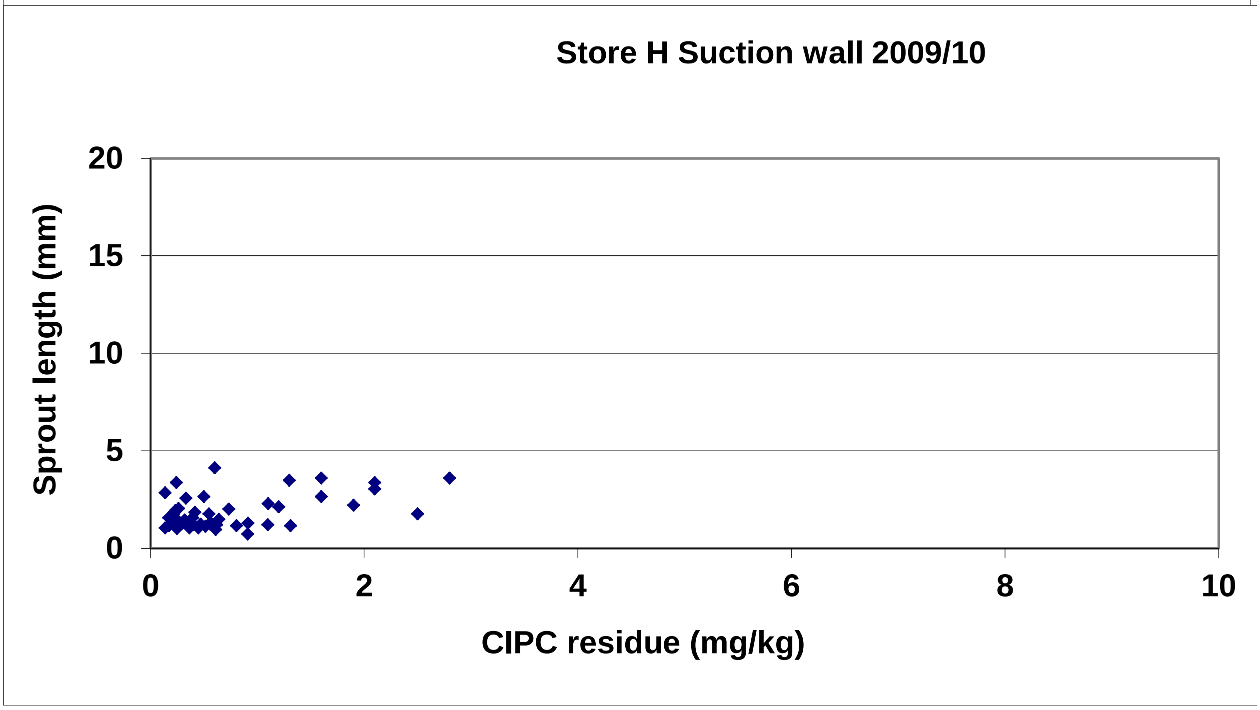
Both control treatments resulted in variable CIPC residue concentrations (mean residue (mg/kg) and relative standard deviation (CV) of 0.81 mg/kg, 122% and 1.72 mg/kg, 158% respectively for 2008/09 and 2009/10 seasons) and middle boxes very low residue values (0.2 mg/kg and 0.3mg/kg respectively for 2008/09 and 2009/1 seasons). In the 2009/10 season, tubers with residue values >10mg/kg were detected in top boxes at two sampling locations (see Annex 1 – raw data).

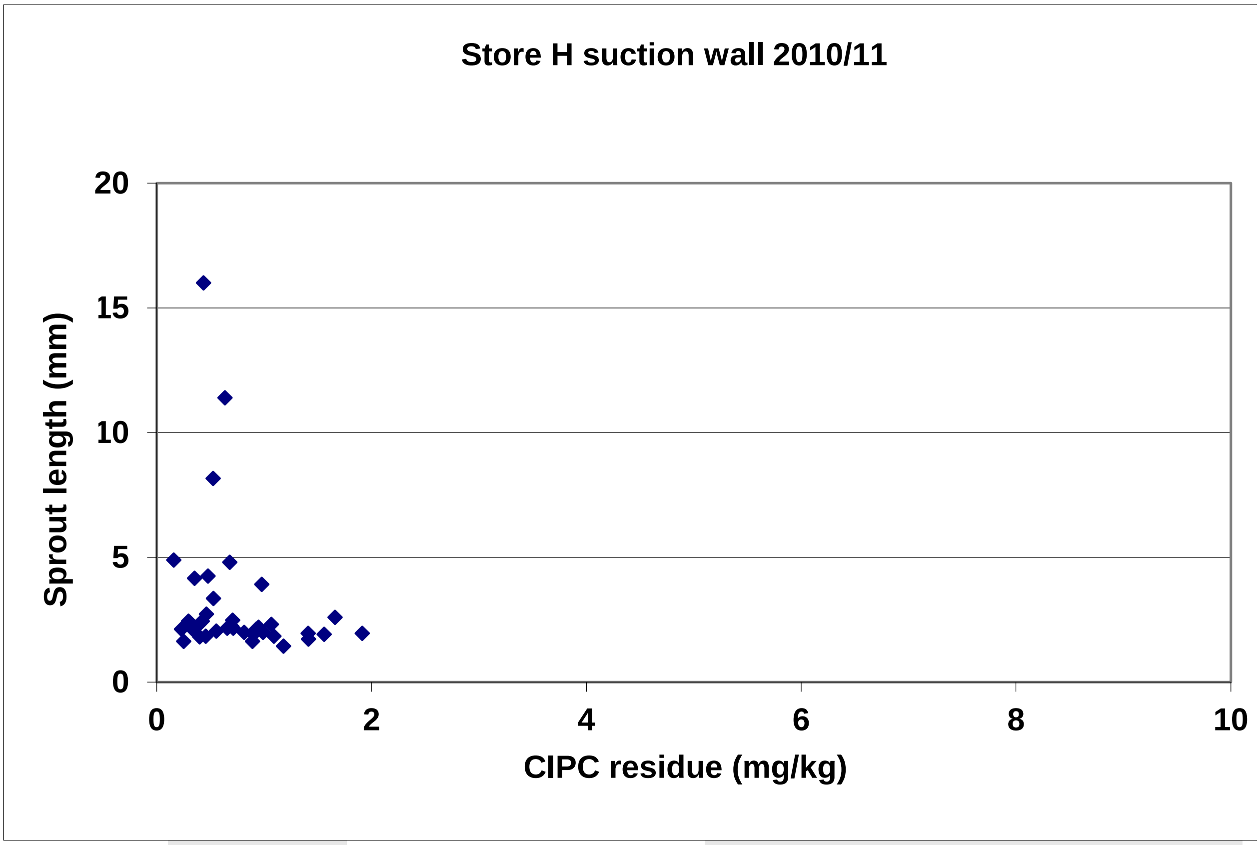
4.2 Suction wall stores

Initial results for a store employing the 'suction wall' principle in 2008/09 were not satisfactory with poor sprout control efficacy (mean 12.7mm) and variable CIPC residue concentrations (0.91mg/kg, CV% 119) similar to the control treatment. The poor result from the suction wall store in 2008/09 was traced to the grower's use of some boxes that were inappropriate (correct use of this system requires boxes to have slatted sides for unimpeded airflow). This result is presented for completeness but should be disregarded.

An alternative store was used in 2009/10 and 2010/11. Results are shown in Fig.4. In both seasons, when store set-up was correct, the CIPC distribution was much improved with low residue concentrations and little variability (0.74 mg/kg, CV% 90 and 0.76 mg/kg, CV% 56 for 2009/10 and 2010/11 respectively). Sprout control efficacy was also generally very effective with mean maximum sprout lengths of 1.9mm and 3.2mm in the two seasons. The store was unloaded relatively early in the 2010/11 season as a result of a high incidence of rotting –the likely cause of greater sprout growth in a small number of samples.


Store G Suction wall 2008/09 : Store layout compromised
Sprout length (mm)
20
15
10
5
0
0
2
4
6
8
10
CIPC residue (mg/kg)


Store H Suction wall 2009/10
Sprout length (mm)
20
15
10
5
0
0
2
4
6
8
10
CIPC residue (mg/kg)



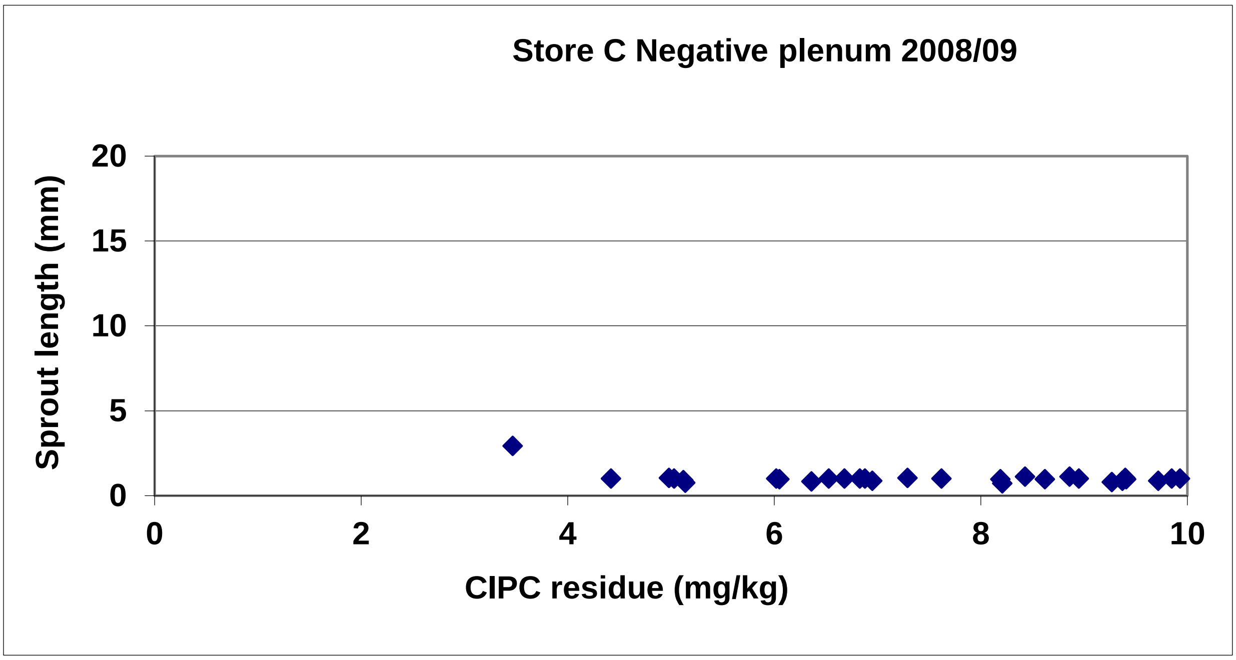
Store	Year	Mean sprouting (mm)	SD	Mean CIPC residue (mg/kg)	SD	CV%
G*	2008/9	12.7	14.13	0.9	1.09	119
H	2009/10	1.9	0.86	0.7	0.67	89
H	2010/11	3.2	2.83	0.8	0.43	56

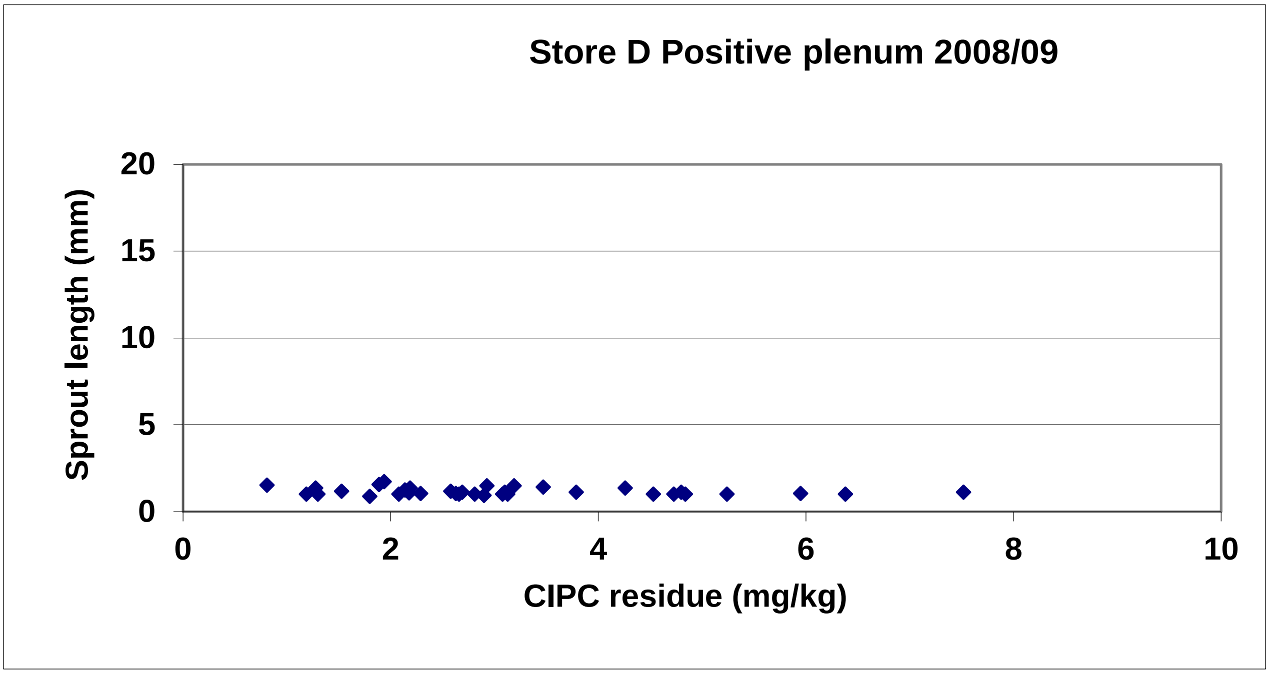
*Store layout compromised

Fig. 4. CIPC residue concentration and maximum sprout length for suction wall stores.

