Project title:	Climatic effects on the vernalization and curd growth of winter cauliflower and subsequent fluctuations in supply
Project number:	HortLINK195/ HL0131/ CSA4462/ FV212
Project Leader:	Dr D C E Wurr
Final Report:	Covering years 1-4
Location of project:	Cornwall, Lincolnshire, Kent and Warwickshire
Project co-ordinator:	Mr Phillip Effingham
Government sponsor:	DEFRA
Date project began:	1 April 1998
Date completed:	31 March 2002

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CONTENTS

PRACTICAL SECTION FOR GROWERS

Background, Scope and Objectives of Project

Extremes of weather and effects of climate change have resulted in irregular production of winter cauliflower from UK crops with widely fluctuating volumes of product. Forecasts of production patterns are inaccurate, leading to uncertainty of UK supplies and reliance on imported crops. This often results in oversupply to the market with UK crops subsequently suffering in both volume and price.

Unless the prediction of the timing of winter cauliflower is substantially improved it is likely that the gains made in import substitution over the last few years will be lost. There is an urgent need for information indicating the overall pattern of supply of winter cauliflower throughout the production season. This project has tried to understand how weather conditions influence the initiation and growth of winter cauliflower curds. It has assessed the timing of maturity of the whole range of genotypes used in winter cauliflower production relative to the varieties sampled in detail and determined the effect of frost during curd growth on curd quality at maturity.

Its objective has been to develop a predictive system to indicate when, and in what quantity, the UK winter cauliflower industry can supply the market with produce. This will enhance the competitive position of the industry, thereby helping more rational marketing and maximising the proportion of the market supplied by UK produce.

Summary of Results

- A prototype software indicator system called ‘WINTER CAULIFLOWER’ has been developed to run within the MORPH system to take account of weather, location and varietal type to indicate patterns of supply of winter cauliflower.

- HDC have agreed funding of additional work to fully validate ‘WINTER CAULIFLOWER’ and develop it into commercial software for the benefit of all HDC members in the UK.

- Light and temperature conditions in Cornwall and Lincolnshire were quite different and influenced crop growth and development. Mean air temperatures in Cornwall were higher than in Lincolnshire from October through to March or April though in summer Cornwall was cooler than in Lincolnshire. Except for February and April 1999 solar radiation in Cornwall was always higher than in Lincolnshire and on average was 33% higher.

- Simple linear models using date of planting were developed to estimate the time of curd initiation and were incorporated into ‘WINTER CAULIFLOWER’.

- Differences in the time of maturity were largely accounted for by differences in the time from curd initiation to maturity suggesting that the key to predicting patterns of crop maturity will be to use an appropriate model of curd growth.

- The pattern of curd growth differed between varieties. Separate models for each variety, based on day-degrees, described curd growth much better than those using solar radiation and were incorporated into 'WINTER CAULIFLOWER'.

- Data on the time of crop maturity of 62 varieties, relative to Medaillon and Renoir, were collected from three locations and are being used in 'WINTER CAULIFLOWER' to adjust predictions made from planting where no curd samples are taken after curd initiation.

- In order for 'WINTER CAULIFLOWER' to take account of new varietal introductions, adjustments relative to the standard varieties were averaged for each varietal type and site of production and varieties were aggregated into half-monthly groupings based on time of maturity.

- A single frost model based on combined data from Alpen, Medaillon and Renoir was devised to adjust crop volumes following severe frosts.

- Validation testing in 84 commercial crops during the 2001/02 winter showed that the prediction system worked well with specific varieties and generally worked well in Cornwall. There was a need for specific varietal adjustments to predictions, particularly in Lincolnshire. In Cornwall, local suggestions for site-specific adjustments consistently improved the accuracy of predictions.

Action points for growers

- Prototype software 'WINTER CAULIFLOWER' has now been produced and has undergone initial validation. HDC funding will be used to further validate the model and develop it into commercial software made available through HDC by September 2004.

- The pattern of curd growth differed between varieties with Medaillon and Renoir showing curvature while that of Tivoli was more linear. Separate models for each variety, based on day-degrees, described curd growth much better than those using solar radiation and were incorporated into 'WINTER CAULIFLOWER'.

- Data on the time of crop maturity of 62 varieties, relative to Medaillon (Roscoff) (Table 5) and Renoir (Roscoff x Walcheren), were collected from three locations and are being used in 'WINTER CAULIFLOWER' to adjust predictions made from planting where no curd samples are taken after curd initiation.

- In order for 'WINTER CAULIFLOWER' to take account of new varietal introductions, adjustments to the time of maturity were averaged for each varietal type and site of production. Varieties were aggregated into half-monthly maturity groupings to indicate when these groupings matured relative to Renoir (Table 6).

- The mean effect of delaying planting of Medaillon by 39 days was to delay maturity by 10 days. In Renoir delaying planting by 41 days on average delayed maturity by 9 days while in Tivoli delaying planting by 40 days delayed maturity by 11 days.

- A single frost model based on combined data from Alpen, Medaillon and Renoir, which responded similarly to freezing conditions, was devised to adjust crop volumes following severe frosts. There was only slight curd damage at -5^{o}C but at -8^{o}C there was significant damage, particularly after 72 h freezing and frost damage increased with curd size.

- Validation testing in 84 commercial crops in Cornwall, Kent and Lincolnshire during the 2001/02 winter showed that the prediction system worked well with specific varieties and generally worked well in Cornwall. It was important to re-run predictions using local observed temperature data. Local site-specific adjustments also improved the accuracy of predictions. The difference between predicted and actual dates of cutting was seven days or less in 9 of 12 single sample varieties and in 9 of 15 varieties using multiple samples. Specific adjustments appear likely to be needed for 6 varieties in all locations and for 2 varieties in Kent and Lincolnshire.

Practical and financial anticipated benefits

If the timing of production of the crop is not addressed there is a potential loss to the UK industry of approximately £10 million a year because of replacement by imports. With better prediction of crop timing, cauliflower suppliers will be more accurate in their volume estimates to the supermarket buyer, who will be able to balance his requirement with imports as necessary. This will result in more stable prices and the whole of the UK marketable crop could be moved to meet supermarket requirements resulting in an increase of about £1.5 million of crop marketed annually. In addition, the export of winter cauliflower is increasing by approximately 25-30% each year, currently amounting to £2.5 million per annum. On the basis of these figures the benefit from this work would amount to at least £14 million a year for the foreseeable future.

MILESTONES

Cropping Year 1

Objective		*Primary milestones*	*Complete*
1.1	Mar 1999	Complete crop sampling to fix time of curd initiation.	Yes
2.1	Jun 1999	Complete crop sampling to determine curd growth rate.	Yes
1.2	Jun 1999	Complete initiation data analyses to determine vernalization response and timing of curd initiation.	Yes
4.1	Apr 1999	Complete screening for frost damage.	Yes
		Secondary milestones	
2.2	Sep 1999	Complete data analyses on curd growth rate.	Yes
3.1	Jul 1999	Complete comparison of test varieties with wide range of genotypes.	Yes
5.1	Dec 1999	Assemble prototype model for vernalization and curd growth. Compare with other published models.	Yes

Cropping Year 2

Objective		*Primary milestones*	
1.3	Mar 2000	Complete crop sampling to fix time of curd initiation.	Yes
2.3	Jun 2000	Complete crop sampling to determine curd growth rate.	Yes
1.4	Jun 2000	Complete second year's data analyses to determine vernalization response and timing of curd initiation.	Yes
4.2	Apr 2000	Complete screening for frost damage.	Yes
		Secondary milestones	
2.4	Sep 2000	Complete data analyses on curd growth rate.	Yes
3.2	Jul 2000	Complete comparison of test varieties with wide range of genotypes.	Yes
5.2	Dec 2000	Refine model for vernalization and curd growth. Compare with other published models.	Yes

