Project title:	Rhubarb: Evaluation of different forcing methods of advancing rhubarb in forcing sheds
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The results and conclusions in this report are based on three experiments. The conditions under which the experiments were carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

Authentication

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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PRACTICAL SECTION FOR GROWERS

Objectives and background

Forced rhubarb has a relatively short season of availability, from mid December until April. There has traditionally been little opportunity to advance cropping into October and November as crowns need sufficient 'cold units' to break dormancy and produce economic yields when forced in sheds. There might be the opportunity to extend the season by lifting crowns in late summer and giving crowns the required number of cold units in cold stores prior to placing in forcing sheds. Information is required on whether all the cold units can be provided artificially and whether they are equivalent to naturally supplied cold units.

In 1996 a range of field lifting dates from 4 September to 5 November were compared to determine if the response to artificially supplied cold units was affected by lifting date. The variety Timperley Early was used and treated with 140 and 210 cold units in a cold store before placing in a blacked out greenhouse.

In 1997 two lifting dates during September were compared with the crowns given 70 or 140 cold units in a cold store maintained at 3 °C. Half the crowns were then treated with gibberellin after placing in a blacked out greenhouse to determine whether artificial cold units could be partially substituted by using gibberellin treatment.

In 1998 crowns were lifted in mid September and stored at 1 °C and 3 °C to provide 140 and 210 cold units as there was some evidence that 3 °C was not sufficient to overcome dormancy. Half the crowns were then treated with gibberellin after placing in a blacked out greenhouse.

Summary of results

In 1996 crowns were lifted on 4 and 17 September, 1 and 15 October and 5 November and placed into a cold store maintained at 3°C to receive 7 cold units per day. The crowns remained in the cold store until they had received 140 or 210 cold units.

Table A: Summary of planting date and first harvest dates (1996).

Lifting Date	Planted		First Harvest Date	
	140 units	210 units	140 units	210 units
4 September	27 September	7 October	1 November	15 November
17 September	7 October	17 October	15 November	21 November
1 October	22 October	31 October	12 December	12 December
15 October	4 November	14 November	24 December	24 December
6 November	25 November	4 December	3 January	10 January

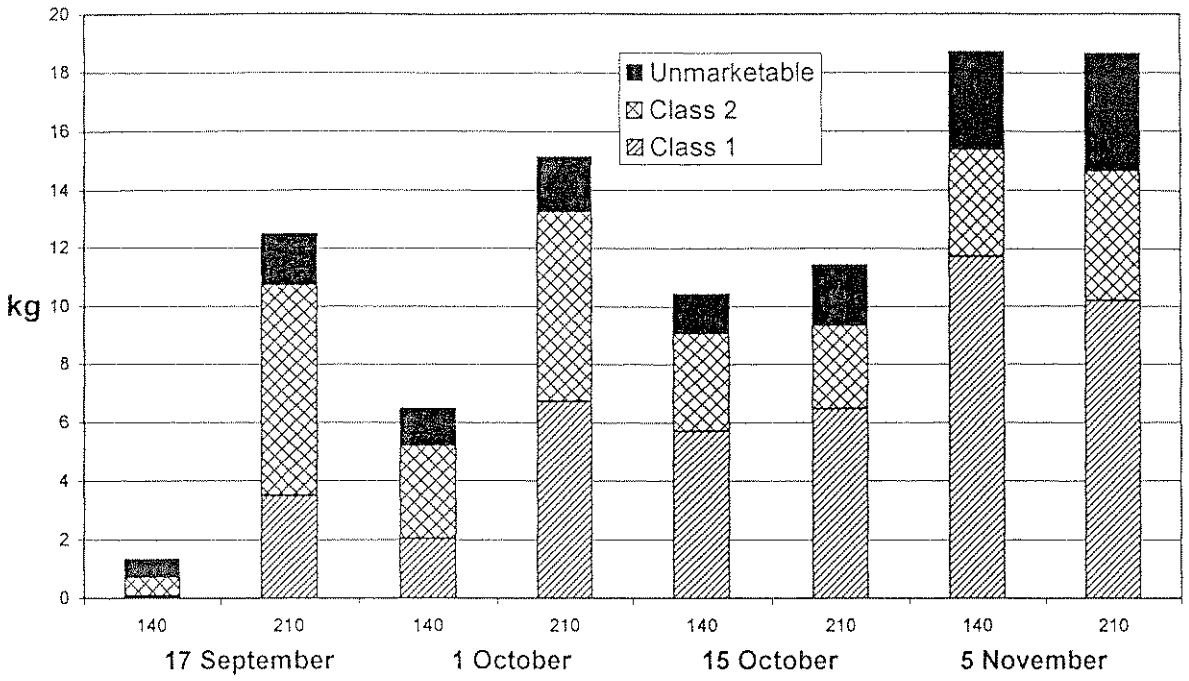
The first rhubarb was harvested in early October but yield was low. Crowns lifted on 17 September and 1 October and given 210 cold units gave good marketable yields, but sticks were mainly Class II due to lack of stick thickness.

Crowns lifted on 15 October gave similar Class I and marketable yields for both 140 and 210 cold unit treatments, but these were not harvested until mid December.

Crowns lifted on 5 November and included as a control gave high yields of good quality rhubarb from early January with no benefit from leaving the crowns in the cold store to receive more than 140 cold units.

The yield of sticks harvested are shown in Figure A.

Fig A. Cumulative yield from 15 crowns (kg)



In 1997 crowns were lifted on 8 and 22 September, and placed into a cold store maintained at 3°C to receive 7 cold units per day. The crowns remained in the cold store until they had received 70 or 140 cold units and half the crowns in each treatment was then treated with gibberellin.