4.3 Low-temperature (pre-pack) stores

Results from low-temperature (pre-pack) stores used in year 1 for positive and negative pressure plenum applications are shown in Figure 5. Both stores show a distinctive pattern with very low levels of sprouting. Although residue variability was low, application efficiency was high and both stores were considered to be at risk of giving an MRL exceedance. Work in low-temperature commercial stores was discontinued and further work carried out at SBCSR. High residue values are considered to be as a result of limited losses of CIPC, through volatilisation, as a result of the low storage temperature (c 3^{o}C). CIPC residue values (from 2 applications at 12 g/tonne) from the negative plenum pressure treatment were especially high; this is thought to be as a result of recirculation fans only being started after application was completed and therefore sedimentation from the store headspace is likely to have been an important component in residue distribution. In both stores CIPC residue levels were greatest in sample boxes adjacent to the plenum.





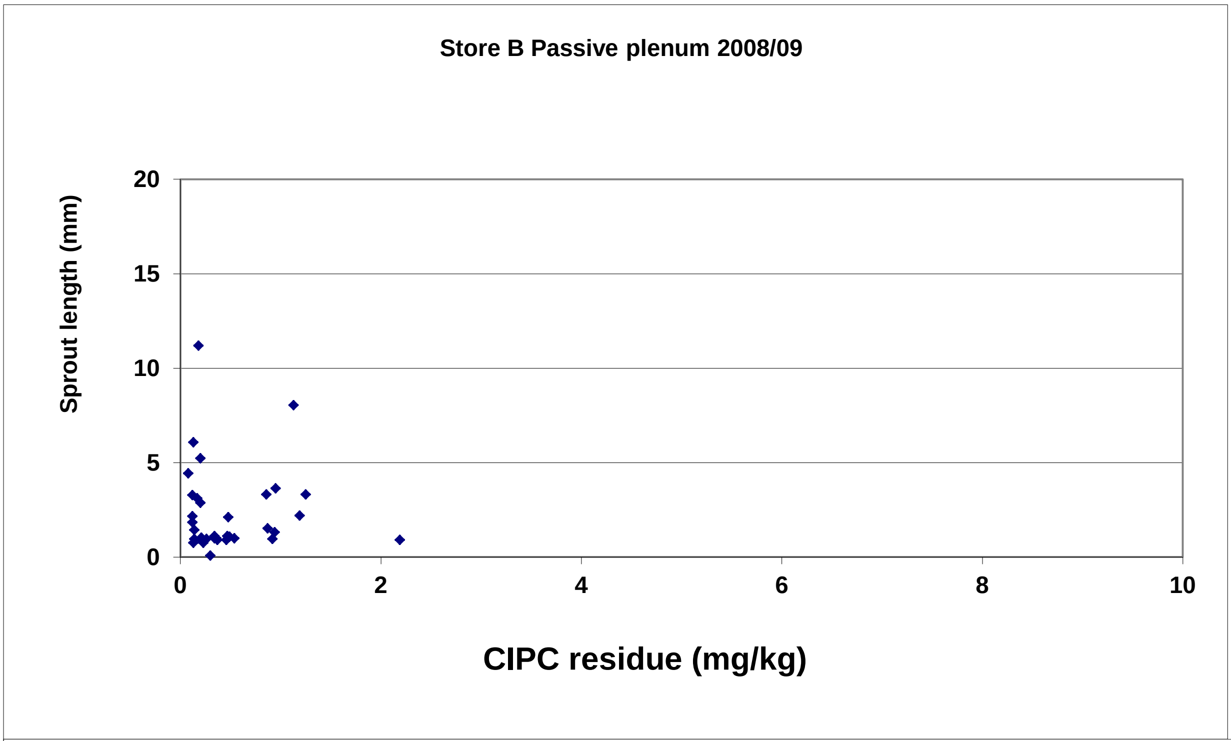
Store	Year	Mean sprouting (mm)	SD	Mean CIPC residue (mg/kg)	SD	CV%
C	2008/09	1.0	0.34	8.3	2.57	31
D	2008/09	1.2	0.21	3.1	1.55	50

Fig. 5. CIPC residue concentration and maximum sprout length for positive and negative pressure plenum treatments in low-temperature stores

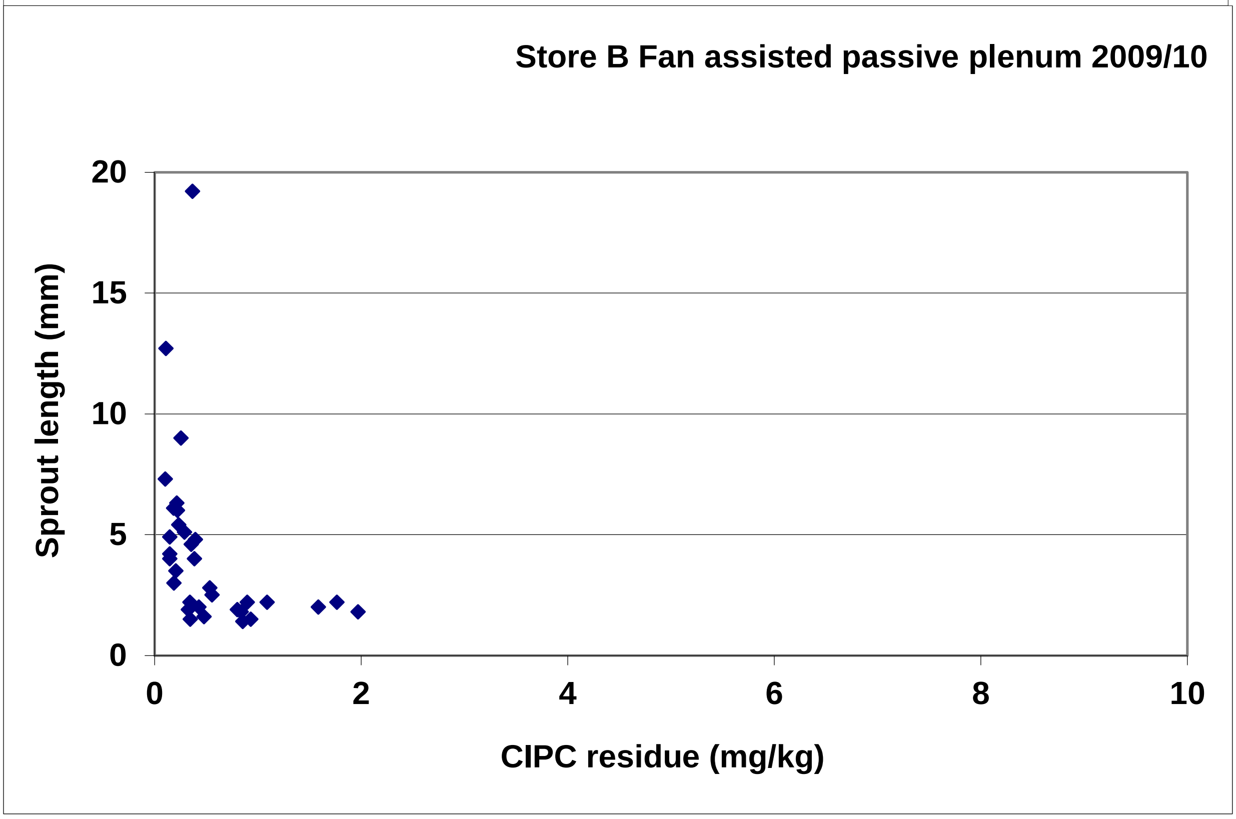
4.4 1,700 tonne box store

Applications of CIPC using a simple plenum system resulted in low (mean 0.5 mg kg^{-1}) and even (CV% 94) CIPC residues in a large, 1,700 tonne box store. Sprout control of cv Saturna was effective with a mean maximum sprout length of 2.3 mm. The addition of a cover and a fan assisted distribution tube within the plenum in 2009/10 (covering was continuous with the plenum cover and extended over 2/3 of each block) did not have an important effect on CIPC residue distribution with a mean residue concentration and residue variability similar to the simple plenum system used in 2008/09. Sprouting was not as effectively controlled in 2009/10, with a mean sprout length of 6.0 mm, however data was skewed by a small number of samples with long sprouts (SD 6.70). In 2008/09 and 2009/10 three applications of CIPC were carried out (total 42 g/tonne).

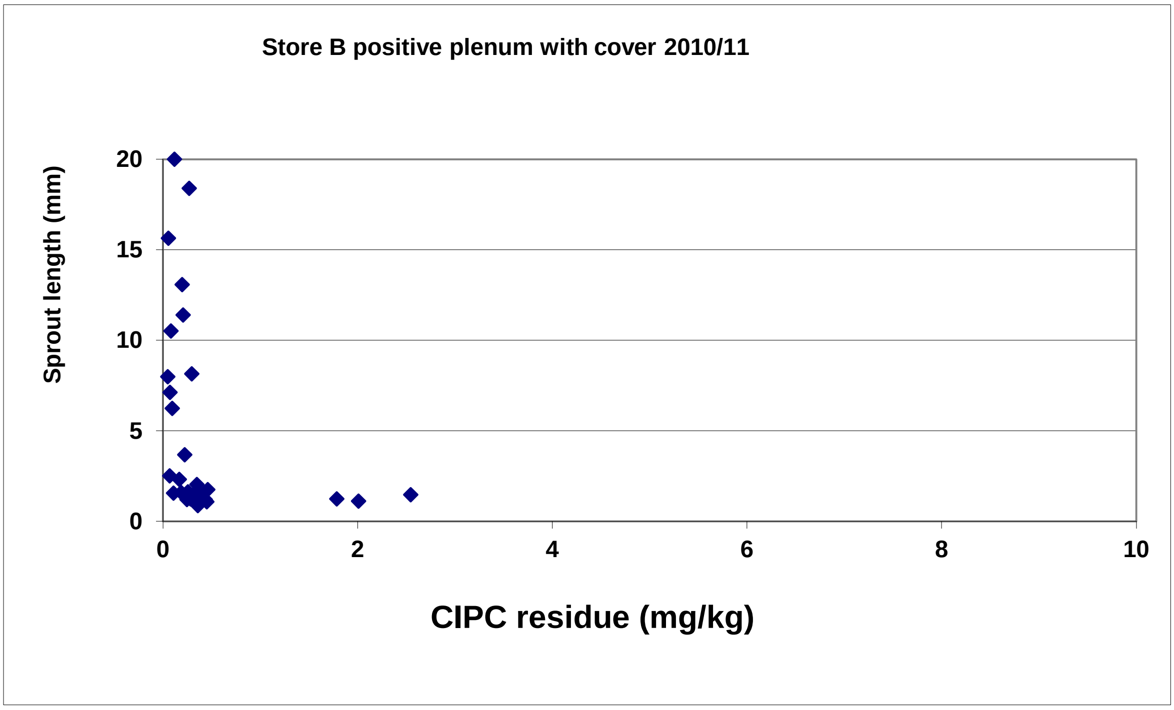
In 2010/11, 4 applications (total 56g/tonne) were carried out using a positive plenum with complete covers and recirculation of fog during and after application. This approach resulted in a lower overall CIPC residue concentration which was more variable (CV% 150). Residue variability was similar to control treatments. Sprout control efficacy was also poorer, with mean maximum sprout length of 7.7mm.