Cropping Year 3

Objective		*Primary milestones*	
1/2.5	Nov 2001	Develop models from combined data.	Yes
3.3	Jul 2001	Produce ranking of timing of maturity of wide range of genotypes relative to test varieties.	Yes
4.3	Apr 2001	Develop indices showing how the proportion of curds of acceptable mature quality is affected by degree of frost	

		and curd growth stage when frosted.	Yes
5.3	Feb 2001	A prototype indicator system of patterns of supply of winter cauliflower in response to weather conditions will be developed.	Yes

Secondary milestones

1.6	Mar 2001	Complete crop sampling to fix time of curd initiation.	Yes
2.6	Jun 2001	Complete crop sampling to determine curd growth rate.	Yes
1.7	Aug 2001	Complete data analyses to determine vernalization response and timing of curd initiation.	Yes
2.7	Oct 2001	Complete data analyses on curd growth rate.	Yes
5.4	Mar 2001	Incorporate prototype indicator system into MORPH	Yes

Cropping Year 4

Objective *Primary milestones*

5.5	Dec 2001	Complete refinement of indicator system within MORPH.	Yes
5.6	Jan 2002	Complete test sampling of crops.	Yes
5.7	Mar 2002	Complete commercial assessments of curd maturity.	Yes
5.8	Mar 2002	Complete testing and calibration of indicator system.	Yes

Secondary milestones

1/2.8	Aug 2001	Establish crops for sampling to test prototype indicator system.	Yes

SCIENCE SECTION

Introduction

The UK winter cauliflower crop currently amounts to 7,000 ha, which is worth approximately £26 million at farm gate prices. The major supermarkets account for 70% of these sales from November through to May. Recent initiatives from within the Industry in developing packing facilities and production programmes have focused multiple buying on the UK crop, particularly from Kent and the South West from September to March. This was traditionally a heavy importing period and as a result of these initiatives, imports have been cut from 80% to 45% of total winter sales.

However, recent extremes of weather have resulted in more spasmodic production from UK crops with widely fluctuating volumes. During the shortages buyers have maintained continuity of supply by importing product from mainland Europe. Because present forecasts of production have no scientific base they are so inaccurate that the buyer frequently over-imports. This results in UK crops suffering in both volume and price because of an artificial oversupply. Supermarket buyers have declared that they want to maximise sourcing of UK product but are becoming very frustrated with the continually disrupted market place caused by imbalanced UK production and imports caused by inaccurate estimates of the volume of UK product (Anon., 1997). Unless the prediction of the timing of winter cauliflower is substantially improved it is likely that the gains made in import substitution over the last few years will all be lost, resulting in the UK winter cauliflower industry losing approximately 35% of their production worth £10 million per annum.

There is an urgent need for the information that this project has provided in order to deal with current variability in supply. It will indicate the overall pattern of supply of winter cauliflower throughout the production season. This will enable the supply of UK winter cauliflower to be managed and marketed to maximise the proportion of the market that is supplied by home product, which is two days fresher than cauliflower from Brittany and two and a half days fresher than product from Spain.

Our understanding of the effect of weather on the growth and development of cauliflowers has changed considerably in recent years. Work at HRI has shown how temperature affects vernalization, curd initiation and curd growth of early summer, summer and autumn cauliflower, with subsequent effects on curd maturity (Wurr, 1990; Wurr *et al*., 1990a, b; Wurr *et al*., 1993; Wurr *et al*., 1994, Fellows *et al*., 1999). This work has stimulated other efforts in the same area (Grevsen & Olesen, 1994; Pearson *et al*., 1994). More recently, there has also been work studying the vernalization of two Codebric selections of Roscoff cauliflower (Wurr & Fellows, 1998, Reeves *et al*. 2001). There has also been recent work on frost resistance of cauliflower (Fuller, 1993).

In this work crop physiological state and curd development have been related to light and temperature. Simple but robust models of vernalization and curd growth have been developed to indicate how the times of curd initiation and curd maturity are affected by weather. Results on the timing of maturity of the whole range of genotypes used in winter cauliflower production are scaled relative to the varieties sampled in detail.

Additionally, the ability of curds of different size to tolerate different levels of frost has been determined.

Objectives 1 and 2 Quantify the effects of light and temperature on vernalization, the timing of curd initiation and the rate of curd growth

Materials and Methods

In Cornwall seed of the varieties Medaillon (Roscoff) and Renoir (Roscoff x Walcheren) were raised by Fentongollen Farms to provide plants for five transplantings in years 1 and 2 and four transplantings in year 3. Crops were planted on David Simmons' farm near Scorrier between 10 June and 24 August and on Chris Osborne's farm near Mousehole between 14 June and 18 August.

In Lincolnshire seed of the varieties Medaillon (Roscoff) and Renoir (Roscoff x Walcheren) and Tivoli (Walcheren) were raised to provide plants for five transplantings in years 1 and 2 and four transplantings in year 3. Crops were planted on S C Shaw & Son's farm at Friskney between 29 June and 18 September and with two other growers (C Crunkhorn and HA Allen) between 27 June and 4 September. In Cornwall the primary site was always Simmons while in Lincs it was Crunkhorn (year 1) and Shaw (years 2 and 3) All crops were fertilized as commercial crops.

Crops were sampled by Alan Edmond in Cornwall and Sarah Edwards in Lincolnshire and dissected by Sara Redstone at Rosewarne and by Kate Dennett, Sally Minns and Katie Elder at HRI Kirton. In both locations sampling on the primary site took place every three weeks and on the secondary site every six weeks. Samples consisted of 10 plants taken in sequence from each plot. Adjacent samples were separated by a row of guard plants. When plants were small they were cut off just above ground level. As plants got larger only part of the plant was sampled. The upper part of the plant was cut off making sure that the growing point was within the sample with an adequate stalk of at least 3 cm beneath it for holding the plant during dissection.

Once curds were initiated a more detailed sample was taken. A photograph of the sample area was taken together with measurements of the height and diameter of each plant. Whole plants were dissected, recording details of numbers of leaves, apex diameter, magnification and state of the apex as vegetative or initiated. Thereafter, all further sampling only required sufficient of the plant to be cut off to contain the growing curd, whose weight, diameter, state (immature, mature or over-mature) were recorded together with indications of frost damage. As each crop approached maturity an assessment, based on 20 plants, was made of the number of plants capable of meeting a supermarket specification.

In addition, in year 3, at the third planting in both Lincolnshire and Cornwall samples of 40 curds were taken near to the time of 50% maturity and curd size was measured to determine the distribution of curd sizes.

Table 1. Monthly mean air temperature (°C) and solar radiation (MJ/m²/d).

Month	Mean air temperature (°C)						Solar radiation (MJ/m²/d)					
	1998-99		1999-2000		2000-2001		1998-99		1999-2000		2000-2001	
	Cornwall	Lincs	Cornwall	Lincs	Cornwall	Lincs	Cornwall	Lincs	Cornwall	Lincs	Cornwall	Lincs
June	13.9		13.7		14.4	13.4	16.2		20.8		20.0	12.7
July	15.0	16.3	16.5	17.5	15.4	14.6	15.3	12.7	20.3	13.6	19.6	13.0
August	15.6	15.6	15.8	16.5	16.0	16.8	17.1	14.3	14.9	9.4	15.4	14.9
September	15.1	14.1	14.8	15.8	14.6	14.7	10.2	8.4	12.1	7.9	10.6	8.3
October	12.2	10.3	11.7	10.3	11.0	9.9	6.3	5.4	6.9	4.9	6.4	4.5
November	9.1	4.8	8.7	7.8	8.1	6.5	3.8	3.1	4.2	2.3	3.4	2.3
December	8.1	4.8	7.7	3.7	7.5	5.1	2.2	1.7	2.1	1.5	2.1	1.4
January	7.8	5.0	6.1	4.6	5.5	2.9	2.7	2.4	3.3	1.9	2.8	2.2
February	7.4	4.6	7.9	5.7	6.6	3.9	4.2	5.0	5.0	3.3	5.9	3.6
March	7.8	7.6	7.7	7.2	7.4	5.1	9.4	7.8	9.7	5.6	7.0	6.1
April	10.2	9.5		6.1		7.5	12.0	12.2		8.2		9.3
May						10.1						11.7

Measures of solar radiation and temperature were taken by OLGA in Lincolnshire and Plymouth University in Cornwall using data loggers and transmitted electronically to HRI Wellesbourne, where they were checked and collated.