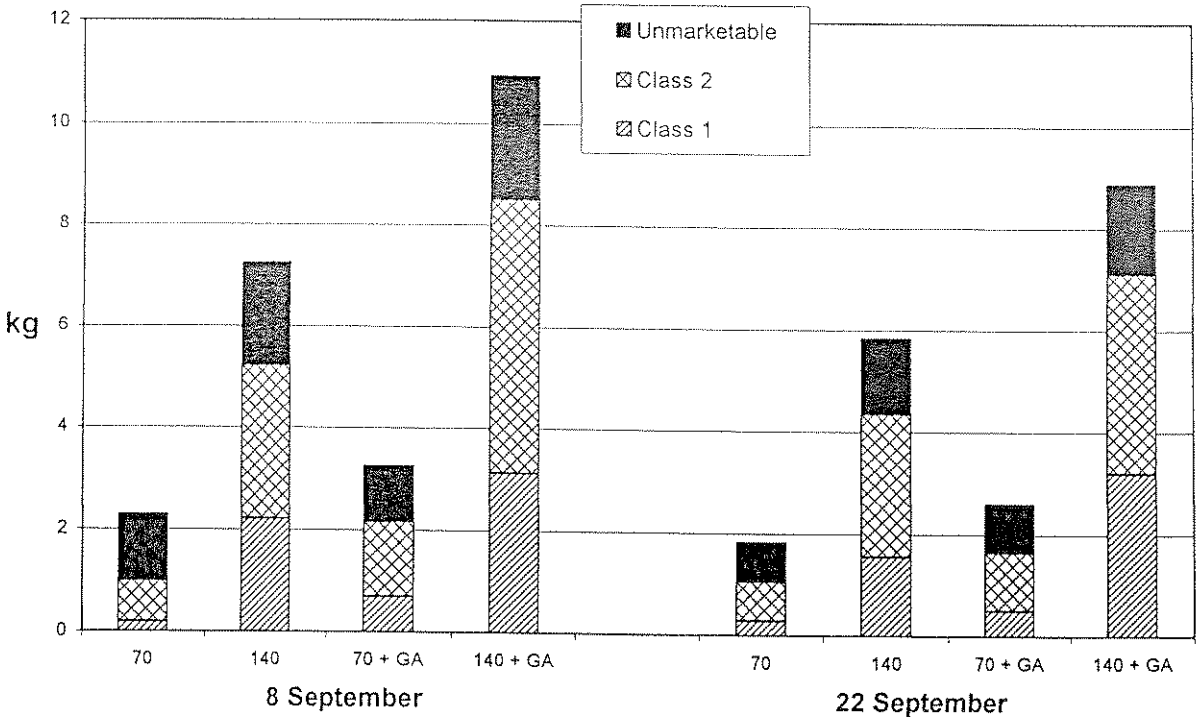
Table B: Summary of planting and first harvest dates (1997).

Cold Unit Treatments	Lifted on 8 September		Lifted on 22 September	
	'Planted'	First Harvest	'Planted'	First Harvest
70 cold units	22 September	22 October	3 October	28 October
140 cold units	3 October	1 November	13 October	15 November
70 cold units + gibberellin	22 September	19 October	3 October	28 October
140 cold units + gibberellin	3 October	27 October	13 October	10 November

The first rhubarb was harvested at the end of October and picking continued for six weeks. Cumulative yields by early December were lower than anticipated, with a benefit from giving the crowns 140 cold units rather than just 70 even where gibberellin was applied. Highest marketable yields were produced from crowns stored in a cold store for 20 days to provide 140 colds units and then given gibberellin after planting. The yield, however, was still only half that normally expected for Timperley Early.

The yield of sticks harvested are shown in Figure B.

Fig B. Cumulative yield from 15 crowns (kg)



In 1998 crowns were lifted on 23 September, and placed into cold stores maintained at 1 or 3°C to receive 9 or 7 cold units per day. The crowns remained in the cold store until they had received 140 or 210 cold units and half the crowns in each treatment were then treated with gibberellin.

Table C: Summary of planting and first harvest dates (1998).

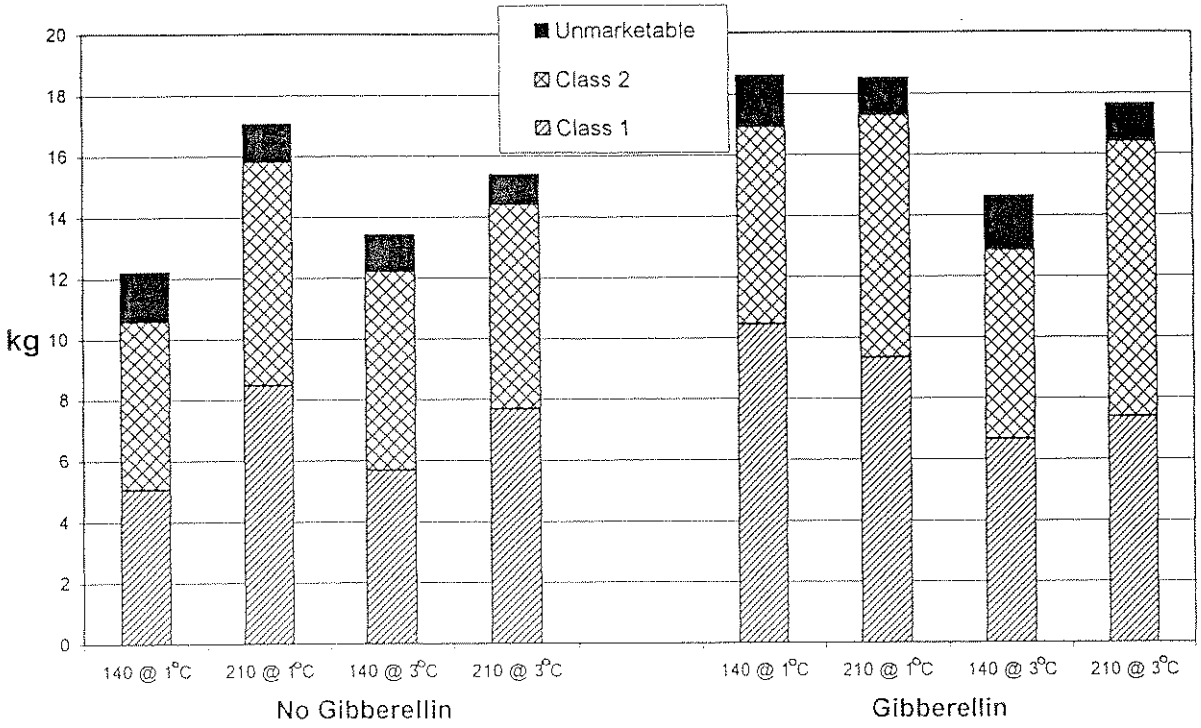
Cold Unit Treatment	Planted	First Harvest	
		- GA	+ GA
140 cold units @ 1 °C	13 Oct	17 Nov	9 Nov
210 cold units @ 1 °C	20 Oct	28 Nov	24 Nov
140 cold units @ 3 °C	16 Oct	22 Nov	17 Nov
210 cold units @ 3 °C	26 Oct	5 Dec	30 Nov

The first rhubarb was harvested on 9 November and picking continued for 6 weeks. Although some of the treatments did not produce any rhubarb until late November this was anticipated and they were included to allow accurate comparisons to be made as to the effect of cold store temperature and duration on productivity.