Store B Passive plenum 2008/09
Sprout length (mm)
20
15
10
5
0
0
2
4
6
8
10
CIPC residue (mg/kg)



Store B Fan assisted passive plenum 2009/10
Sprout length (mm)
20
15
10
5
0
0
2
4
6
8
10
CIPC residue (mg/kg)

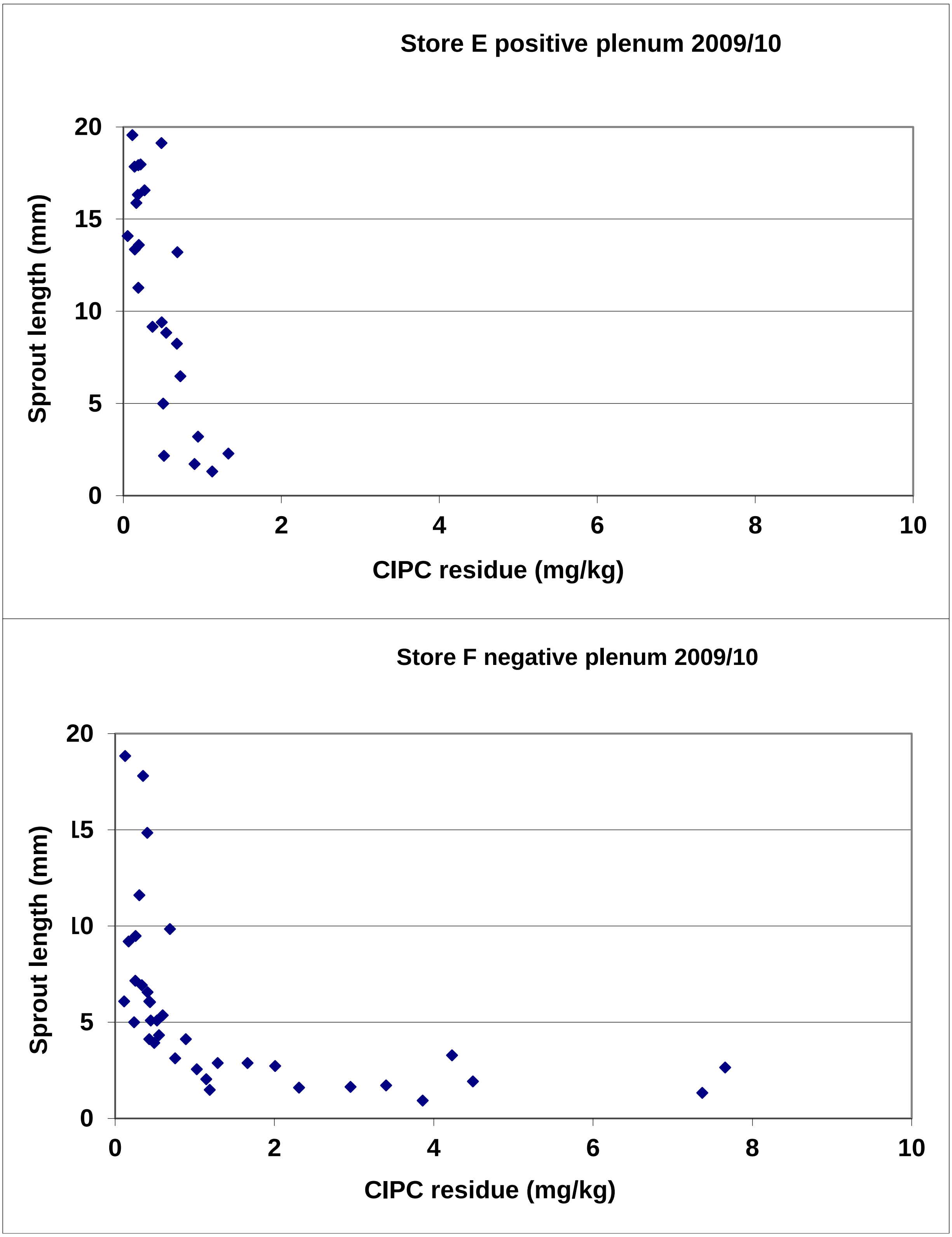


Store	Year	Mean sprouting (mm)	SD	Mean CIPC residue (mg/kg)	SD	CV%
B	2008/09	2.3	2.29	0.5	0.45	94
B	2009/10	6.0	6.70	0.5	0.47	92
B	2010/11*	7.7	8.79	0.4	0.56	150

Fig. 6. CIPC residue concentration and maximum sprout length for a 1,700 tonne box store filled with cv. Saturna (*$^2/_3$ covers in 2010/11).

4.5 Two 1,200 tonne box stores

In 2009/10, two virtually identical 1,200 tonne box stores loaded with cv. Markies were used to assess positive and negative pressure plenum applications. Four applications were carried out in both stores. Using a positive plenum application residue values with little variability were achieved (CV% 86). However, residue values were particularly low (0.37 mg kg^{-1}) and sprout control efficacy was poor, with a mean sprout length of 15.2mm. In a similar store and with similar inputs, a negative pressure plenum application resulted in improved sprout control efficacy, as a result of higher residue values, but with residue variability similar to control treatments.

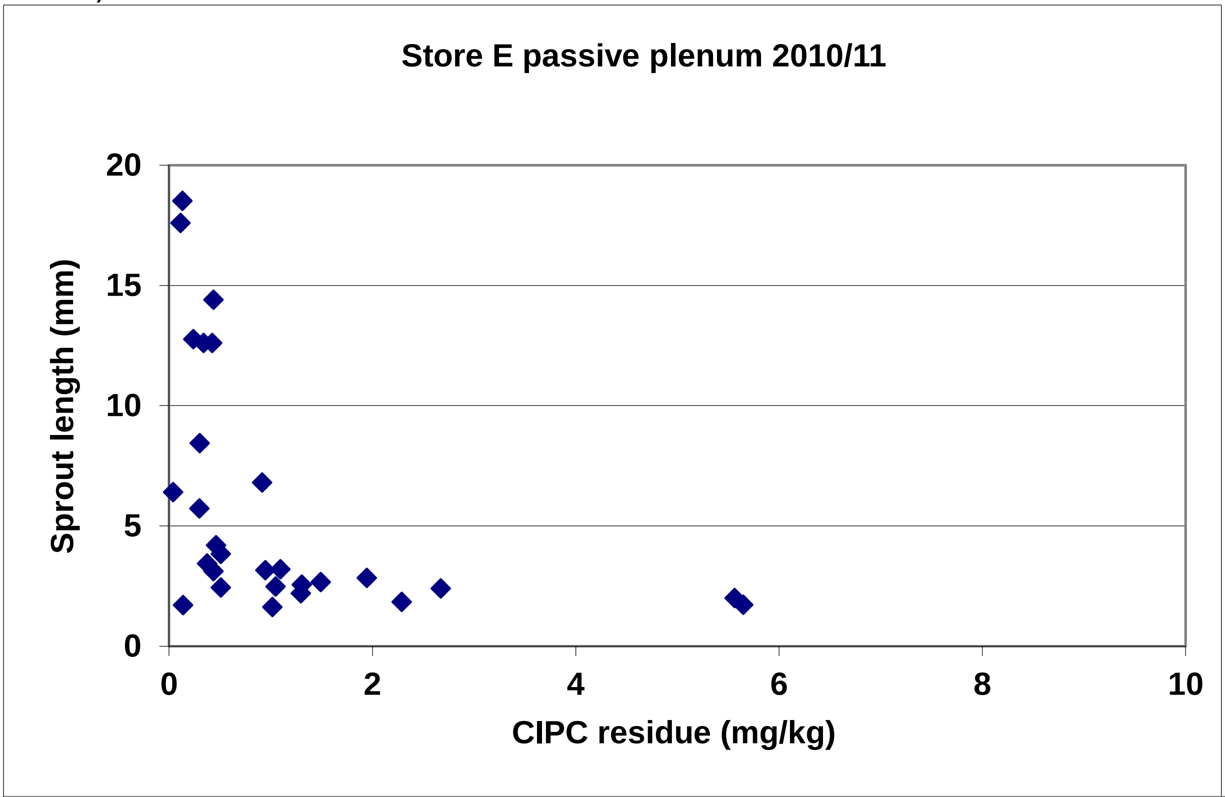


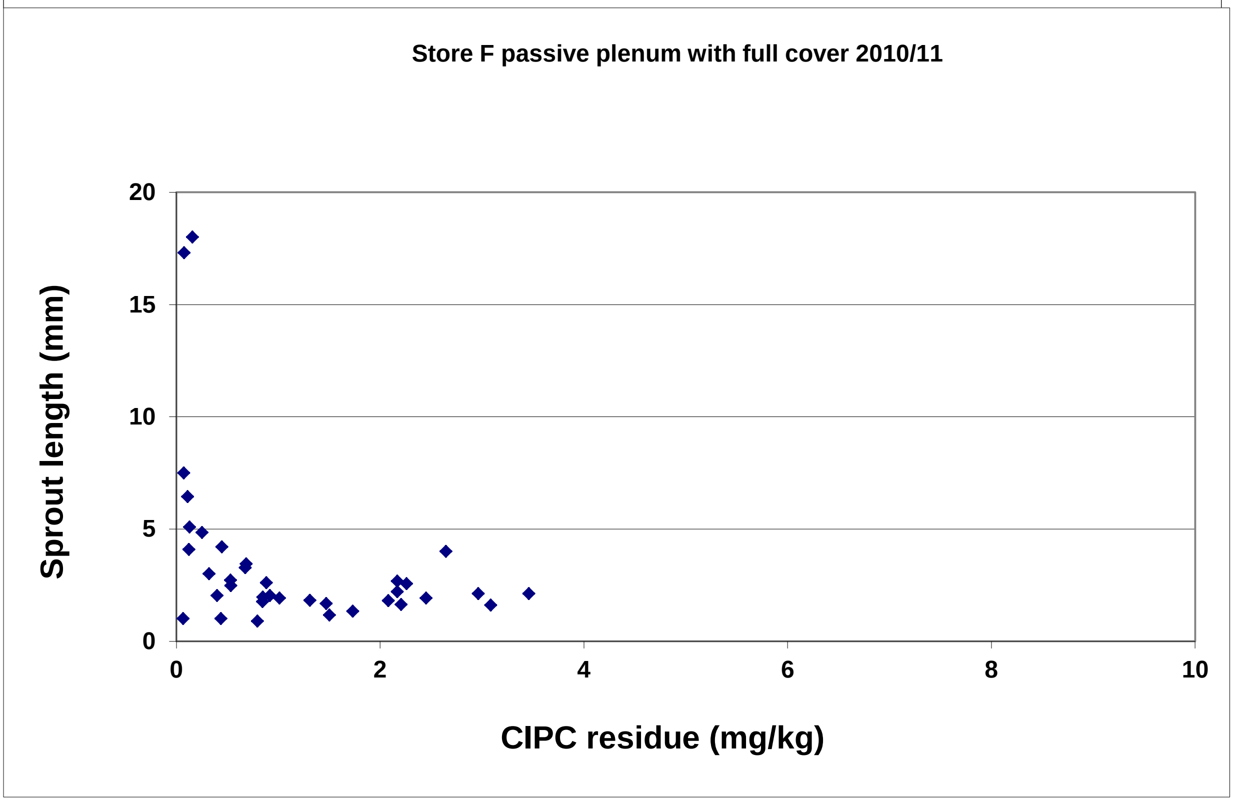
Store	Year	Mean sprouting (mm)	SD	Mean CIPC residue (mg/kg)	SD	CV%
E	2009/10	15.2	7.82	0.4	0.32	88
F	2009/10	5.6	4.44	1.5	1.91	128

Fig. 7. CIPC residue concentration and maximum sprout length for 1,200 tonne box stores with cultivar Markies in 2009/10.