Results

Temperatures

Table 1 shows that in all three years of basic data collection mean air temperatures in Cornwall were higher than in Lincolnshire from October through to March or April. In summer Cornwall was cooler than in Lincolnshire. Except for February and April 1999 solar radiation in Cornwall was always higher than in Lincolnshire and on average was 33% higher.

Curd induction

The intention of this work was to develop models of curd induction in order to predict the time of curd initiation so that in conjunction with models of curd growth, it might be possible to directly predict the time of crop maturity. The rate of progress (*p*) through curd induction, is given by a function of temperature, *T*, which is itself a function of time, *t*.

$$\frac{dp}{dt} = f(T(t))$$

so that the end of the phase, here *tp*, is reached as follows

$$1 = k\int_0^{tp} f(T)dt$$

where *k* is a scaling parameter.

The function of temperature proposed was a continuous asymmetric function based on a gamma distribution (Fig.1), where α and β were constants.

$$f(T) = \frac{1}{\Gamma(\alpha)\beta^{\alpha}} T^{\alpha-1} e^{-\frac{T}{\beta}} \quad \text{for } T>0$$

To reduce the correlation between the parameter estimates and to give a more meaningful parameterization, the gamma distribution was redefined in terms of the mode, ζ, which is equal to $\beta(\alpha-1)$ and the distance from the mode to the points of inflexion, η, which is equal to $\beta\sqrt{(\alpha-1)}$.

Model fitting was carried with the Genstat 5 (Payne *et al.* 1993) computer package using hourly air temperatures and apex diameter data from dissections. The curd induction phase started at the end of the juvenile phase (defined as the time when the apex diameter was 0.2 mm) and continued until curd initiation, when the apex diameter was 0.6 mm.

Fig. 1. A gamma function.

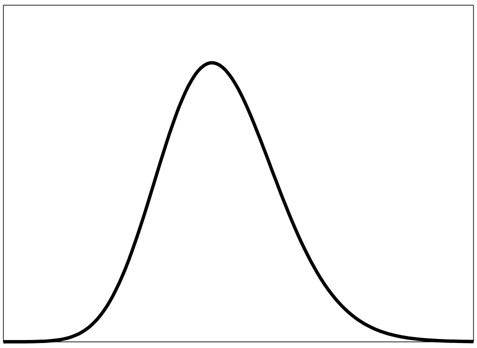


Table 2 shows results of fitting the model to data from each variety. In no case did the model provide an optimum solution, and these fits are the best achieved.

Table 2. The accuracy of curd induction models.

Variety	**% variance accounted for by model**	***Gamma* function**	
		ζ Mode or optimum	**η Spread**
Medaillon	69.4	9.72	1.68
Renoir	74.8	8.43	1.84
Tivoli	77.0	8.92	1.50

The model for Tivoli was reasonable, with the deviations in fit ranging from 1 to 16 days. However, the models for both Medaillon and Renoir showed a systematic lack of fit based on location and Fig. 2 shows results with Medaillon. The deviations in fit ranged from –12.7 to 21.2 days for the Cornwall crops and from –25.9 to 3.6 days for the Lincolnshire crops. A negative deviation means that initiation occurs later than predicted while a positive deviation means that initiation occurs earlier than predicted. Thus in Cornwall there is a trend towards initiation occurring earlier than predicted while the opposite is true in Lincolnshire.

The obvious difference between sites could be the light integral and Table 1 showed that mean solar radiation was 33% higher in Cornwall so there might be some sort of pattern in the relationship between the deviations in fit and the solar radiation. Figure 3(a) shows the deviations for the Medaillon model fit plotted against mean solar radiation over the entire curd induction phase but no relationship was evident. However, when the data were averaged over the seven days prior to curd initiation a slight positive trend in deviation increasing with solar radiation can be seen (Fig.

3(b)). Further analyses investigated more complex models incorporating solar radiation data in an attempt to predict the time of curd initiation but these did not improve the fit.

Fig. 2. Observed and fitted values for curd initiation of Medaillon (3 years' data).

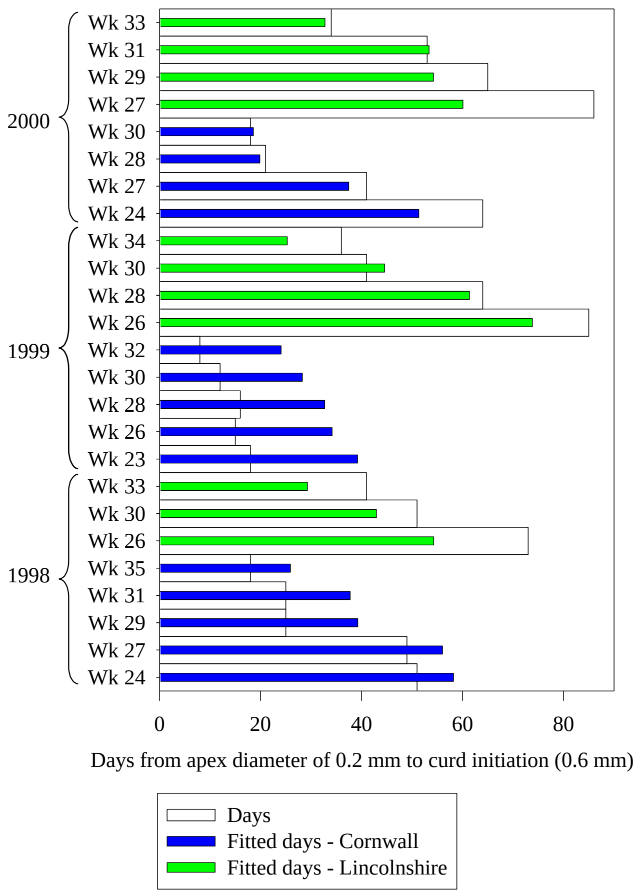
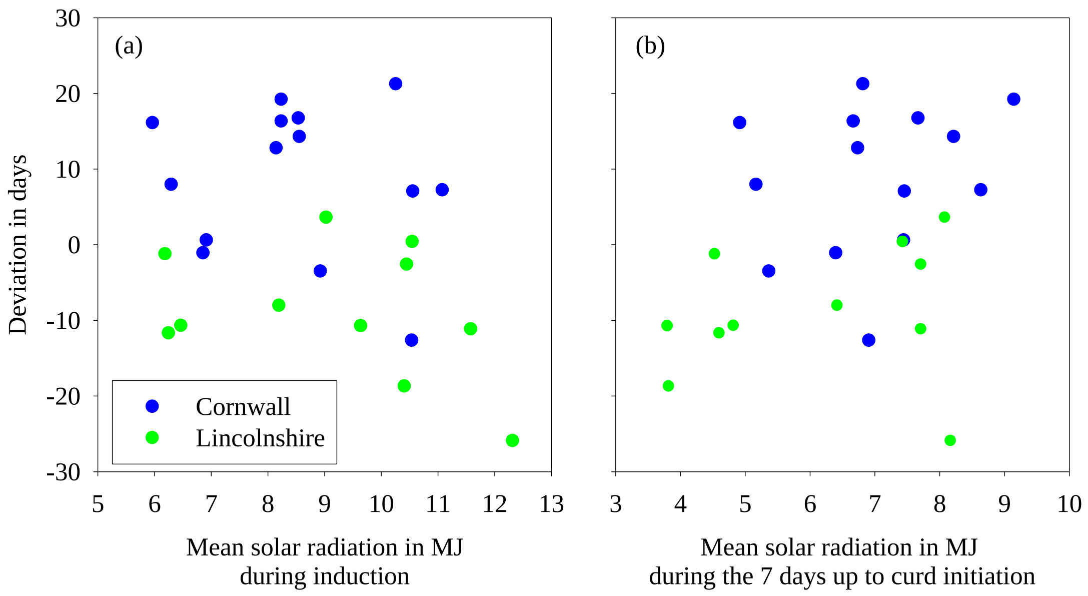


Fig. 3. Deviations in model fit for curd initiation of Medaillon plotted against mean solar radiation (3 years' data).