Cumulative yield were far higher than obtained in 1997 with much thicker petioles produced. Class I yields were highest where crowns had been stored at 1 °C to accumulate 140 cold units and then treated with gibberellin and where crowns had been stored at 1 °C to accumulate 210 cold units but this extra time in cold storage delayed maturity. Storage at 3 °C did not allow crowns to fully overcome dormancy and there was no benefit from using gibberellin.

The yield of sticks harvested are shown in Figure C.

Fig C. Cumulative yield from 15 crowns (kg)



Action points for growers

1. For early forcing use only the best crowns. It is advisable to remove leaves and petioles in the field to reduce the risk of disease development during forcing.

2. For harvesting in early November crowns need to be lifted in early September cold stored at 1 °C for at least 16 days and treated with gibberellin.

3. Crowns should not be stored above 3°C during cold storage as this does not appear sufficient to fully break dormancy.

4. Gibberellin treatment advanced maturity by 6 days and also increased yields where crowns had been given 140 cold units when stored at 1 °C.

Practical and financial benefits from the study

This study has shown that good quality rhubarb can be produced from early/mid November onwards by lifting crowns into a cold store for 16 days and treated with gibberellin after planting. By lifting crowns in early September and cold storing them at 1 °C then maturity could potentially be further advanced. This study has demonstrated that cold store temperature and duration has an important effect on Class I yield and that crowns must be stored at below 3 °C and 1 °C seemed to work well and allowed rapid accumulation of cold units and advanced maturity.

The economics of the technique are difficult to determine. Cold stores capable of reducing air temperatures down to 1 °C will be required for up to 16 days per lifting date. The easiest way of chilling crowns is to load them as a single layer into bulk bins, placed into a cold store and then forced in-situ after the required storage period by increasing the air temperature to 10-12 °C. Stacking bulk bins on top of each other and allowing access between rows of bins for watering, spraying and harvesting would increase productivity per unit of floor area. An alternative would be cold storage and then transfer the chilled crowns into forcing sheds but this would involve double handling although it may be possible to put refrigeration equipment into forcing sheds.

EXPERIMENTAL SECTION

INTRODUCTION

Forced rhubarb has a relatively short season of availability from mid December until April. There has traditionally been little opportunity to advance cropping into October and November as crowns need sufficient 'cold units' before forcing to produce economic yields when forced in sheds. There may be the opportunity to extend the season by lifting crowns in late summer and giving crowns the required number of cold units in cold stores prior to placing in forcing sheds. Trials carried out from 1977 to 1982 at HRI Stockbridge House studied production techniques to advance the maturity of forced crops into early December. In most cases the crowns were lifted after they had accumulated some natural cold units. The work suggested that yield and quality increased when a higher number of cold units were applied but the optimal number of artificially applied cold units was not identified. Information is required on whether all the cold units can be provided artificially and whether they are equivalent to natural cold units. The use of gibberellin as a partial replacement for cold units also required investigation.

The forced rhubarb industry has identified a need to extend the season of supply. Advancing the maturity of forced rhubarb would extend the season of availability and could increase revenue for producers. The overlap in production during March with the film covered outdoor crop has reduced returns for producers of traditionally forced rhubarb. The main aim of this project was to identify the most cost effective method to advance maturity of high quality forced rhubarb. This information could then be used to assess the economics of investing in cold stores or cooling forcing sheds and to estimate likely throughput of crowns during the autumn period. There may be the potential to use existing cold stores before they are filled with crops such as potatoes in mid/late October, thereby reducing capital investment.

MATERIALS AND METHODS

Site

The project was undertaken at HRI Stockbridge House, Cawood, Selby, North Yorkshire, YO8 3TZ. The crowns were supplied by a commercial rhubarb grower near Wakefield.

Year 1 (1996)

Treatments

A. Lifting date in the field:

1. 4 September
2. 17 September
3. 1 October
4. 15 October
5. 5 November

Note: The crowns at the first lifting date of 4 September were unusually small and the results have not been included in the analysis due to low yields. Crowns from a different field were used for the other four lifting dates.

B. Number of cold store cold units:

1. 140 cold units
2. 210 cold units

Details

Crowns of Timperley Early were purchased from a local rhubarb producer, graded and loaded into cold store on each date. The cold store was set at a constant temperature of 3°C, so that the crowns accumulated seven cold units per day.

After the crowns had been treated with the appropriate number of cold units they were bedded into a blacked-out glasshouse. The target temperature for forcing was 11°C.

Year 2 (1997)

Treatments

A. Lifting dates in the field:

1. 8 September
2. 22 September

B. Number of cold store cold units:

1. 70 cold units
2. 140 cold units

C. Application of gibberellin:

1. None
2. Berelex 1 g tablet in 10 l per 45 crowns

Details

Two year old crowns of Timperley Early were supplied by a local rhubarb producer, graded and loaded into cold store on each date. Seven days before lifting the top growth was mown off in the field. The cold store was set at a constant temperature of 3°C, so that the crowns accumulated seven cold units per day.

After the crowns had been treated with the appropriate number of cold units they were bedded into a blacked-out glasshouse. The gibberellin was applied using a watering can following bedding in and watering. The target temperature for forcing was 11°C.

Year 3 (1998)

Treatments

A. Cold store temperature and duration

1. 1 °C to provide 140 cold units
2. 1 °C to provide 210 cold units
3. 3 °C to provide 140 cold units
4. 3 °C to provide 210 cold units

B. Application of gibberellin:

1. None
2. Berelex 1 g tablet in 10 l per 45 crowns

Details

Two year old crowns of Timperley Early were supplied by a local rhubarb producer, graded and loaded into cold store. Seven days before lifting the top growth was mown off in the field. The cold stores were set at a constant temperature of 1 °C and 3 °C, so that the crowns accumulated either nine or seven cold units per day.

After the crowns had been treated with the appropriate number of cold units they were bedded into a blacked-out glasshouse. The gibberellin was applied using a watering can following bedding in and watering. The target temperature for forcing was 11°C.

For All Trials

Plot Size

In all trials each plot consisted of 15 large crowns. All crowns were included in the harvest assessments. Plot areas for each treatment are given in Appendix I.

Trial Design

In each year the trial was of a factorial design with three replicates of each treatment arranged in randomised blocks.

Harvesting

Weak or damaged shoots were removed ('trashed') on a weekly basis and plots were harvested when the sticks had reached marketable size. Sticks were graded into Class I, Class II and unmarketable, depending on colour, stick diameter and length. In general Class I sticks were straight of good red coloration, over 15 mm in diameter and over 30 cm in length. Class II sticks were 12-15 mm in diameter or less straight. Unmarketable sticks were below 12 mm in diameter, twisted or pale.