In the 2010/11 storage season, the same stores were used to assess applications using plenums with and without covers. Application by plenum without covers resulted in a variable CIPC residue concentration (CV% 136), and variable sprout control efficacy (mean 15.6mm, SD 30.96). The use of complete covers on boxes improved residue distribution (CV% 85) and sprout control efficacy (mean 3.5mm, SD 3.78). These treatments were repeated in the 2011/12 season, again using the cultivar Markies. On this occasion, in contrast to previous seasons, samples from just top and bottom boxes were analysed for CIPC residue levels (Fig.9) while *top*, *middle* and *bottom* samples were assessed for sprout control efficacy. CIPC residue analysis in the final season was carried out by Fera.

Two 1,200 tonne box stores with cv Markies 10/11

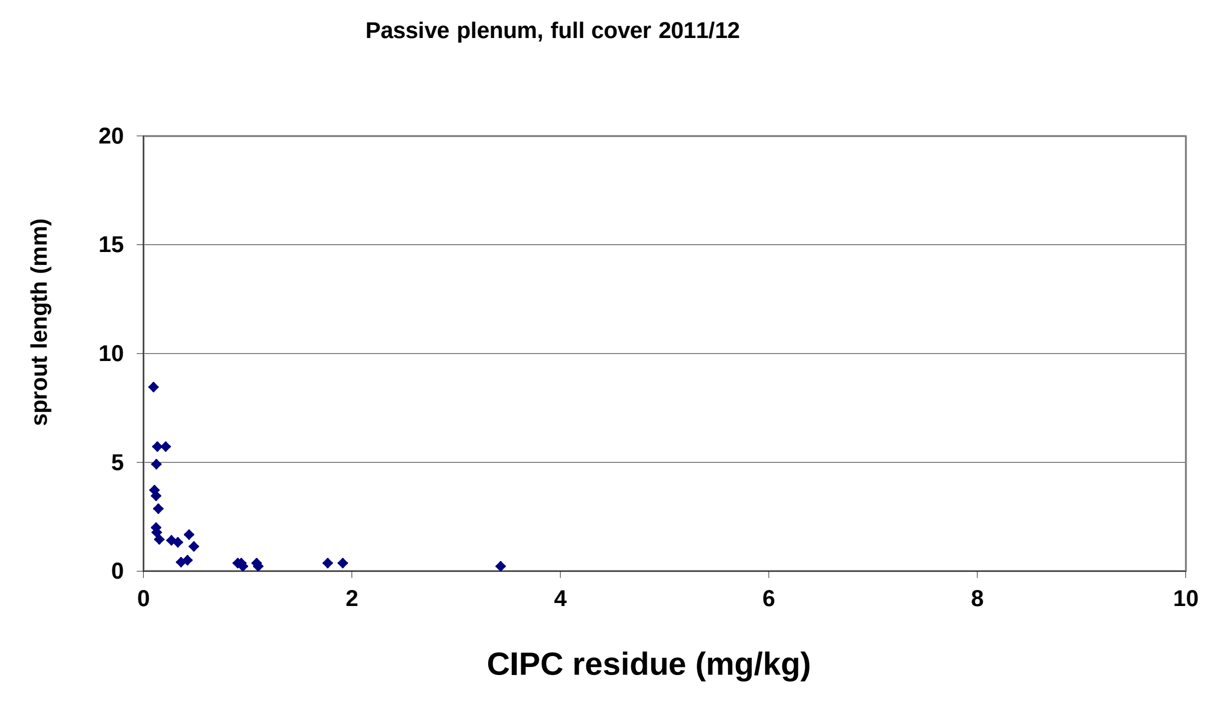


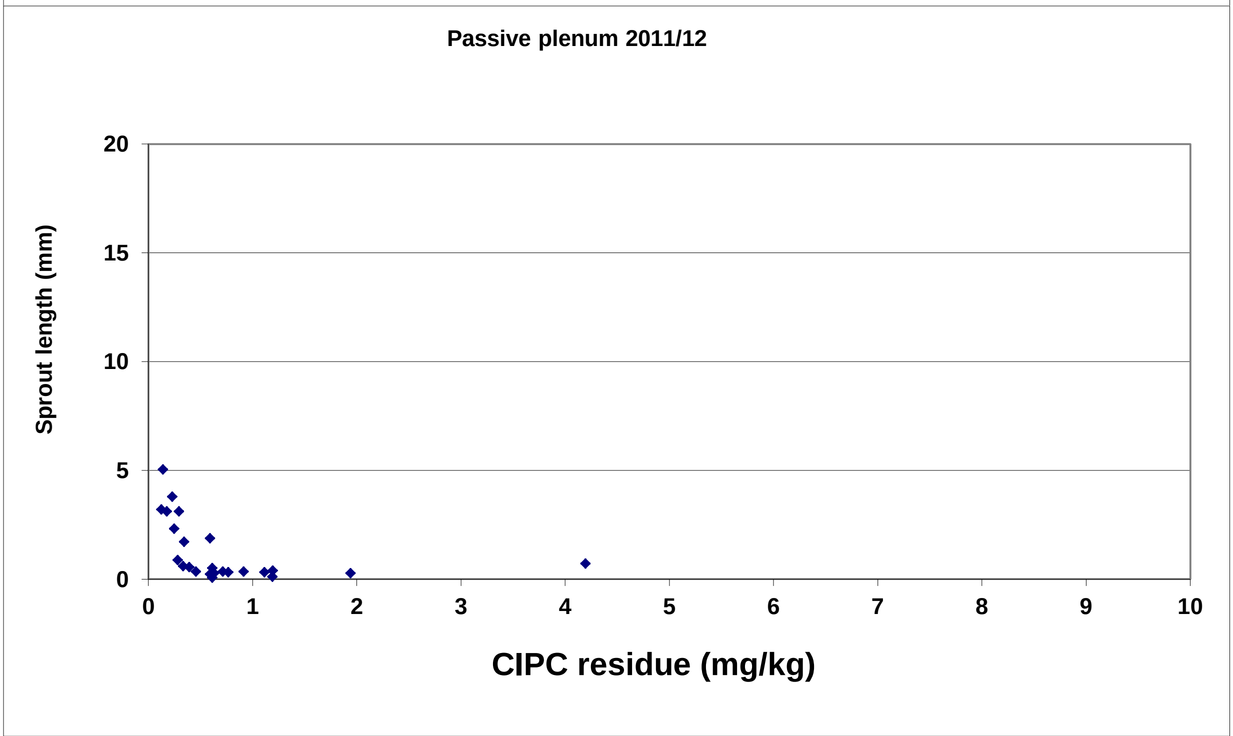


Store	Year	Mean sprouting	SD	Mean CIPC residue (mg/kg)	SD	CV%
E	2010/11	15.6	30.96	1.0	1.38	136
F	2010/11	3.5	3.78	1.2	0.99	85

Fig. 8. CIPC residue concentration and maximum sprout length for a 1,200 tonne box store with cultivar Markies in 2010/11.

Two 1,200 tonne box stores with cv Markies 11/12





Store	Year	Mean sprouting (mm)	SD	Mean CIPC residue (mg/kg)	SD	CV%
E	2011/12	2.1	2.31	0.7	0.79	120
F	2011/12	1.3	1.41	0.8	0.85	113

Fig. 9. CIPC residue concentration and maximum sprout length for a 1,200 tonne box store with cultivar Markies in 2011/12.

In the 2011/12 storage season, passive plenum and passive plenum with cover treatments gave similar results in terms of sprout control and mean residue levels with residue variability only marginally improved with that of control stores.

5 Discussion

In order for CIPC to remain available for the industry, application systems need to be developed that will ensure CIPC residue levels are reliably maintained below the Maximum Residue Level (10ppm). This needs to occur with sprout control efficacy that is sufficient for end users. In addition, systems that would allow CIPC inputs to be reduced are also important[3].

In bulk stores a modified application procedure was developed, based on practices used in North America (Briddon & Jina, Potato Council study tour 2004). The modified application procedure (McGowan et al, Potato Council project R265) demonstrated significant input reductions (up to 50%) could be achieved in bulk stores when sprout control was effective throughout stores, as a result of even distribution of CIPC. This system was only demonstrated in bulk stores, which have positive ventilation.

Approximately 50% of stores in GB are box stores. In ‘overhead throw’ configurations, which are used in a large majority of these, ventilating air is delivered non-positively. In these stores air is propelled, by use of a fan, to one end of the building with low pressure, as a result of this displacement, drawing air back to the fan. Ventilating air does not pass through crop but returns to the fan primarily through pallet apertures and around blocks of boxes. Airflow rates within the tubers to be treated, in this store type, are very low.

Also, in this type of store, ventilation systems are traditionally turned off during application and CIPC is introduced into a void area (an inspection or perimeter corridor for example) between or around blocks of boxes. Typically, no attempt is

[3] In GB, CIPC applications up to 63.75 g/tonne are permitted on potatoes destined for processing. This is higher than rates used in EU. Although registration of CIPC is governed by the EU, formulations are controlled by member states. Continued use of CIPC is subject to crops meeting the MRL (and other conditions of use).

made to limit vertical movement, and the hot fog rises into the roof-space. Relatively high deposits of loosely attached CIPC can therefore be found on surface potatoes of top boxes as a result of sedimentation. In addition, there is little impetus for CIPC fog to enter boxes. Movement of fog into boxes is ‘driven’ by convection currents. Potatoes warm the surrounding air increasing its buoyancy, and cause it to rise up through the box. This air is replaced with air, laden with CIPC fog, at the time of CIPC application, which enters blocks of boxes along pallet apertures. Distribution of CIPC in such stores is therefore problematic because of the importance of the sedimentation component, and the low airflow rates into boxes. The aim of the modifications tested was to reduce the magnitude of the sedimentation component of CIPC distribution, and to increase movement into boxes. By applying CIPC fog into a plenum, the fog is prevented from rising directly into the roof-space and tends to be propelled along pallet apertures thereby, it is anticipated, increasing movement of fog into boxes.

Results for the control stores in these trials (Fig. 3) demonstrate the variability of CIPC residue levels and sprout control efficacy in conventionally treated OHT stores with alternative stacking patterns. In 2008/9, efficacy was poor (mean 15.2 mm) with residue levels below 0.5ppm in many samples (after application of 42 g/tonne). In 2009/10, when the store was stacked according to current best practice, efficacy was improved (mean 4.3 mm) as a result of higher average residue values, however residue variability was also considerably greater (158 CV%). In a similar store (store B 2008/09), the adoption of a simple plenum resulted in improved sprout control efficacy (mean 2.4 mm) and a narrower range of CIPC residue concentrations (94 CV%). Further development of the application system in this store (the use of a fan assisted duct for introducing fog along the plenum and 2/3 covering of the top boxes, store B 2009/10) did not further improve residue distribution (96 CV%). The use of a simple plenum with fan assisted duct was not completely successful in store E. Including all data, residue distribution was similar to control stores, however this was due to just two sample points with relatively high residue values. Excluding these values (5.6 and 5.7 mg/kg) resulted in a mean residue value of 0.71mg/kg (SD 0.69) and a relative standard deviation of 97CV%. The high values were in sample boxes immediately adjacent to the plenum and occurred as a result of short circuiting. The use of complete covers in a similar store (store F, 2010/11) did not improve the CIPC residue distribution. Although sprout control was more effective in store F (3.45 mm), compared with store E (15.11 mm), storage duration was curtailed in store F because of high levels of soft rotting. A similar pattern occurred when plenum and plenum with cover treatments were repeated in the 2011/12 storage season, in the 1,200 tonne box stores. CIPC residue levels, on the whole were relatively even, but higher levels were associated with crop adjacent to the plenum/application point.