Another possible explanation of differences in curd induction between sites is that plant size at curd initiation differed and indeed, Wellington (1954) found that delaying transplanting reduced plant size, resulting in some plants remaining vegetative throughout the winter. This suggests that there may be a critical plant size before curd induction will begin. There was certainly a trend for plants to be larger in Cornwall than in Lincolnshire from plantings in 1998 and 1999 (Fig. 4). Figure 5, showing plots of temperature frequencies during the period of curd induction, supports the suggestion of a critical plant size, showing that Renoir planted in Cornwall in 1999 completed curd induction very rapidly.

Fig. 4. Plant size at curd initiation

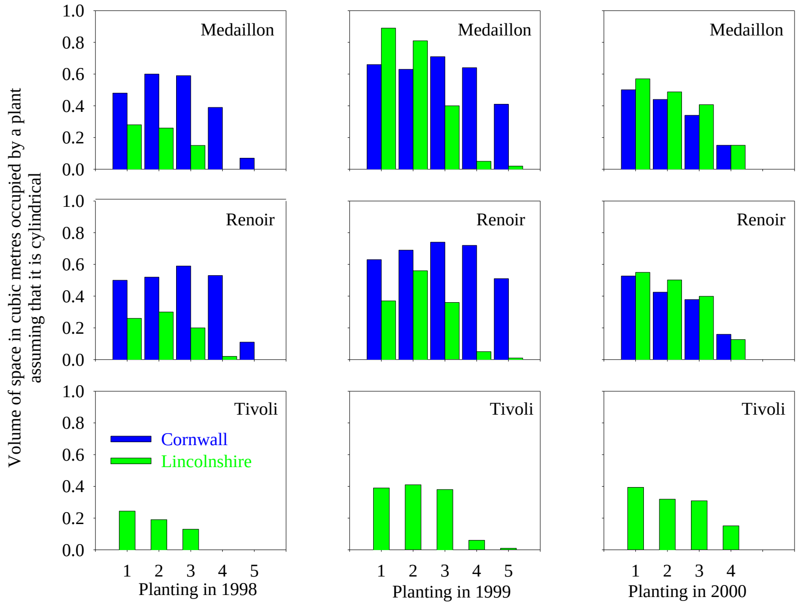
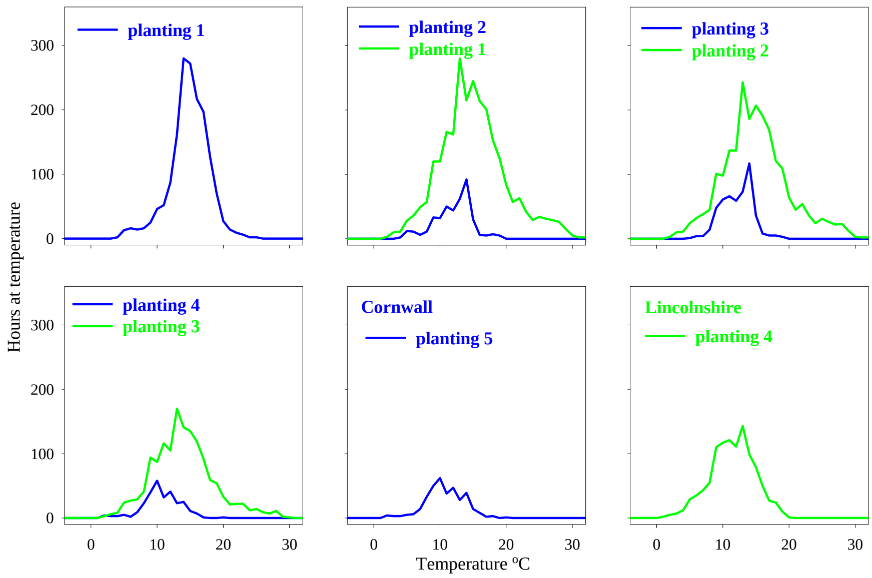
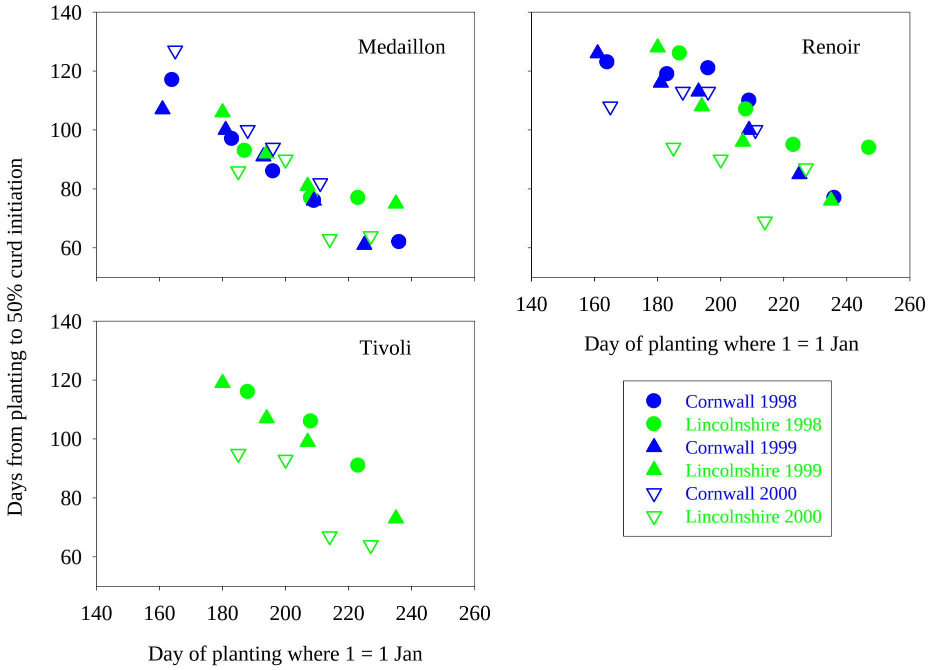


Fig. 5. Frequencies of hours at different temperatures during the period of curd initiation for Renoir crops planted in 1999. Cornwall is blue and Lincolnshire green.



Time of curd initiation

Fig. 6. Time from planting to curd initiation (3 years' data).



Thus the work on curd induction gives a reasonable estimate of the time of curd initiation but the data in Fig. 6, presenting time from planting to initiation plotted against planting date, shows a simpler, and possibly more reliable approach. Figure 6 shows that the time from planting to initiation declined with later planting. Linear regression analysis suggested that data from the 2000-2001 season differed from the previous two seasons, so models were fitted omitting these data. For simplicity and to use the most robust model for predictions, a linear model was used.

$$days = bx + c$$

where x is the day of planting and days are from planting to curd initiation. Figure 7 shows the fitted relationships and these will be used in the prediction software 'WINTER CAULIFLOWER' resulting from this project to estimate the time of initiation when no crop sample is taken after curd initiation.