Records/Assessments

1. Cold store temperatures.

2. Yield and quality from all 15 crowns per plot (for a maximum of 6 weeks per plot).

Statistical Analysis

The data were analysed using a factorial analysis of variance. Data have been expressed as the number and yield of sticks per 15 crowns. The number of sticks was transformed and analysed on a square root scale to improve the validity of the analysis.

RESULTS

Year 1 (1996)

The crowns were kept in the cold store until the appropriate number of cold units had been provided, Table 1.

Table 1: Summary of planting date and first harvest dates.

Lifting Date	Placed into Forcing Shed		First Harvest Date	
	140 units	210 units	140 units	210 units
4 September	27 September	7 October	1 November	15 November
17 September	7 October	17 October	15 November	21 November
1 October	22 October	31 October	12 December	12 December
15 October	4 November	14 November	24 December	24 December
6 November	25 November	4 December	3 January	10 January

The first rhubarb was picked in November from the crowns lifted in the field on 4 September, but yield and quality were poor. This was probably due to the size of crowns.

The crowns lifted from 17 September to 6 November were from a different field and were more typical in size of those used commercially for forcing. They were harvested from mid November onwards.

Class I yields are given in Table 2.

Table 2: Class I yield (kg/15 crowns).

		Cumulative Class I Yield (kg/15 crowns)					
		Harvest Date					
Treatment		1	2	3	4	5	6
17 September	140	0.04	0.06	0.06	0.06	0.08	0.08
	210	0.64	1.62	2.25	2.50	3.04	3.49
1 October	140	0.13	0.30	0.57	0.88	1.27	2.03
	210	0.43	2.27	4.09	5.14	5.84	6.72
15 October	140	0.41	1.40	2.01	3.83	4.85	5.70
	210	0.46	1.90	3.19	5.13	6.08	6.46
5 November	140	0.42	2.24	6.72	9.66	10.79	11.72
	210	2.44	6.10	8.20	9.69	10.12	10.18
Mean of 140		0.25	1.00	2.34	3.61	4.25	4.88
Mean of 210		0.99	2.97	4.43	5.61	6.27	6.71
SED (14 df) for comparing means of:							
lifting dates		0.32 (0.69)	0.26 (0.56)	0.53 (1.14)	0.70 (1.50)	0.82 (1.76)	0.91 (1.95)
cold units		0.22 (0.47)	0.18 (0.39)	0.38 (0.82)	0.50 (1.07)	0.58 (1.24)	0.65 (1.39)
lifting date x cold units		0.45 (0.97)	0.36 (0.77)	0.75 (1.61)	0.99 (2.12)	1.16 (2.49)	1.29 (2.76)

LSDs at 5% are given in brackets.

Class I yields increased as the lifting date got later. For the 17 September and 1 October lifting dates, yields were poor, particularly where only 140 cold units had been supplied.

Marketable yields are given in Table 3.

Table 3: Marketable yield (kg/15 crowns).

		Cumulative Marketable Yield (kg/15 crowns)					
		Harvest Date					
Treatment		1	2	3	4	5	6
17 September	140	0.17	0.38	0.52	0.53	0.61	0.71
	210	1.19	3.05	4.94	6.84	8.50	10.74
1 October	140	0.64	1.23	1.96	3.14	4.01	5.20
	210	1.20	4.36	7.51	10.17	11.62	13.23
15 October	140	0.80	2.53	3.73	6.11	7.94	9.07
	210	0.68	2.98	5.08	7.58	8.82	9.33
5 November	140	0.69	2.99	8.02	11.91	13.45	15.37
	210	2.88	7.39	10.01	12.60	13.92	14.64
Mean of 140		0.57	1.78	3.56	5.42	6.50	7.59
Mean of 210		1.49	4.45	6.89	9.29	10.71	11.98
SED (14 df) for comparing means of:							
lifting dates		0.36 (0.77)	0.41 (0.88)	0.69 (1.48)	0.91 (1.95)	1.05 (2.25)	1.24 (2.66)
cold units		0.25 (0.54)	0.29 (0.62)	0.49 (1.05)	0.64 (1.37)	0.74 (1.59)	0.87 (1.87)
lifting date x cold units		0.51 (1.09)	0.59 (1.27)	0.98 (2.10)	1.29 (2.77)	1.49 (3.20)	1.75 (3.75)

LSDs at 5% are given in brackets.

Marketable yields increased as lifting date got later. There was a yield benefit for the two earliest lifting dates by leaving them longer in the cold store to accumulate more cold units.

Unmarketable yield is given in Table 4.

Table 4: Unmarketable yield (kg/15 crowns).

		Cumulative Unmarketable Yield (kg/15 crowns)					
		Harvest Date					
Treatment		1	2	3	4	5	6
17 September	140	0.03	0.26	0.32	0.40	0.50	0.62
	210	0.25	0.63	0.95	1.24	1.42	1.75
1 October	140	0.08	0.26	0.36	0.57	0.79	1.27
	210	0.15	0.39	0.53	0.80	1.12	1.91
15 October	140	0.04	0.10	0.28	0.63	1.14	1.36
	210	0.01	0.20	0.61	1.04	1.91	2.10
5 November	140	0	0.21	0.58	1.67	2.08	3.34
	210	0.21	1.05	1.60	2.22	3.28	4.00
Mean of 140		0.04	0.21	0.39	0.82	1.13	1.65
Mean of 210		0.16	0.57	0.92	1.32	1.93	2.44
SED (14 df) for comparing means of:							
lifting dates		0.07 (0.15)	0.15 (0.32)	0.12 (0.26)	0.16 (0.34)	0.17 (0.36)	0.24 (0.52)
cold units		0.05 (0.11)	0.11 (0.24)	0.09 (0.19)	0.11 (0.24)	0.12 (0.26)	0.17 (0.34)
lifting date x cold units		0.11 (0.23)	0.22 (0.47)	0.17 (0.37)	0.22 (0.47)	0.24 (0.51)	0.34 (0.73)

LSDs at 5% are given in brackets.

Unmarketable yields were low as a proportion of the marketable yield. Although unmarketable yields were high for the last lifting date total marketable yield was also high.

Table 5: Number of Class I sticks and number of shoots removed ('trashed') per 15 crowns.