In addition to simple plenums, more sophisticated modifications to the application process were evaluated. Auxiliary fans located on plenums were used recirculate applied fog through blocks of boxes. Two arrangements were assessed – positive plenum pressure, with fog ‘extracted’ from the store headspace and re-introduced to the plenum, and negative plenum pressure, where fog was drawn out of the plenum and discharged at the open end of blocks of boxes. In 2008/09 treatments were applied to low temperature, pre-pack stores. Although CIPC residue distributions were even, with relative standard deviations of 31% and 50% for negative and positive pressure plenums respectively, data were characterised by very low sprouting levels and very high residue levels, especially in the negative pressure treatment which received just 24 g/tonne CIPC compared with the positive plenum which received 36 g/tonne. Further work in low temperature stores was suspended and treatments carried out in processing stores in the subsequent seasons.

Additional small-scale work was carried out in stores at Sutton Bridge to investigate possible reasons for these high residue values. Results suggest that at low storage temperatures, there is limited re-distribution of CIPC because of low saturation vapour pressures. Where saturation vapour pressure is limited by storage temperature, rather than the amount present in the store, further applications of CIPC are not anticipated to improve sprout control efficacy. Data indicate a reduction in CIPC dose rate was justified. Further applications under such conditions can only serve to increase the risk of an MRL exceedance, as was the case in store C.

Positive plenum pressure applications were also carried out in processing stores (store B in 2010/11, with complete covers, and store E in 2009/10). In comparison with other treatments in store B, this method of application was not as effective, with sprout control not as complete and CIPC residue concentrations more variable (relative standard deviation 151%). Residue variability was skewed by three relatively high values (1.79, 2.00 and 2.55 mg/kg), all in bottom boxes, adjacent to the plenum, indicating a disproportionate movement of fog into lower boxes as a result of the fans. Application in Store E was more successful with limited residue variability (CV% 86), though sprout control efficacy here was relatively poor.

Negative pressure plenum applications were assessed in a processing store in 2009/10 (store F). Although efficacy was improved, in comparison with positive plenum applications in a similar store (store E, 2009/10) residue distribution was poor with a relative standard deviation of (CV% 127). All top boxes typically had high CIPC residue concentrations.

A ‘suction wall’ store was assessed in each season. In 2008/09, some inappropriate boxes were used resulting in variable sprout control efficacy and variable CIPC residue levels; these results should be ignored. In another suction store, in subsequent seasons, good sprout control efficacy (generally <3.5mm) and even variability of residues (relative standard deviations of 90% and 56%) were recorded. In the 2009/10 season, a fourth CIPC application was made (total 48 g/tonne applied) which was considered unnecessary by the researchers.

6 Conclusions

In terms of residue variability and sprout control efficacy the 'suction wall' store used in years 2 and 3 was by far the most effective giving a low level of residue variability and good sprout control efficacy. This store design employs positive ventilation and therefore, it is unsurprising that results are most similar to previous data from bulk stores (Fig 10) where CIPC fog is recirculated through the bulk pile.

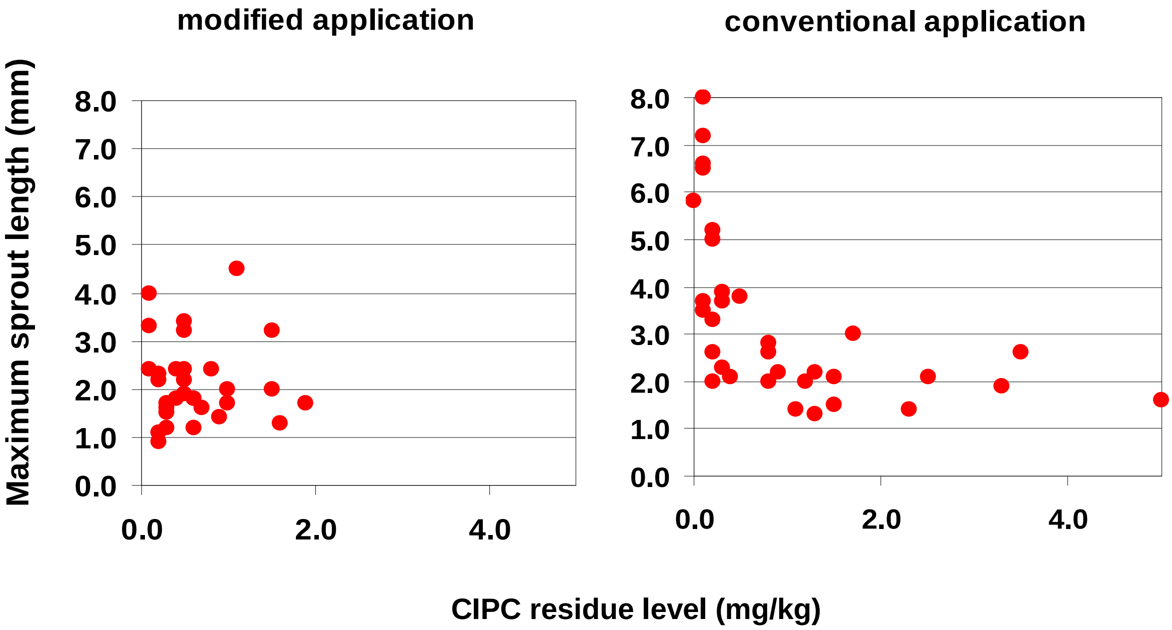


Figure 10. Comparative data for CIPC residue and maximum sprout length from **bulk** stores treated with 42 g/tonne CIPC applied conventionally or using recirculation (data from Potato Council project R265)

In stores *without* positive ventilation, a similar clustering of data occurred when applications were made using a passive plenum (store B, 2008/09 & 2009/10, store E 2010/11 and store F 2010/11), however data is generally more dispersed especially in terms of sprout control efficacy. This is perhaps to be anticipated given the non-positive method of distribution. Although simple plenum applications typically improved residue distribution, there is scope for short-circuiting of fog through boxes close to the point of fog introduction (for example store E 2010/11) resulting in higher residue values locally.

7 Recommendations

In ‘overhead throw’ box stores, commercial trials indicate that residue distribution can be improved (i.e.variability reduced) by carrying out applications of CIPC using a simple plenum within the box stack. Although recommended to enhance efficacy and to give more even residues, the adoption of such systems alone is not thought likely to result in any major reductions in CIPC inputs. Such systems may also result in higher localised residue levels in crop immediately adjacent to the fogging point, although values in excess of the Maximum Residue Level were not found.

In addition, the use of plenums and any fans associated with this, may require working at height and electrical switching may increase fire risk. Given these difficulties and the uncertainty of improving residue distribution, it is suggested that further limits on CIPC inputs and/or a management system with positive release (i.e. tested residues before sale) should be considered for this store type to address the issue of MRL exceedance.

In order to reduce chemical inputs, and provide a predictable and reliably even CIPC residue distribution, it is likely that positive ventilation systems (bulk stores; ‘letterbox’ or ‘suction wall’ box stores) are required to assist application. Where new stores are being constructed, or if retrospective upgrades are being made, these should be of a type that uses positive ventilation systems for optimal CIPC performance.

ANNEX 1. RAW DATA

Control store 2008/09

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)

	Fan End						
Top	3.12	2.12	2.52				
Middle	15.00	46.56	51.92				
Bottom	7.04	54.56	21.80				
Top					1.08	1.28	1.12
Middle					10.08	85.44	14.92
Bottom					6.56	1.96	4.36
Top	1.00	0.96	2.32				
Middle	1.96	16.32	19.76				
Bottom	4.08	20.56	4.52				
	Door End						
	↑ Application ↑						

CIPC concentration key (mg/kg)

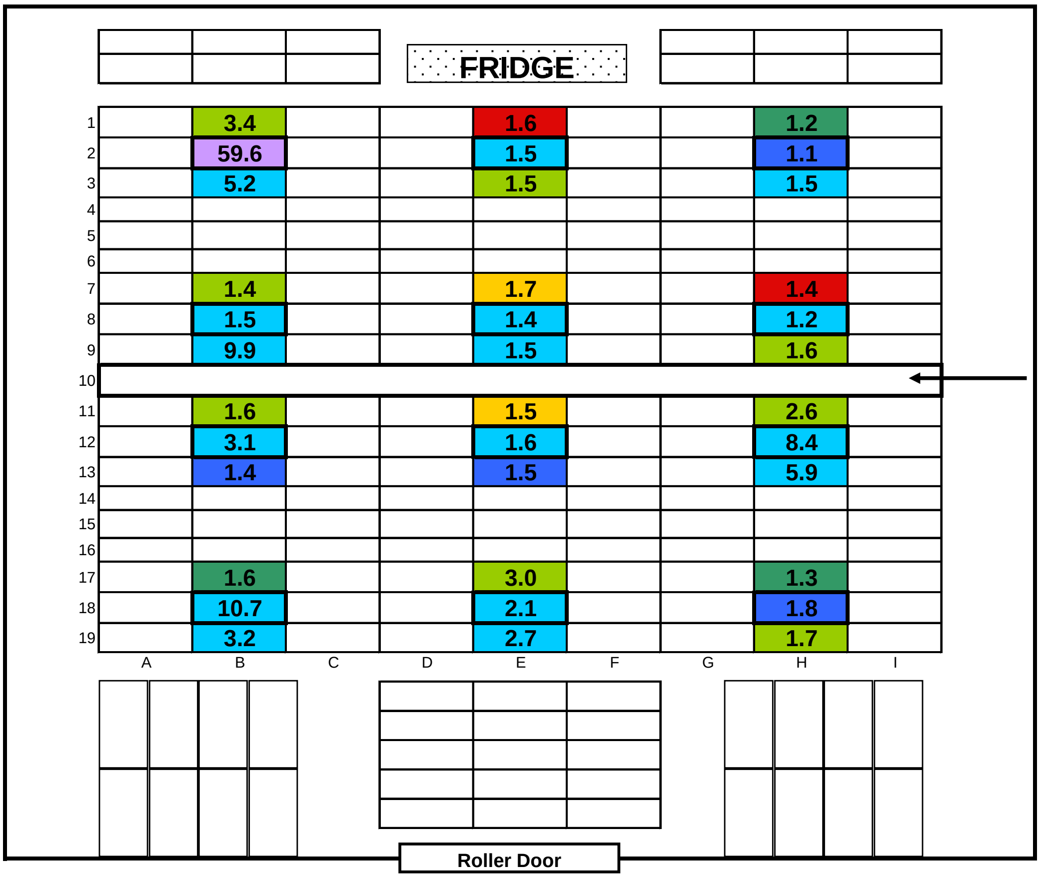
<0.1	>0.1-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	**mean**	stdev
top	**2.0**	0.86
middle	**0.2**	0.16
bottom	**0.3**	0.15
mean	**0.8**	0.99

Control store 2009/10

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues	box position	**mean**	stdev
	top	**5.0**	4.07
	middle	**0.3**	0.18
	bottom	**0.7**	0.45
	mean	**2.0**	3.16
		mean	stdev
near corridor		**2.0**	3.06
away from corridor		**2.0**	3.35

	mean	stdev
fog entry side	**2.2**	3.25
far side	**1.1**	1.20
centre line	**2.8**	4.26

‘Suction wall’ 2008/9

CAUTION: store performance compromised in this trial; see text

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)

↓ Application

Fan End

			PLENUM						PLENUM			CIPC residue (mg/kg) mean	stdev
Top	4.48	1.00		1.40	7.64		1.40	1.00		1.00	1.12	1.2	1.34
Middle	29.20	14.00		35.04	42.12		38.08	3.00		20.16	9.52		
Bottom	22.00	21.80		48.88	46.32		11.88	40.40		8.72	12.68		
Top	1.44	2.20		1.64	2.12		0.08	2.24		1.04	2.16		
Middle	11.60	46.96		5.64	30.72		8.48	51.52		33.68	17.68	0.7	0.84
Bottom	14.32	29.12		20.20	10.92		14.08	18.00		11.72	34.76		
Top	1.00	1.28		1.40	1.00		2.88	1.08		1.00	1.08		
Middle	1.44	3.60		1.28	11.12		7.00	10.48		22.04	13.00	0.7	1.00
Bottom	4.84	2.12		5.60	10.32		1.20	8.92		1.16	5.48		