Curd maturity and curd growth

Figure 8 shows how the day of 50% maturity varied in relation to the day of 50% curd initiation over all three years. In Medaillon there were major differences between sites in every year and still considerable differences between years at the same site. In Renoir, differences between sites were smaller while Tivoli, grown only in Lincs, was relatively consistent. Figure 9 shows how differences in the time of maturity were largely attributable to differences in the time from curd initiation to maturity and hence emphasizes the importance of using a model of curd growth to predict the time of maturity in 'WINTER CAULIFLOWER'.

Fig. 7. Time from planting to curd initiation omitting data from 2000/2001.

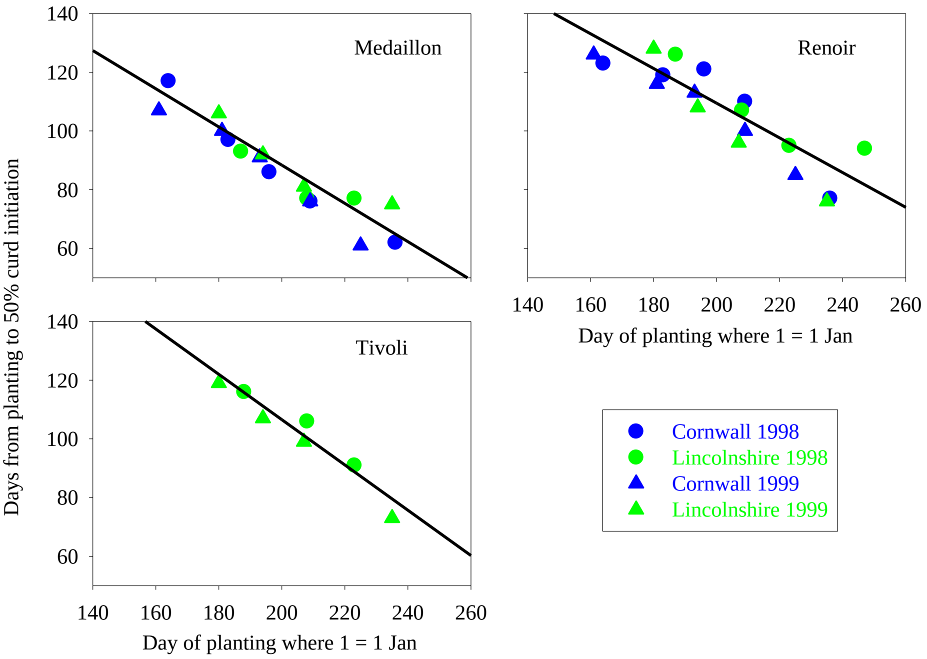
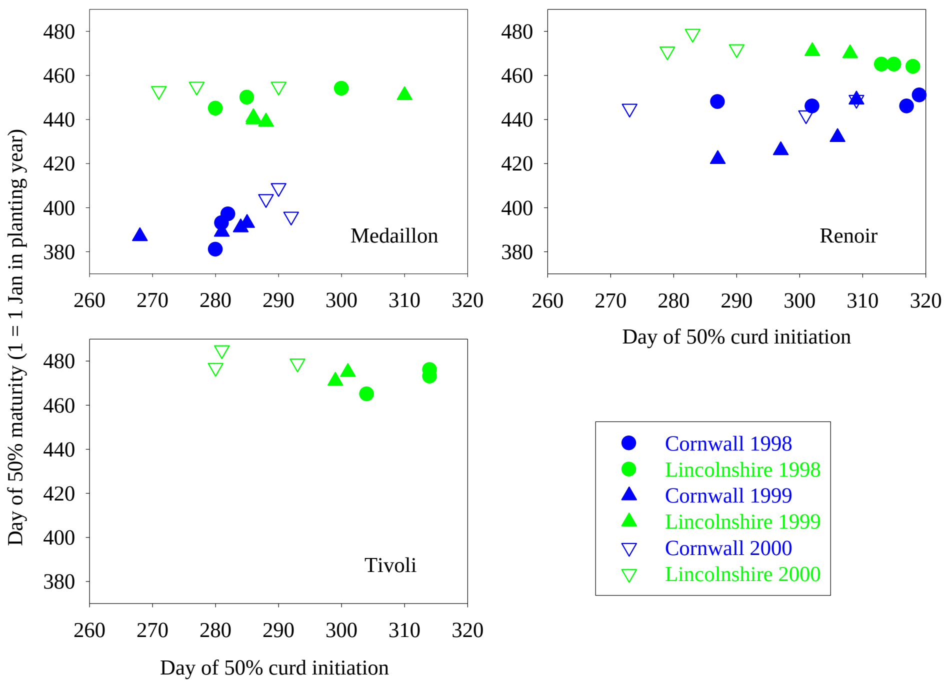


Fig. 8. Day of 50% maturity relative to day of 50% initiation (3 years' data).



Simple empirical models describing curd growth were fitted to each of the three varieties separately and showed that the relationship between curd diameter and thermal time was curvi-linear for Medaillon and Renoir but linear for Tivoli. The analyses investigated solar radiation and base temperatures for day-degrees and effective day-degrees and as an example Fig. 10 shows curd growth plotted against accumulated day-degrees > 0°C from curd initiation. Medaillon data from the first planting made in Cornwall in 2000 were removed from analyses because they were regarded as atypical.

Fig. 9. Days from initiation to maturity relative to day of 50% initiation (3 years' data).

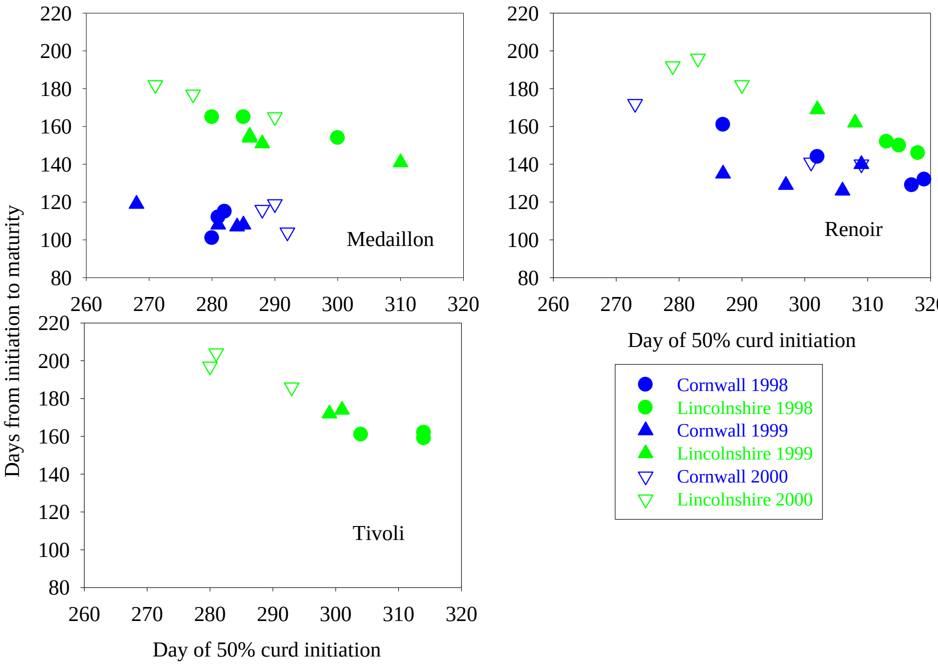
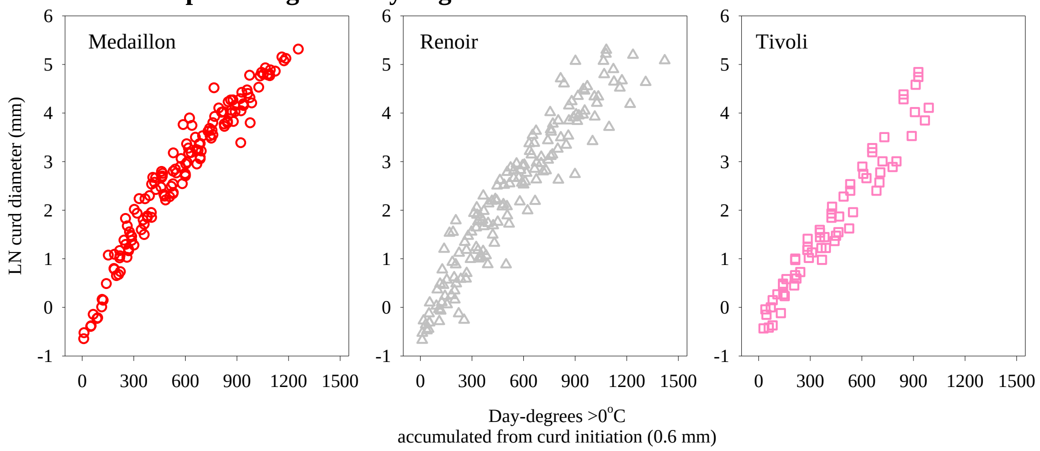