		Cumulative Number of Sticks						Total No. of Shoots Removed
		Harvest Date						
Treatment		1	2	3	4	5	6	
17 September	140	1	1	1	1	2	2	45
	210	10	24	32	35	43	50	108
1 October	140	2	4	8	12	18	32	128
	210	5	26	47	59	70	83	146
15 October	140	5	17	24	47	62	77	154
	210	6	23	35	60	75	81	189
5 November	140	5	23	76	109	125	136	217
	210	28	69	93	110	116	116	249
Mean of 140		3	11	27	43	52	62	136
Mean of 210		12	36	52	66	76	83	173

The number of Class I sticks was highest for the 5 November lifting date. For crowns lifted on 1 October and given 210 cold units, and lifted on 15 October and given 140 and 210 cold units the number of Class I sticks were similar. The number of weak shoots removed at weekly intervals was generally higher where the crowns had received 210 cold units.

The mean weights of Class I and marketable sticks are given in Table 6.

Table 6: Mean weight of Class I and marketable sticks (g) - averaged over all harvests.

Lifting Date	140 Cold Units		210 Cold Units	
	Class I	Marketable	Class I	Marketable
17 September	40	37	61	48
1 October	40	46	70	57
15 October	63	58	75	62
5 November	79	72	87	69

Mean stick weights increased as lifting date was delayed. Class I sticks were heavier where the crowns had been given 210 cold units.

Year 2 (1997)

The crowns were kept in the cold store until the appropriate number of cold units had been provided, Table 7.

Table 7: Summary of planting and first harvest dates.

Cold Unit Treatments	Lifted on 8 September		Lifted on 22 September	
	'Planted'	First Harvest	'Planted'	First Harvest
70 cold units	22 September	22 October	3 October	28 October
140 cold units	3 October	1 November	13 October	15 November
70 cold units + gibberellin	22 September	19 October	3 October	28 October
140 cold units + gibberellin	3 October	27 October	13 October	10 November

The first rhubarb was pulled in late October from the crowns lifted in the field on 8 September, but yield and quality were poor. Crown size was good and the crowns had not been harvested during 1997. Treatment of the crowns with gibberellin after planting in the forcing shed advanced the date of first harvest by an average of three days.

The harvest dates for each treatment are presented in Table 8.

Table 8: Harvest dates (meaned for the 3 replicates).

Treatment	Harvest Number					
	1	2	3	4	5	6
8 September						
70 cold units	22 Oct	29 Oct	5 Nov	12 Nov	19 Nov	25 Nov
140 cold units	1 Nov	7 Nov	15 Nov	20 Nov	28 Nov	5 Dec
70 cold units + GA	19 Oct	25 Oct	1 Nov	8 Nov	15 Nov	20 Nov
140 cold units + GA	27 Oct	3 Nov	10 Nov	17 Nov	23 Nov	1 Dec
22 September						
70 cold units	28 Oct	5 Nov	12 Nov	19 Nov	25 Nov	1 Dec
140 cold units	15 Nov	20 Nov	28 Nov	6 Dec	13 Dec	16 Dec
70 cold units + GA	28 Oct	5 Nov	12 Nov	19 Nov	25 Nov	3 Dec
140 cold units + GA	10 Nov	16 Nov	23 Nov	30 Nov	8 Dec	12 Dec

Class I yields are given in Table 9.

Table 9: Class I yields (kg/15 crowns).

Treatment	Cumulative Class I Yield (kg/15 crowns) Harvest Number					
	1	2	3	4	5	6
8 September						
70 cold units	0.09	0.11	0.16	0.19	0.19	0.19
140 cold units	0.34	1.01	1.57	1.94	2.16	2.21
70 cold units + GA	0.37	0.49	0.65	0.69	0.69	0.69
140 cold units + GA	0.39	1.56	2.68	3.10	3.12	3.12
22 September						
70 cold units	0.01	0.13	0.28	0.28	0.28	0.28
140 cold units	0.0	0.39	0.59	1.11	1.55	1.55
70 cold units + GA	0.01	0.32	0.45	0.48	0.50	0.50
140 cold units + GA	0.01	0.56	1.51	2.33	2.70	3.19
SED (14 df) for comparing means of:						
lifting date	0.06 (0.12)	0.21 (NS)	0.36 (NS)	0.47 (NS)	0.54 (NS)	0.55 (NS)
cold units	0.06 (NS)	0.21 (0.45)	0.36 (0.77)	0.47 (1.01)	0.54 (1.16)	0.55 (1.19)
GA	0.06 (NS)	0.21 (NS)	0.36 (NS)	0.47 (NS)	0.54 (NS)	0.55 (NS)

LSDs at 5% are given in brackets. NS = Not significant.

The Class I yields were disappointingly low even where the crowns had been given 140 cold units plus gibberellin. The Class I yields were similar for both lifting dates after the first harvest. The main reason for downgrading was lack of stick thickness.

Marketable yields are given in Table 10.

Table 10: Marketable yields (kg/15 crowns).

Treatment	Cumulative Marketable Yield (kg/15 crowns) Harvest Number					
	1	2	3	4	5	6
8 September						
70 cold units	0.31	0.44	0.78	0.92	0.96	0.99
140 cold units	0.59	1.73	2.97	4.06	4.73	5.21
70 cold units + GA	0.86	1.21	1.73	2.02	2.10	2.16
140 cold units + GA	0.85	3.03	5.42	6.95	7.79	8.51
22 September						
70 cold units	0.18	0.48	0.82	0.90	9.77	1.05
140 cold units	0.19	1.06	1.95	2.78	3.99	4.34
70 cold units + GA	0.17	0.80	1.09	1.26	1.51	1.64
140 cold units + GA	0.20	1.32	3.07	4.49	6.03	7.11
SED (14 df) for comparing means of:						
lifting date	0.11 (0.24)	0.31 (0.67)	0.50 (NS)	0.73 (NS)	0.89 (NS)	1.01 (NS)
cold units	0.11 (NS)	0.31 (0.67)	0.50 (1.07)	0.73 (1.56)	0.89 (1.91)	1.01 (2.17)
GA	0.11 (NS)	0.31 (NS)	0.50 (1.07)	0.73 (NS)	0.89 (NS)	1.01 (NS)

LSDs at 5% are given in brackets. NS = Not significant.

The marketable yields were also disappointing, but higher where the crowns had been given 140 cold units plus gibberellin. Although the red coloration was good the stick thickness was poor. The two lifting dates gave similar results after the first two harvests.

Unmarketable yield is given in Table 11.

Table 11: Unmarketable yields (kg/15 crowns).