Door

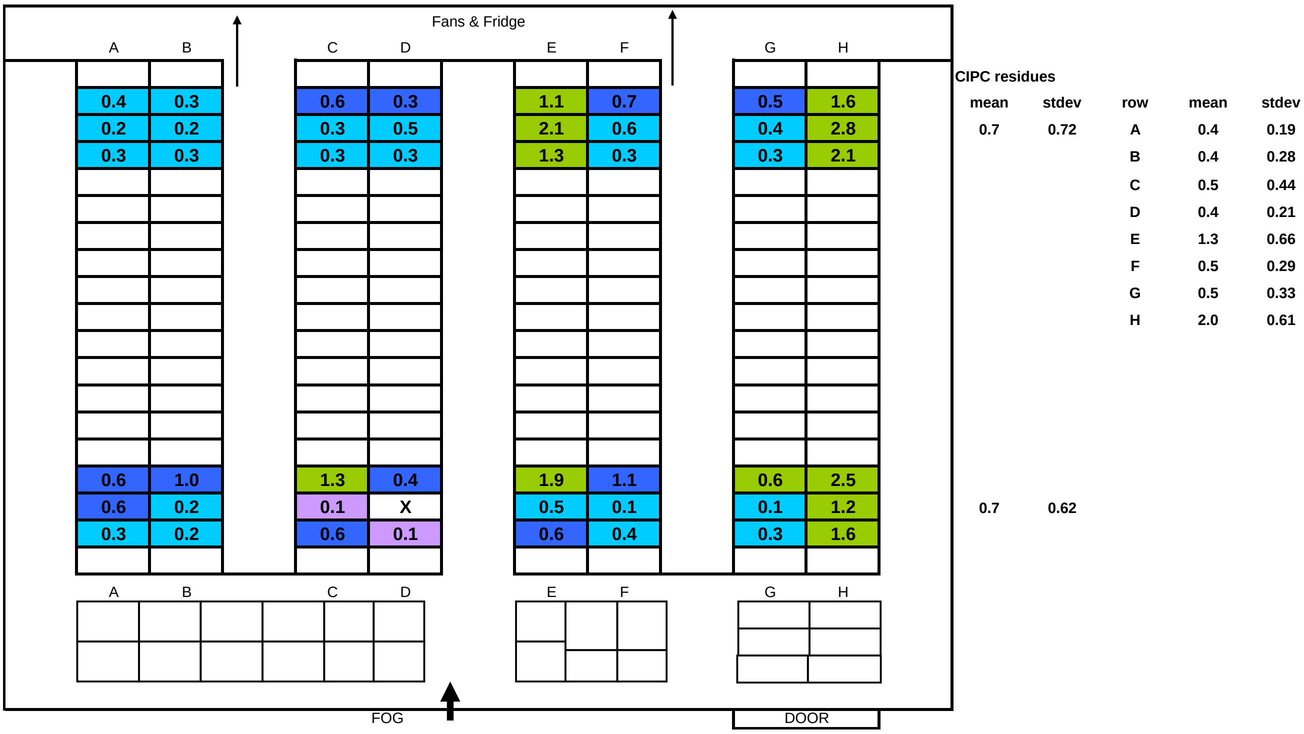
CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	mean	stdev
top	**2.1**	1.20
middle	**0.4**	0.31
bottom	**0.3**	0.14
mean	**0.9**	1.01

Suction wall 2009/10

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

X – missing value

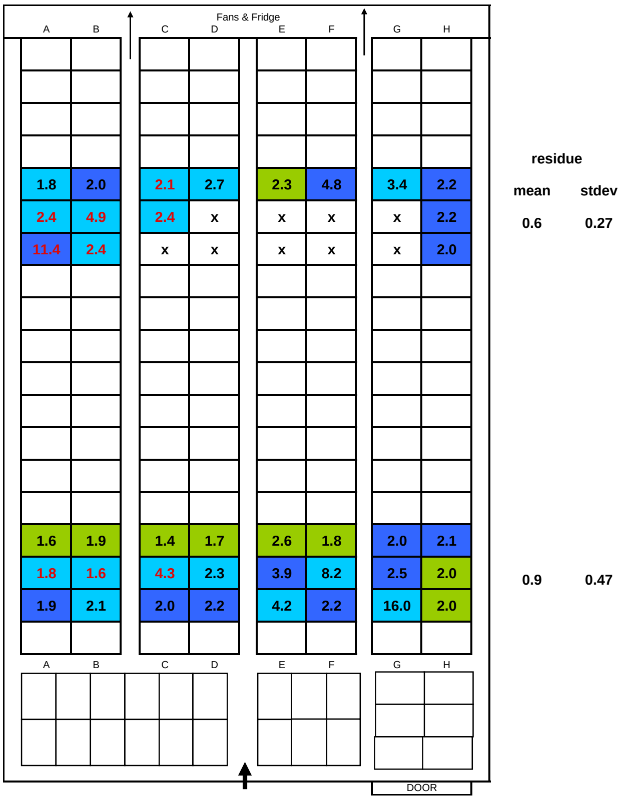
CIPC residues

box position	mean	stdev
top	0.9	0.63
middle	0.7	0.80
bottom	0.6	0.58
mean	0.7	0.68

There was no significant effect of box height or proximity to plenum on CIPC residue levels. Residue levels were higher in samples in rows E and H. These were unloaded earlier because of soft-rotting.

Suction wall 2010/11

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	mean	stdev
top	**0.9**	0.41
middle	**0.6**	0.39
bottom	**0.7**	0.46
mean	**0.8**	0.43
row		
near plenum(rows B & C)	**0.6**	0.44
away from plenum(rows A & D)	**0.7**	0.34
near plenum(rows F & G)	**0.7**	0.23
away from plenum(rows E & H)	**1.1**	0.46

Negative plenum, low temperature store 2008/09

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)

		Fridge					
	1.00			1.00		mean	stdev
	1.00			0.96		6.1	2.35
	2.92			0.76			
	1.00			0.88			
	1.00			1.00		7.4	1.92
	0.92			0.84			
	1.00			0.92			
	1.00			0.96		10.5	2.02
	0.96			0.68			
➔Application				Covered Plenum			
	1.00			0.88			
	1.04			0.80		10.2	2.88
	1.00			0.72			
	1.00			1.12			
	1.00			1.00		7.5	2.14
	1.04			1.04			
	0.96			1.04			
	1.00			1.12		7.8	1.49
	1.00			0.88			
	Door						
mean	8.1			8.4			
stdev	3.31			1.61			

CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	mean	stdev
top	**9.6**	1.59
middle	**8.5**	3.08
bottom	**6.7**	2.10
mean	8.3	2.57

Positive plenum, low temperature 2008/09

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)

		Fridge			CIPC residue mean	CIPC residue stdev
	1.48			1.40		
	1.24			1.16	2.6	0.57
	1.04			1.72		
	1.00			1.36		
	1.12			1.12	3.0	1.06
	1.12			1.48		
	1.04			1.00		
	1.12			1.16	4.4	2.28
	1.12			1.00		
Covered Plenum			Application ←			
	1.00			0.92		
	1.00			1.56	3.9	1.67
	1.00			1.00		
	1.00			1.00		
	1.00			1.12	2.9	1.35
	1.08			1.00		
	1.00			1.04		
	1.36			0.88	1.9	0.75
	1.36			1.52		
	Door					
mean	3.5			2.7		
stdev	1.82			1.13		

CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	mean	stdev
top	3.3	1.32
middle	2.8	1.12
bottom	3.3	2.12
mean	**3.1**	1.55

Passive plenum 2008/09

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)

				Residues mean	Residues stdev
		Fan End			
Top	3.32	3.64	0.96		
Middle	0.92	1.00	0.76	0.5	0.34
Bottom	1.12	1.04	3.28		
Top	1.52	3.32	2.12		
Middle	0.96	0.96	1.12	0.4	0.39
Bottom	1.44	6.08	0.76		
	→ Application		Covered Plenum		
Top	1.00	8.04	0.08		
Middle	5.24	3.12	1.00	0.4	0.32
Bottom	0.92	1.84	2.16		
Top	1.32	2.20	0.92		
Middle	4.44	11.20	0.96	0.6	0.70
Bottom	0.96	1.08	2.88		
		Door End			
mean	0.4	0.5	0.4		
stdev	0.31	0.45	0.57		

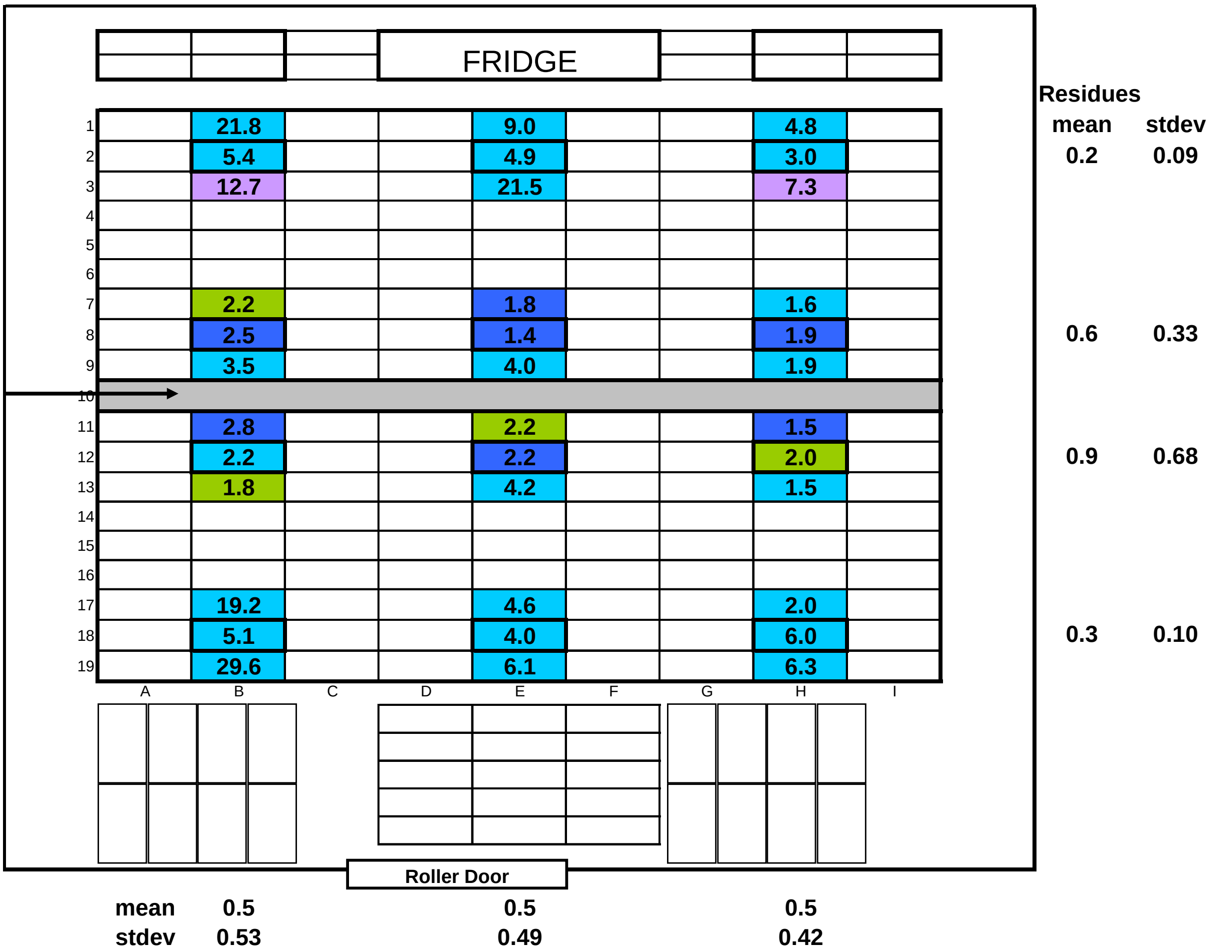
CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	**mean**	stdev
top	**1.0**	0.48
middle	**0.2**	0.14
bottom	**0.2**	0.13
mean	**0.5**	0.45