Fig. 10. Curd growth of Medaillon, Renoir and Tivoli crops from all three years plotted against day-degrees > 0°C accumulated from curd initiation



For Renoir, analyses confirmed that models fitting separate lines for each site should be used and Table 3 shows resulting fits for each variety with best fits highlighted in bold. Results using effective day-degrees are not shown because they never gave a better fit than day-degrees. The base temperatures of 8 and 9°C for Tivoli and Renoir seemed high but the incidence of day-degrees > 9°C during curd growth was checked and the data were found to be reasonable. However, such high base temperatures were not suitable for use in predictive models using historic weather data. When averaging data over several years, temperature fluctuations are smoothed out, making it difficult to use functions with either high base or low upper temperature limits. Therefore in order to develop 'WINTER CAULIFLOWER' for commercial use the curd growth models used had a base temperature of zero.

Table 3. Percentage variation accounted for by fitting regression models.

Base temperature for day-degrees	Medaillon quadratic model	Renoir in Cornwall quadratic model	Renoir in Lincolnshire quadratic model	Tivoli Linear Model
0	94.4	87.8	90.7	92.4
1	**94.4**	86.9	89.4	91.3
2	94.2	85.8	88.1	90.3
3	93.8	84.8	87.9	90.2
4	93.7	83.9	89.3	91.3
5	93.3	83.7	91.9	93.3
6	92.0	85.0	94.5	95.2
7	90.7	89.1	96.0	96.4
8	87.5	92.0	**96.9**	**96.8**
9	87.1	**93.3**	96.4	96.6
Solar radiation MJ	87.3	85.2	91.2	87.2

The distribution of curd diameter at maturity

The curd growth component of 'WINTER CAULIFLOWER' predicts both when an average curd reaches a specified size at maturity and the distribution of curd sizes around that average. This distribution is estimated using the mean diameter and standard deviation of a sample of curds taken shortly after curd initiation. None of the five curd samples taken in year 3 was significantly skewed (Table 4) and so a normal distribution has been used in developing the maturity prediction component of 'WINTER CAULIFLOWER'.

Table 4. Summary of samples of 40 curds taken from the third planting in year 3.

	Curd diameter (mm)			Coefficient of skewness	Number of curds		
	Minimum	Maximum	Mean		Immature	Mature	Over-mature
Cornwall							
Medaillon	8.8	21.7	15.5	-0.018	1	21	18
Renoir	12.2	22.3	16.0	0.633	0	31	9
Lincolnshire							
Medaillon	8.9	15.5	12.9	-0.660	6	33	1
Renoir	8.3	13.8	10.8	-0.053	21	19	0
Tivoli	8.4	18.2	13.4	0.209	0	13	27

Objective 3 Assess how the results on the timing of maturity of the whole range of genotypes used in winter cauliflower production can be scaled to apply to the varieties sampled in detail

Materials and Methods

Over the three years of this project Elsoms planted four variety trials in Cornwall between 13 and 20 July, three in Lincolnshire between 3 and 8 August and three in Kent between 17 and 29 July.

Results

Table 5, using data from all three years, shows the day of 50% maturity relative to Medaillon, at the same planting, for Cornwall, Kent and Lincolnshire and the average over all three locations. The data can be used to adjust a simulation of crop production made from planting where there is no crop sample taken after initiation. They may also be used as a basis for adjusting predictions made for any variety other than Medaillon, Renoir and Tivoli when using a curd growth model. The reliability of the adjustment will be greater where data are derived from more trials

Following the consortium meeting on 10 July 2001 further data from Elsoms' trials planted in Cornwall, and in Kent in 1997 was supplied together with data from Duchy of Cornwall College trials planted in the six years from 1995 to 2000, and were incorporated into the varietal adjustments. Data were averaged for each site of production and the varieties, pooled by varietal type, were aggregated into half-monthly groupings based on time of maturity to provide adjustments for new introductions. Table 6 shows the resulting day of 50% maturity for Roscoffs relative to Medaillon at the same planting, for Cornwall, Kent and Lincolnshire together with the number of crops that contributed to the adjustments as an example of the practical adjustment values.

Table 5. 50% maturity in days relative to Medaillon for all three years.

Variety	Cornwall	No.	Kent	No.	Lincs	No.	Average	No.
Phantom	*	0	-146	1	*	0	-146	1
Skywalker	*	0	-136	1	*	0	-136	1
Balmoral	*	0	-117	1	*	0	-117	1
Castlegrant	*	0	-106	1	*	0	-106	1
Valis	*	0	-98	1	*	0	-98	1
Talbot	-80	4	-95	2	*	0	-85	6
Galiote CLX33706	-76	1	-75	1	*	0	-76	2
Belot	-66	5	-59	3	*	0	-64	8
Pierrot	-64	5	-54	3	*	0	-60	8
Maginot	-61	5	-52	3	*	0	-58	8
Clovis	*	0	-55	1	*	0	-55	1
Triumphant CLX33707	-73	1	*	0	*	0	-73	1
SG4076 Lauren	-50	1	*	0	*	0	-50	1
Astral	-47	3	-58	1	*	0	-50	4
Bardot	-55	1	-43	1	*	0	-49	2
Arven	-33	1	-27	1	*	0	-30	2
Hermine CLX33708	-30	1	-28	1	*	0	-29	2
SG4075 Alpen	-27	2	-3	2	*	0	-15	4
Code January	-12	1	*	0	*	0	-12	1
BJ 1935 Catherine	-15	1	-7	1	*	0	-11	2
Miracle	-12	4	-9	3	-9	2	-10	9
Caprio	-20	1	0	1	*	0	-10	2
Festus BJ1822	0	3	0	1	-14	1	-3	5
Breven	-5	1	2	1	*	0	-2	2
Codebric Jan Feb	-1	1	*	0	*	0	-1	1
Medaillon	0	5	0	3	0	2	0	10
Ciren	-1	1	5	1	*	0	2	2
Broden	2	2	4	2	*	0	3	4
Luxor	6	4	7	3	3	2	6	9
Utopia	6	1	*	0	*	0	6	1
Boulen SG4351	*	0	7	1	*	0	7	1
Bounty	9	2	7	1	*	0	8	3
Kerio	*	0	*	0	14	1	14	1
Sidor	*	0	20	3	10	2	16	5
Madiot	21	5	17	3	8	2	17	10
Twilight	22	4	19	3	10	2	18	9
Colombo	16	1	20	1	*	0	18	2
Deveron	26	1	20	1	9	1	18	3
Mystique	23	5	17	3	10	2	19	10
Amadeus	22	1	24	3	10	2	19	6
Amarok	*	0	20	1	*	0	20	1
Armetta	*	0	20	1	26	1	23	2
Invicta	32	4	23	3	12	2	25	9
Bolina	26	2	24	2	*	0	25	4
Prior	33	3	26	3	18	2	26	8
Picasso	31	4	26	3	22	1	28	8
Code Feb Mar	28	1	*	0	*	0	28	1
Renoir	35	4	30	3	20	2	30	9
Fabian	*	0	*	0	31	2	31	2
Tivoli	*	0	36	2	28	2	32	4
Martian	*	0	33	2	31	2	32	4
BJ 1879 Icicle	41	1	35	1	22	1	33	3
Arthur	*	0	26	1	40	1	33	2
Dalton	*	0	40	2	31	2	35	4
Agadir	37	1	*	0	*	0	37	1
Jerome	44	4	33	2	29	2	37	8
Maverick	*	0	41	3	39	2	40	5
Vogue	47	4	39	3	31	2	41	9
Admirable	48	3	38	3	36	2	41	8
Protector	50	3	36	3	37	2	42	8
Fortrose	51	4	39	3	37	2	44	9
Mayfair	*	0	52	1	42	1	47	2
Passion	53	4	44	1	38	2	47	7
Nomad	56	4	48	2	39	2	49	8