Treatment	Cumulative Unmarketable Yield (kg/15 crowns) Harvest Number					
	1	2	3	4	5	6
8 September						
70 cold units	0.13	0.31	0.73	1.07	1.22	1.30
140 cold units	0.51	0.84	1.21	1.51	1.90	2.04
70 cold units + GA	0.11	0.33	0.62	0.82	0.98	1.09
140 cold units + GA	0.36	0.93	1.33	1.57	2.13	2.42
22 September						
70 cold units	0.11	0.27	0.51	0.59	0.75	0.78
140 cold units	0.08	0.25	0.50	0.56	1.13	1.50
70 cold units + GA	0.17	0.40	0.53	0.68	0.89	0.95
140 cold units + GA	0.15	0.38	0.64	0.87	1.26	1.79
SED (14 df) for comparing means of:						
lifting date	0.05 (0.11)	0.08 (0.17)	0.09 (0.20)	0.11 (0.22)	0.15 (0.32)	0.18 (0.39)
cold units	0.05 (0.11)	0.08 (0.17)	0.09 (0.20)	0.11 (0.22)	0.15 (0.32)	0.18 (0.39)
GA	0.05 (NS)	0.08 (NS)	0.09 (NS)	0.11 (NS)	0.15 (NS)	0.18 (NS)

LSDs at 5% are given in brackets. NS = Not significant.

Overall, unmarketable yields were low and although higher for the 140 cold unit treatments they were similar irrespective of whether the crowns had been treated with gibberellin.

The number of Class I sticks and number of shoots trashed is given in Table 12.

Table 12: Number of Class I sticks and number of shoots removed ('trashed') per 15 crowns.

Treatment	Cumulative Number of Class I Sticks Harvest Number						Total No. of Shoots Removed
	1	2	3	4	5	6	
8 September							
70 cold units	1	2	2	3	3	3	103
140 cold units	4	13	20	25	28	29	229
70 cold units + GA	6	8	10	11	11	11	140
140 cold units + GA	5	20	36	42	42	42	322
22 September							
70 cold units	1	2	3	4	4	4	119
140 cold units	1	5	8	16	25	25	187
70 cold units + GA	1	5	7	7	7	7	156
140 cold units + GA	1	7	18	28	33	45	215

The number of Class I sticks was low, but highest where crowns had been given 140 cold units plus gibberellin treatment.

The number of small shoots removed was also increased where the crowns had been given more cold units combined with gibberelin.

The mean weights of Class I and marketable sticks are given in Table 13.

Table 13: Mean weight of Class I and marketable sticks (g) - averaged over all harvests.

Treatment	8 September		22 September	
	Class I	Marketable	Class I	Marketable
70 cold units	62	38	70	46
140 cold units	76	54	62	50
70 cold units + gibberellin	63	46	72	46
140 cold units + gibberellin	74	56	71	57

Mean weights of Class I sticks were higher where the crowns had been given 140 cold units for the first lifting date, but were similar for all treatments from the second lifting date. Marketable stick lengths were similar for both lifting dates.

Year 3 (1998)

The crowns were kept in the cold store until the appropriate number of cold units had been provided, Table 14.

Table 14: Summary of planting and first harvest dates.

Cold Unit Treatments	Planted	First Harvest	
		- GA	+ GA
140 cold units @ 1 °C	13 Oct	17 Nov	9 Nov
210 cold units @ 1 °C	20 Oct	28 Nov	24 Nov
140 cold units @ 3 °C	16 Oct	22 Nov	17 Nov
210 cold units @ 3 °C	26 Oct	5 Dec	30 Nov

The first rhubarb was pulled on 9 November from the crowns lifted in the field and exposed to 1 °C to accrue 140 cold units. Treatment of the crowns with gibberellin after planting in the forcing shed advanced the date of first harvest by an average of six days.

The harvest dates for each treatment are presented in Table 15.

Table 15: Harvest dates (meaned for the 3 replicates).

Treatment	Harvest Week					
	1	2	3	4	5	6
No Gibberellin						
140 cold units @ 1 °C	17 Nov	24 Nov	30 Nov	8 Dec	14 Dec	21 Dec
210 cold units @ 1 °C	28 Nov	6 Dec	12 Dec	19 Dec	28 Dec	2 Jan
140 cold units @ 3 °C	22 Nov	28 Nov	6 Dec	12 Dec	19 Dec	28 Dec
210 cold units @ 3 °C	5 Dec	11 Dec	18 Dec	27 Dec	1 Jan	8 Jan
Gibberellin						
140 cold units @ 1 °C	9 Nov	17 Nov	24 Nov	30 Nov	8 Dec	14 Dec
210 cold units @ 1 °C	24 Nov	30 Nov	8 Dec	14 Dec	21 Dec	30 Dec
140 cold units @ 3 °C	17 Nov	24 Nov	30 Nov	8 Dec	14 Dec	21 Dec
210 cold units @ 3 °C	30 Nov	8 Dec	14 Dec	21 Dec	30 Dec	4 Jan

The treatment structure meant that some treatments were unlikely to be ready for harvesting during November due to the duration of cold storage. However useful comparisons between storage temperatures and duration would indicate the effect on yield and quality. This could then be extrapolated for slightly earlier lifted crowns.

The Class I yields are presented in Table 16.

Table 16: Class I yields (kg/15 crowns).

Treatment	Cumulative Class I Yield (kg/15 crowns) Harvest Week					
	1	2	3	4	5	6
No Gibberellin						
140 cold units @ 1 °C	874	1769	3846	4678	4964	5044
210 cold units @ 1 °C	2056	5275	6907	7842	8192	8457
140 cold units @ 3 °C	737	2783	4863	5308	5400	5664
210 cold units @ 3 °C	1186	3244	5060	6527	7314	7667
Gibberellin						
140 cold units @ 1 °C	3386	5718	7626	9948	10336	10443
210 cold units @ 1 °C	1628	6673	7940	9067	9299	9324
140 cold units @ 3 °C	882	2224	5112	5928	6538	6652
210 cold units @ 3 °C	1128	3475	5817	6513	7228	7369
SED (14 df) for comparing mean of:						
cold units/storage temp/GA	265 (569)	483 (1037)	540 (1157)	575 (1234)	632 (1355)	654 (1403)
all 2 way interactions	375 (805)	683 (1466)	763 (NS)	814 (1746)	893 (1916)	925 (1984)
all treatments	531 (1138)	967 (NS)	1079 (NS)	1151 (NS)	1263 (NS)	1308 (NS)

LSDs at 5% are given in brackets. NS = Not significant.