Fan assisted passive plenum 2009/10

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



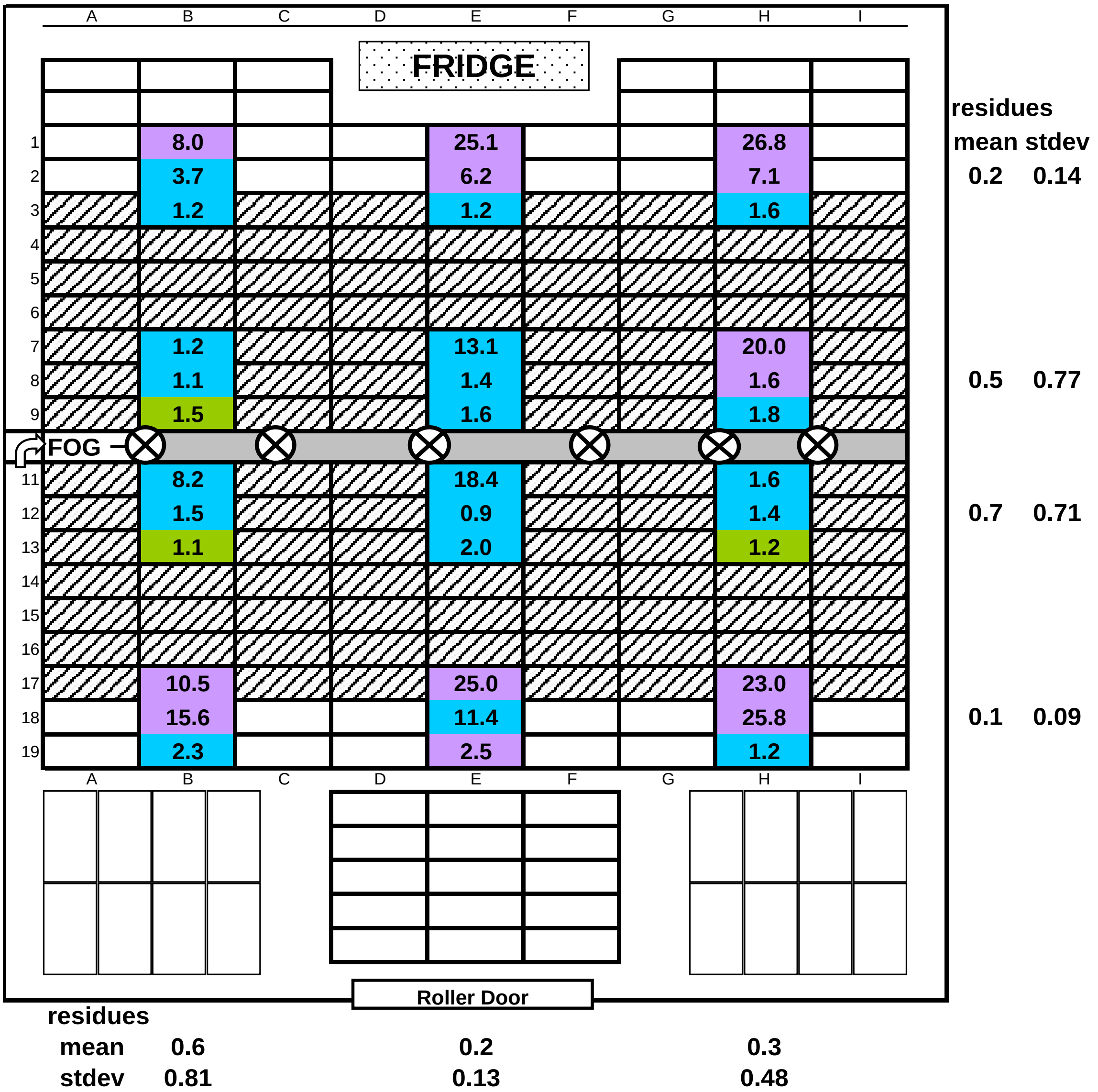
CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	mean	stdev
top	**0.6**	0.45
middle	**0.5**	0.43
bottom	**0.3**	0.52
mean	**0.5**	0.47

Positive plenum with $^{2}/_{3}$ covers 2010/11

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



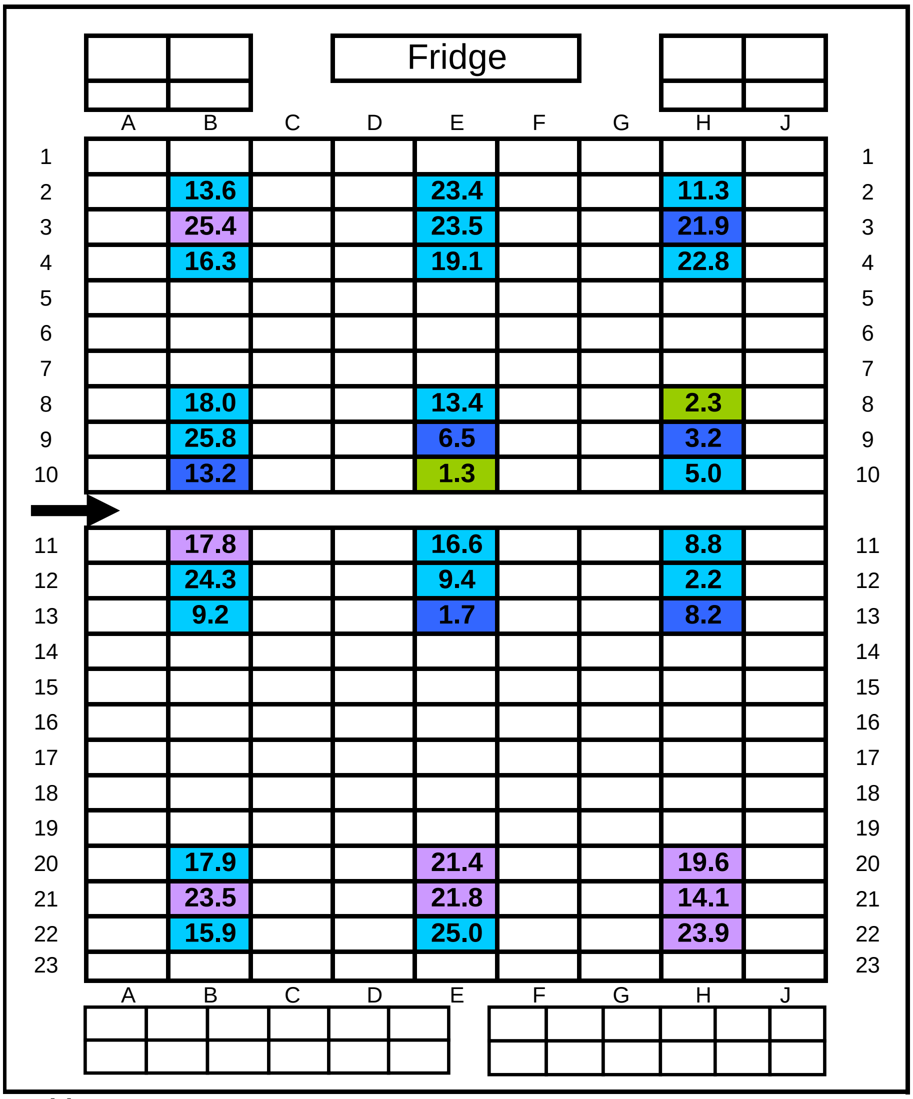
CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	**mean**	stdev
top	**0.1**	0.09
middle	**0.2**	0.13
bottom	**0.8**	0.84
mean	**0.4**	0.56

Positive plenum 2009/10

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



Rows	residues mean	stdev
1–4	0.2	0.12
8–10	0.7	0.42
11–13	0.5	0.22
20–22	0.1	0.05

residues	B	E	H
mean	0.2	0.4	0.4
stdev	0.173	0.344	0.39

CIPC concentration key (mg/kg)

<0.1	**0.2-0.5**	**0.6-1.0**	**1.1-3.0**	**3.1-5.0**	**5.1-8.0**	**8.1-10.0**	**10.0+**

CIPC residues

box position	**mean**	stdev
top	**0.3**	0.34
middle	**0.3**	0.29
bottom	**0.5**	0.33
mean	**0.4**	0.32

Negative plenum 2009/10

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)

Fridge

	A	B	C	D	E	F	G	H	J		residues mean	residues stdev
1										1		
2										2		
3										3		
4		2.6			2.9			2.9		4		
5		7.2			3.9			2.0		5	0.8	0.54
6		4.1			6.1			6.9		6		
7										7		
8		1.7			2.6			1.9		8		
9		4.1			5.1			1.6		9	2.3	2.54
10		6.0			18.8			6.1		10		
11		2.7			3.3			1.6		11		
12		6.6			9.8			3.1		12	1.4	1.41
13		5.1			9.2			4.3		13		
14										14		
15										15		
16										16		
17										17		
18										18		
19										19		
20		1.5			1.3			0.9		20		
21		17.8			14.8			11.6		21	1.6	2.45
22		5.4			5.0			9.5		22		
23										23		
	A	B	C	D	E	F	G	H	J			
residues mean		**1.0**			**2.0**			**1.6**				
stdev		**0.917**			**2.831**			**1.489**				

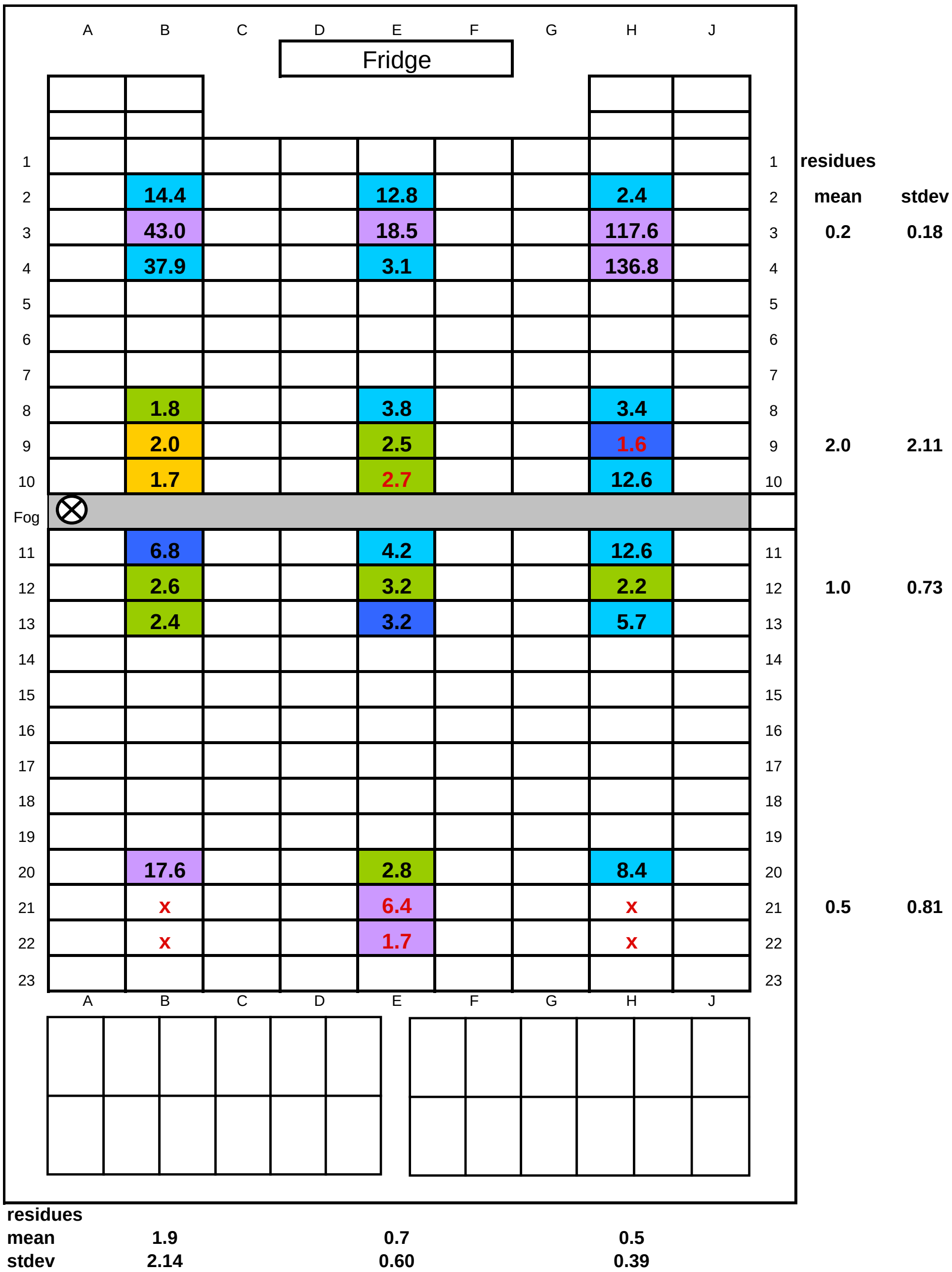
CIPC concentration key (mg/kg)							
<0.1	**0.2-0.5**	**0.6-1.0**	**1.1-3.0**	**3.1-5.0**	**5.1-8.0**	**8.1-10.0**	**10.0+**