Table 6. 50% maturity for Roscoffs in days relative to Medaillon. The number of trials is also shown.

Grouping	Cornwall	No.	Kent	No.	Lincs	No.
Late November	-84.0	5	-117.0	1	*	*
Early December	-72.4	34	-99.5	4	*	*
Late December	-68.0	2	*	*	*	*
Early January	-48.5	4	-75.0	1	*	*
Late January	-23.6	5	-55.5	11	*	*
Early February	-5.5	24	-43.0	1	*	*
Late February	1.1	14	-27.0	1	*	*
Early March	20.1	35	-6.3	6	-8.0	3
Late March	31.7	21	3.5	14	5.6	15
Early April	46.0	7	21.8	18	13.5	10
Late April	56.6	9	36.8	4	31.0	7

Objective 4 Determine the effect of severe frosts applied to plants with immature curds of different size on curd quality at maturity

Materials and Methods

In year 1 plants of Medaillon were raised in the glasshouse in 104 plug trays. Thirty cm pots were sunk into the field, filled with fertilized soil and on 13 July plants were planted into them and the surrounding soil. There were two replicates of four treatments representing different growth stages for frost treatment.

On 4 and 18 January and 1 and 15 February 1999, fifty uniform plants in pots were dug up from each plot and moved to a growth room at 5^{o}C for 24 h. Fifteen pots were then transferred to the freezing chamber whose temperature was dropped to –8^{o}C. Samples of five plants per plot were removed after 24, 48 and 72 h and returned to the growth room at 5^{o}C. The process was repeated at –5^{o}C and then at -2^{o}C with control plants remaining at 5^{o}C throughout. After a final period of 24 h at 5^{o}C plants from all treatments were moved to a plastic tunnel. When a curd was first visible it was cut, its wrapper leaves removed, head diameter measured, and leaf and curd damage recorded on a scale of 0 to 4. During freezing, representative records of the temperature of the 10 cm soil, stump, curd, leaf and air were taken with a data logger.

In year 2 the varieties Alpen, Medaillon, Madiot and Renoir, chosen to give a range of heading dates, were subjected to frost treatment at –8 ^{o}C for 24, 48 and 72 hours using the protocol developed in year 1. Plants were raised as before and transplanted into pots in the field on 12 July using the same design as in year 1. Each variety was frost-tested when curds were approximately 50, 75 and 100 mm in diameter.

Data from all trials carried out in Devon during the first two cropping years were combined and the effect on percentage curd damage of units of frost was investigated using linear regression analysis. Units of frost were expressed in hourly degrees below zero.

Results

In the freezing chamber the temperatures achieved were -1.3, -4.5 and -7.5^{o}C and representative temperature traces for the nominal -8^{o}C are given in Fig 11. Curd surface temperature achieved -1^{o}C within 4 h but then took a further 18 h to drop halfway to the set point and another 24 h to reach the set point. The choice of 24, 48 and 72 h freezing durations respectively led to leaf freezing, some curd freezing and total plant freezing. There was no effect of the time of sampling on curd damage and no effect of treatment at -2^{o}C. There was only slight curd damage at -5^{o}C but at -8^{o}C there was significant damage, particularly after 72 h freezing where between 60 and 100% of heads showed frost damage lesions.

In year 2 analyses showed that the variety Madiot differed from Alpen, Medaillon and Renoir. When Madiot data were excluded (Fig. 12) there was a significant effect of frost damage increasing with curd size, whereas the data for Madiot only (Fig. 13) show greater variability. Large curds reached a damage level of >80% after only 200 hours of frost and fitting separate slopes for curd size was not significant. Fitting a single response line to all the data accounted for 73% of the variation, but this model under-estimates the severity of possible effects on large curds after relatively low exposure to frost. It is suggested that since Madiot as a late variety is not usually frosted in commerce a single frost model should be used in 'WINTER CAULIFLOWER' based on the combined data from Alpen, Medaillon and Renoir.

Fig. 11. Air, soil and plant temperatures during freezing to –8°C.

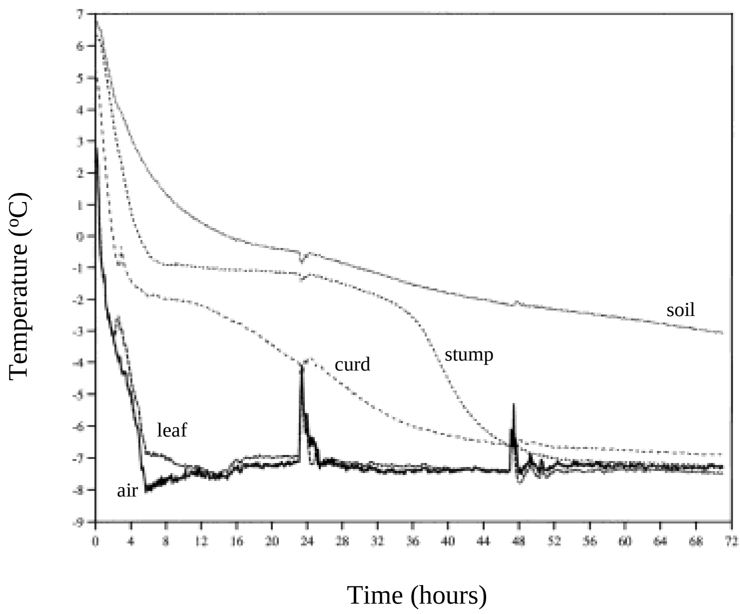


Fig. 12. The effect of frost index on % curds damaged for all varieties excluding Madiot.