At all the harvests there were significant differences between store temperature and the use of gibberellin. The highest earliest yields were from where crowns had been stored at 1 °C to accumulate 140 cold units and given gibberellin. Total Class I yields at the end of the harvest period were generally higher where the crowns had been stored at 1 °C and given gibberellin.

The marketable yields are presented in Table 17.

Table 17: Marketable yields (kg/15 crowns).

Treatment	Cumulative Marketable Yield (kg/15 crowns) Harvest Week					
	1	2	3	4	5	6
No Gibberellin						
140 cold units @ 1 °C	1727	2725	5388	7743	9265	10273
210 cold units @ 1 °C	2297	7096	10194	12429	14294	15810
140 cold units @ 3 °C	1134	4290	7338	9596	10830	12216
210 cold units @ 3 °C	1811	5004	7999	10581	12530	14409
Gibberellin						
140 cold units @ 1 °C	4433	7507	9761	13143	15451	16927
210 cold units @ 1 °C	1793	8652	11466	14283	15577	17285
140 cold units @ 3 °C	1715	3206	7648	9920	12051	12867
210 cold units @ 3 °C	1861	5513	10101	12662	15012	16401
SED (14 df) for comparing mean of:						
cold units/storage temp/GA	368 (790)	693 (1487)	779 (1672)	945 (2028)	999 (2142)	1025 (2199)
all 2 way interactions	521 (1117)	980 (2103)	1102 (NS)	1337 (NS)	1412 (NS)	1450 (NS)
all treatments	736 (NS)	1386 (NS)	1559 (NS)	1891 (NS)	1997 (NS)	2050 (NS)

LSDs at 5% are given in brackets. NS = Not significant.

Marketable yields were significantly affected by length of cold storage with lower yields where crowns were given only 140 cold units unless treated with gibberellin.

The unmarketable yields are presented in Table 18.

Table 18: Unmarketable yields (kg/15 crowns).

Treatment	Cumulative Unmarketable Yield (kg/15 crowns) Harvest Week					
	1	2	3	4	5	6
No Gibberellin						
140 cold units @ 1 °C	174	230	453	1158	1493	1640
210 cold units @ 1 °C	28	600	796	1077	1190	1257
140 cold units @ 3 °C	37	180	447	939	1106	1211
210 cold units @ 3 °C	203	393	592	721	905	975
Gibberellin						
140 cold units @ 1 °C	166	600	674	912	1377	1685
210 cold units @ 1 °C	22	408	737	949	1112	1235
140 cold units @ 3 °C	269	318	655	1325	1610	1754
210 cold units @ 3 °C	168	638	1001	1217	1246	1246
SED (14 df) for comparing mean of:						
cold units/storage temp/GA	52 (NS)	81 (174)	103 (220)	127 (NS)	145 (NS)	188 (NS)
all 2 way interactions	74 (NS)	114 (NS)	145 (NS)	180 (386)	205 (NS)	265 (NS)
all treatments	105 (NS)	162 (NS)	205 (NS)	254 (NS)	289 (NS)	375 (NS)

LSDs at 5% are given in brackets. NS = Not significant.

Unmarketable yields were generally low and similar for all treatments.

The number of Class I and marketable sticks are presented in Table 19.

Table 19: Number of Class I sticks and marketable (in parentheses) per 15 crowns.

Treatment	Cumulative Class I Sticks Harvest Week					
	1	2	3	4	5	6
No Gibberellin						
140 cold units @ 1 °C	10 (23)	19 (33)	42 (67)	52 (106)	56 (132)	57 (151)
210 cold units @ 1 °C	20 (24)	51 (85)	68 (130)	77 (165)	81 (197)	84 (224)
140 cold units @ 3 °C	7 (13)	30 (56)	51 (97)	56 (136)	57 (159)	60 (187)
210 cold units @ 3 °C	13 (24)	33 (66)	52 (110)	71 (150)	80 (180)	84 (212)
Gibberellin						
140 cold units @ 1 °C	32 (46)	53 (80)	72 (105)	98 (148)	102 (186)	103 (212)
210 cold units @ 1 °C	15 (18)	59 (93)	75 (137)	87 (175)	89 (199)	90 (230)
140 cold units @ 3 °C	9 (23)	26 (43)	52 (91)	61 (125)	68 (163)	69 (179)
210 cold units @ 3 °C	12 (24)	37 (73)	60 (138)	67 (178)	75 (218)	77 (241)

The number of Class I sticks were higher were the crowns had been stored at 1 °C and given gibberellin. Without gibberellin the number of Class I sticks was higher where the crowns had been given 210 cold units and unaffected by storage temperature.

There were significant differences between the duration of cold storage with higher numbers of marketable sticks from where the crowns had been stored to provide 210 cold units.

The mean weight of Class I and marketable sticks are given in Table 20.

Table 20: Mean weight of Class I and marketable sticks (g) - averaged over all harvests.

Treatment	Class I		Marketable	
	- GA	+ GA	- GA	+ GA
140 cold units @ 1 °C	89	101	68	80
210 cold units @ 1 °C	101	104	71	75
140 cold units @ 3 °C	94	96	65	72
210 cold units @ 3 °C	91	96	68	68

The mean weight of Class I sticks was similar for all treatments. The mean weight of marketable sticks was lower than for the Class I sticks but similar for all treatments. Using gibberellin on the crowns which had only received 140 cold units appeared to produce heavier sticks.

DISCUSSION

The autumn of 1996 was particularly mild and soil temperatures were on average above 10°C at 10 cm depth for much of October. The crowns lifted on 15 October received only 10 natural cold units compared to those crowns lifted on 5 November which received 31 cold units. The natural cold unit requirement of Timperley Early is 140, based on a soil temperature at 10 cm at 9 am accumulated from 1 October.

Crowns lifted in mid September and 1 October produced sticks from mid November onwards. Early lifted crowns which received only 140 cold units gave lower yields than when they had remained in the cold store longer to accumulate more cold units. For crowns lifted in mid October and early November yields were similar for both the 140 and 210 cold unit treatments.

Crop quality was poor for the first two lifting dates and although the sticks had good length they were narrow and considered Class II. Colour was good. For the two later lifting dates crop quality was superior with wider sticks with good red coloration but maturity was outside the required period.

In the second year the plants were still actively growing in September and the decision was made to mow the leaves off the crowns to enable easier lifting. The plants were flailed one week before lifting and prior to placing them into the cold store the remains of all petioles were carefully removed to reduce the risk of *Botrytis* developing during forcing.

The crowns used in the trial had not been harvested during 1997 and they were considered to be ideal for forcing. They were lifted carefully and placed as a single layer in bulk bins for cold storage.