CIPC residues

box position	**mean**	stdev
top	**3.4**	2.26
middle	**0.7**	0.57
bottom	**0.4**	0.16
mean	**1.5**	1.91

Passive plenum 2010/11

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



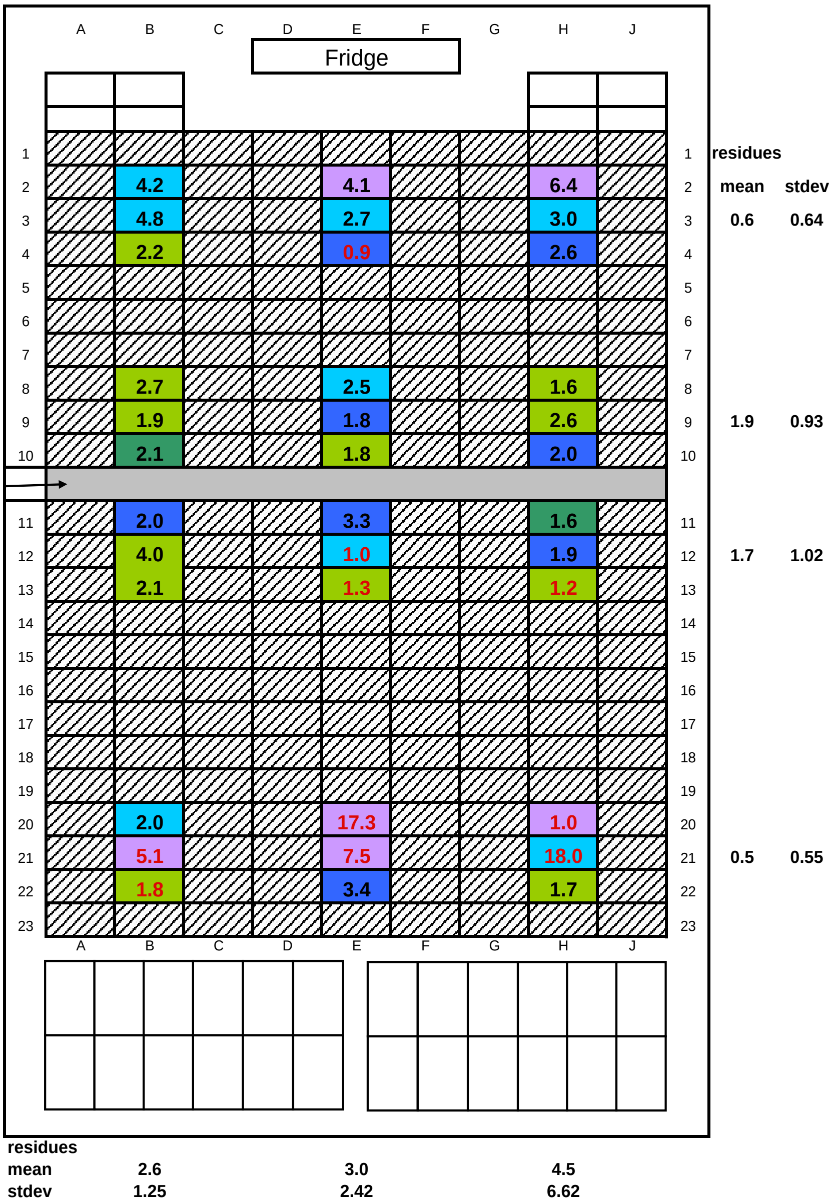
CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	**mean**	stdev
top	**0.7**	0.69
middle	**1.2**	1.64
bottom	**1.2**	1.78
mean	**1.0**	1.38

Passive plenum with cover 2010/11

Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



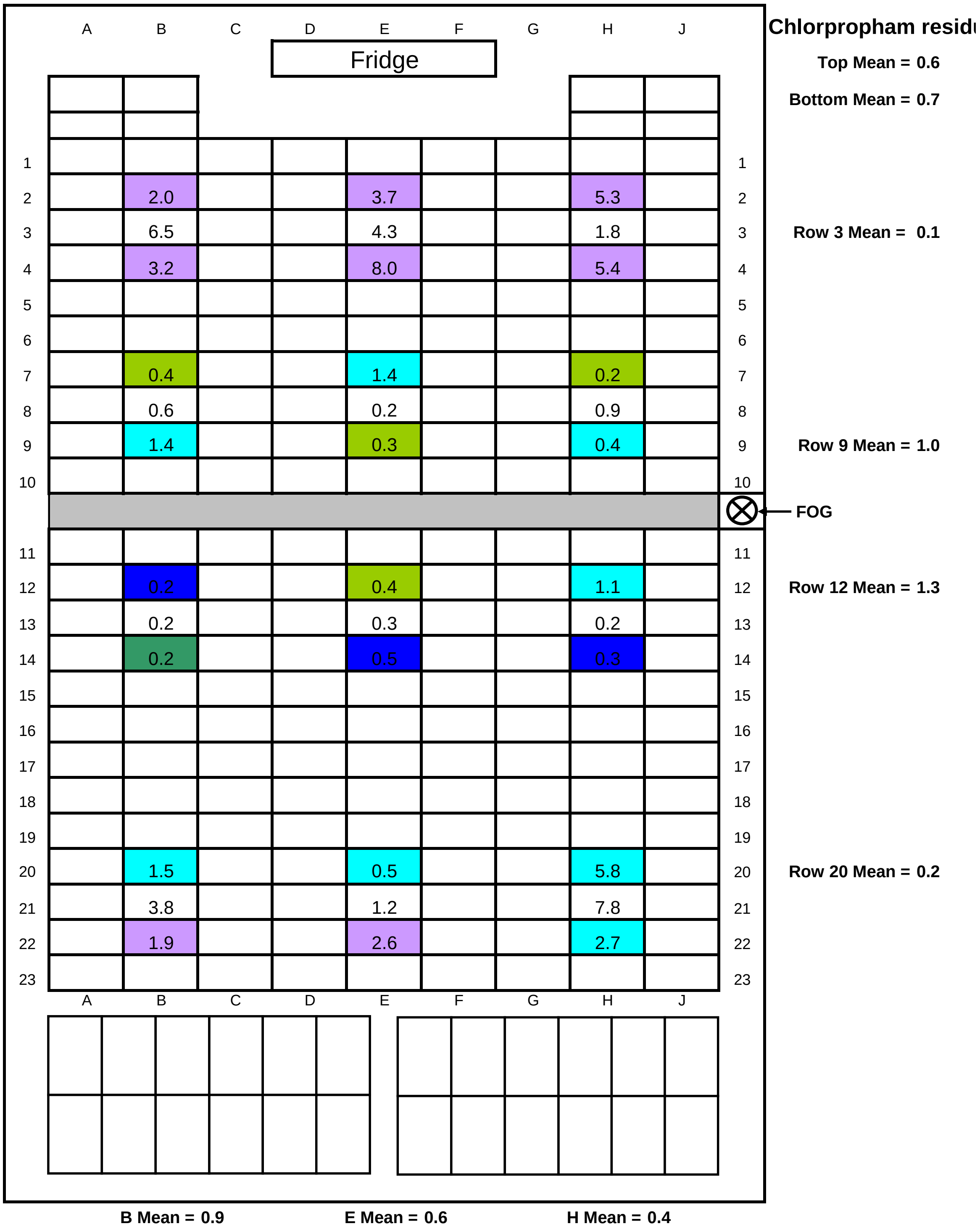
CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

CIPC residues

box position	**mean**	stdev
top	**0.9**	1.09
middle	**1.0**	0.99
bottom	**1.7**	1.01
mean	**1.2**	0.99

Passive plenum with cover 2011/12

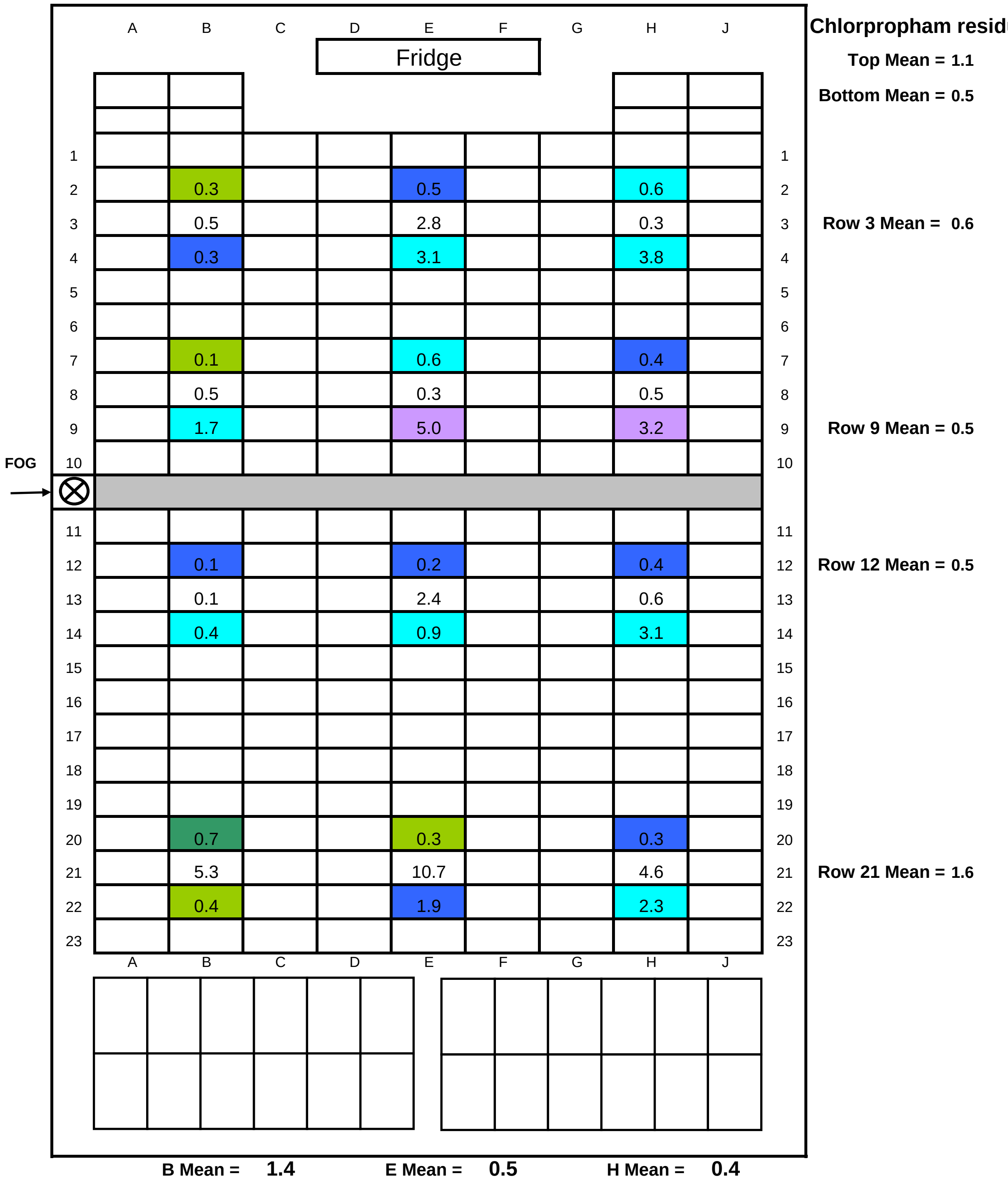
Mean maximum sprout length (mm) and CIPC residue level (mg/kg, colour coded)



CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

Passive plenum 2011/12

Mean maximum sprout length (mm) and CIPC residue level (mg/kg) colour coded)



CIPC concentration key (mg/kg)							
<0.1	0.2-0.5	0.6-1.0	1.1-3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+