The first harvest was in late October and this was at the right time for the intended marketing period. The sticks produced were of good red coloration but petiole thickness was poor and although it was hoped that thickness would increase for subsequent flushes it did not.

Class I yields were poor and although higher where the crowns had been given 140 cold units plus gibberellin they were well below those required to make the technique viable. The marketable yields followed a similar pattern with the best treatment of 140 cold units plus gibberellin producing 8.5 kg/15 crowns. This result was considerably better than that obtained from the 17 September lifting in 1996. The highest total yield in 1997 was only 10.9 kg/15 crowns approximately half that normally expected for Timperley Early.

The reasons for the poor yields are unclear but it is unlikely to be the size of crowns as these were of a good size and quality. The main reason could be due to the number of cold units given to the crowns. Much higher numbers may be required to boost petiole thickness so that more become marketable, particularly into the premium Class I grade.

The industry reported a general lack of vigour of Timperley Early lifted in late November 1997 for harvesting during January 1998. Although the crowns had received sufficient 'normal' cold units in the field many growers claimed that the bud size was small and yield potential looked poor. Records of soil temperatures at 10°C depth showed that although crowns had received in excess of 140 units soil temperatures had rarely been below 3°C. Rhubarb crowns may need to be exposed to a minimum temperature for a period of time to fully break dormancy and the use of a cold store set at 3°C may not have been sufficiently low to fully break dormancy and allow the plants to reach their full yield potential in the forcing shed. The cold store may need to be set at a lower temperature as there might be an interaction between exposure to a minimum temperature and duration rather than a straight accumulation of cold units. However, during 1997 many fields of Timperley Early flowered due to the weather conditions and this may have been the primary cause of smaller buds and lower yield potential.

In 1998, the plants were still actively growing in September but had not flowered during the summer in contrast to the previous year. The leaves were mown off a week before lifting with the petiole bases carefully removed prior to storage. Crowns were carefully placed as a single layer in bulk bins for cold storage at 1 °C and 3 °C.

The first harvest was at the end of the first week of November as the forcing environment had been kept at 10-11 °C to ensure that petiole quality was maximised. Higher temperatures could have resulted in paler and smaller petioles which had predominated in the 1997 trial.

The Class I yields in 1998 were higher than had been achieved in 1997. The best treatment yielded just over 10 kg from 15 crowns where the crowns had been stored at 1 °C and where gibberellin was used. Class I yields for crowns stored at 1 °C for 140 cold units but without gibberellin were 50% lower. Similar yields were produced where crowns had received 210 cold units at 1 °C and when stored at 3 °C irrespective of gibberellin treatment. However gibberellin treatment did advance first harvest date by about 6 days.

Marketable yields produced during November were highest where crowns had been stored at 1 °C and given 140 cold units. Crowns stored at 3 °C for 140 cold units gave on average over 8 kg/15 crowns by the end of November but less total yield at the end of the 6 week period. Unmarketable yields were low and generally similar for all treatments.

This trial indicates that cold units provided in cold stores are not directly equivalent to those accumulated naturally despite being continually at the low temperature. Crowns which received 140 cold units by storing at 1 °C benefited from gibberellin treatment which allowed harvesting to start from early/mid November. Crowns stored at 3 °C took longer to accumulate cold units and this temperature did not appear sufficient to fully

overcome dormancy of the crowns. This confirms the findings in 1997 when yields were very low following storage at 3 °C, with some evidence to suggest that flowering of the plants in the field during the summer also affected yield and quality.

Determining the economic viability of supplying artificial cold units to crowns in September and early October is difficult to calculate. The options available to growers are either to install refrigeration units into insulated forcing sheds or to chill the crowns in bulk bins in cold stores prior to bedding into forcing sheds. The disadvantages of this approach would be the double handling of crowns, or the investment in refrigeration units for cooling forcing sheds to below 3 °C.

An alternative would be to place crowns into bulk bins, place in cold store to supply cold units and then to force 'in-situ'. The advantage of this technique is that the crowns would only be handled once and by stacking bulk bins in layers and removing part of the sides of the bulk bins the cropped area can be increased.

Finally, the economic viability of the technique will depend on the market price. Traditional wholesale market prices would be insufficient to cover the additional costs but by 'adding value' to the product by making it into a prepared food item, a price premium should be obtained and potentially more of the rhubarb produced could be marketed.

CONCLUSIONS

1. The mechanism of breaking dormancy artificially in rhubarb is very complex.

2. Only best quality crowns should be used for early lifting and cold storage with petioles removed prior to storage.

3. Crowns should be carefully lifted into a cold store maintained at 1 °C to accumulate artificial cold units for a minimum of 16 days and then treated with gibberellin.

4. Crowns stored for longer at 1 °C may not benefit from gibberellin treatment as they may have received sufficient cold to overcome dormancy.

5. Crowns should not be stored at 3 °C as this delays the start of harvesting , appears insufficient to properly overcome dormancy and reduces Class I yield with a higher proportion of thinner (Class II) sticks produced.

6. From this study it looks as though it is possible to extend the forced rhubarb season to early November by lifting crowns in early September, placing them into into cold stores at 1 °C for a minimum of 16 days and then treating with gibberellin.

7. Further research is required to look at the optimal storage temperature and lifting date to encourage harvesting into early November and to undertake an economic assessment of the techniques viability.

RECOMMENDATIONS FOR FUTURE WORK

Crowns should be lifted in early and mid September and then stored at 1°C and 3°C for different periods to provide 140 and 210 cold units to determine whether there is an interaction between temperature and duration of storage. Half the crowns should then be treated with gibberellin at the recommended rate to determine whether gibberellin can reduce the need for prolonged storage without the crowns receiving any field cold units.

APPENDIX I: MEAN PLOT AREA FOR EACH TREATMENT

Year 1 (1996)

Treatment	Plot Area (m^2)	
	140	210
17 September	1.30	1.30
1 October	1.30	0.78
15 October	1.17	0.91
5 November	1.04	1.17

Year 2 (1997)

Treatment	Plot Area (m^2)	
	8 September	22 September
70 cold units	1.27	1.08
140 cold units	1.50	1.35
70 cold units + GA	1.61	1.34
140 cold units + GA	1.64	1.49

Year 3 (1998)

Treatment	- GA	+ GA
140 cold units @ 1 °C	0.91	0.95
210 cold units @ 1 °C	0.84	0.82
140 cold units @ 3 °C	0.90	0.87
210 cold units @ 3 °C	1.0	1.04