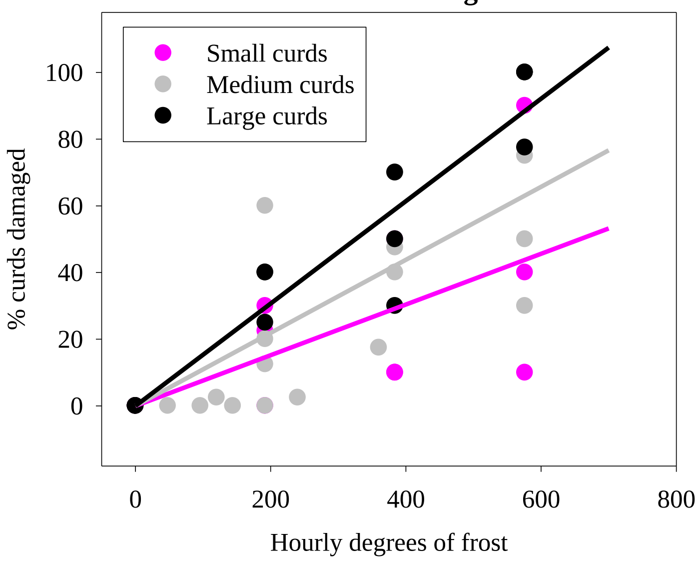
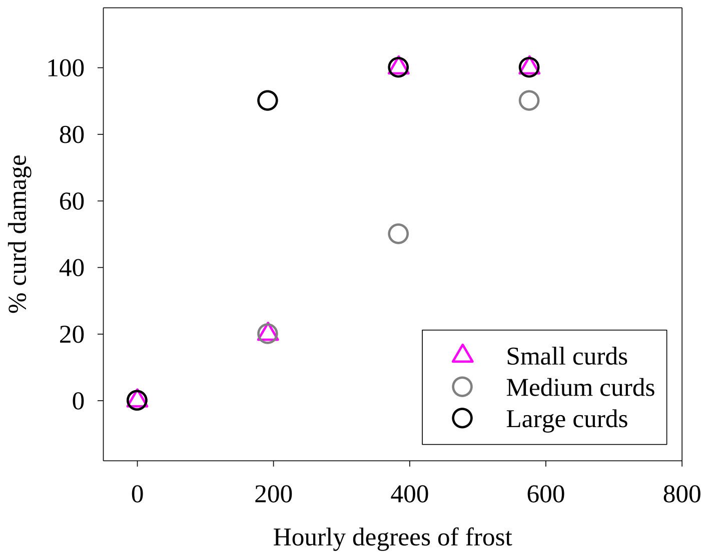


Fig. 13. The effect of frost index on % curds damaged for Madiot only.

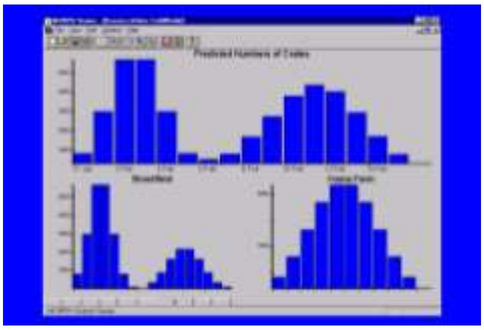


Objective 5 Model development

A prototype software indicator system called 'WINTER CAULIFLOWER' (For an example of output see Fig.14) was developed to take account of weather, location, varietal type and frost damage and indicate patterns of supply of winter cauliflower. 'WINTER CAULIFLOWER' provides the ability to:

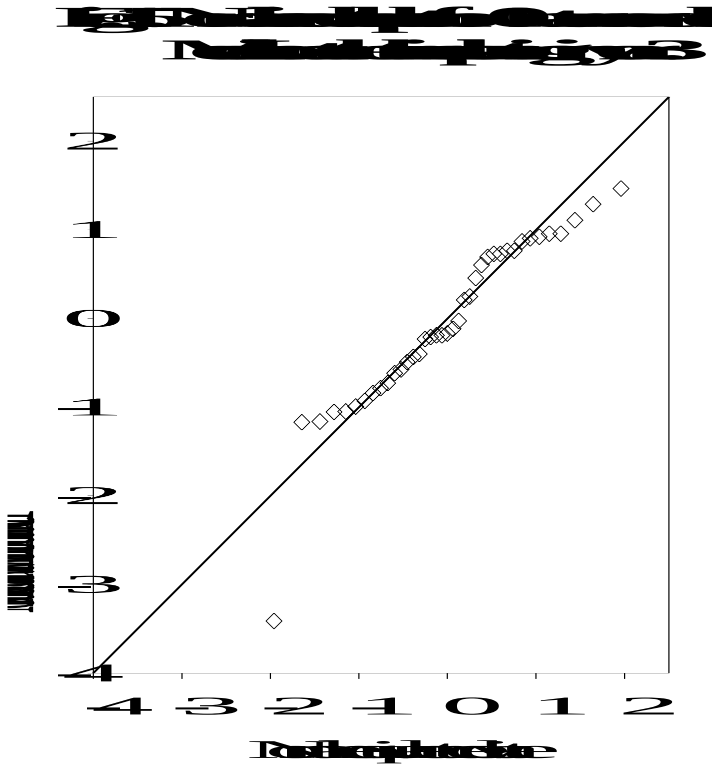
- Run predictions from planting when no crop samples are taken.
- Run predictions having taken crop samples after curd initiation.
- Run predictions for named varieties.
- Run predictions for varietal types.
- Run predictions for maturity groupings.
- Take account of future varietal introductions.
- Adjust predictions for local conditions.
- Use weather data for specific sites.
- Ask and answer 'What if' questions using historic or forecast weather data for specific sites, years and seasons.
- Output files which are compatible with Excel.

Fig. 14. An example of predicted production output for three crops



The use of the crop sample data

The distribution of curd sizes at maturity was further investigated by converting diameters to a normalised distribution with a mean of 0 and variance of 1, plotting them against normal equivalent deviates. There was some evidence of outlying values (Fig. 15) and to remove these, the sample diameter distribution was censored by removing 10% from either end. The percentage of heads predicted to mature each day was estimated by using the variation in thermal time between the days when 90th and 10th percentiles were predicted to be at the target diameter. The resulting prediction method was confirmed by simulating the time when the target diameter would be reached for a sample of 500 individual curds.



In preparation for testing 'WINTER CAULIFLOWER' background weather data were estimated for six production regions and Table 7 shows their average daily minimum and maximum temperatures from 1991 to 2001 inclusive. Although data prior to 1991 were available, averages based on recent data were considered more suitable, to ensure that possible effects of climate change were not diluted. The data fall into two groupings, the west and the east of UK.

Table 7. Average daily minimum and maximum temperatures.

Minimum ^{o}C

Month	**Cornwall** Camborne	**The Gower** The Mumbles	**Pembrokeshire** Milford Haven	**Lincolnshire** HRI Kirton	**Kent** Manston	**Suffolk** Walton on the Naze
July	12.9	13.3	12.9	11.9	13.4	13.7
Aug	13.2	13.6	13.1	11.9	13.9	14.0
Sept	11.7	11.9	11.5	9.9	11.6	12.0
Oct	9.3	9.0	8.8	6.5	8.1	8.7
Nov	7.0	6.6	6.9	3.6	4.9	5.3
Dec	5.1	4.3	4.5	1.6	2.8	3.1
Jan	4.5	3.6	3.9	1.2	2.1	2.4
Feb	4.9	4.0	4.3	1.7	2.2	2.5
March	5.6	5.0	5.1	3.0	3.7	4.1
April	6.2	6.2	5.9	4.5	5.3	5.6
May	8.7	9.0	8.4	7.0	8.5	8.8
June	10.9	11.2	10.8	9.9	11.2	11.3

Maximum ^{o}C

Month	**Cornwall** Camborne	**The Gower** The Mumbles	**Pembrokeshire** Milford Haven	**Lincolnshire** HRI Kirton	**Kent** Manston	**Suffolk** Walton on the Naze
July	18.6	19.5	18.9	21.7	21.6	21.0
Aug	19.3	19.7	19.2	21.9	22.4	21.5
Sept	17.2	17.6	17.2	18.2	18.7	18.5
Oct	14.1	14.1	13.9	13.8	14.5	14.4
Nov	11.6	11.1	11.2	9.8	10.6	10.5
Dec	9.7	8.7	9.1	6.9	8.1	8.0
Jan	9.0	8.0	8.4	6.7	7.4	7.2
Feb	9.5	8.4	8.8	8.1	8.2	8.0
March	10.3	9.6	9.9	10.2	10.5	10.2
April	11.5	11.6	11.7	12.6	12.6	12.1
May	14.7	15.2	15.1	16.4	16.2	15.4
June	16.7	17.6	17.1	19.2	19.2	18.8

Validation of the prediction system
During 2001/2 samples were taken from 89 commercial crops in Cornwall, Kent and Lincolnshire for testing and refining the model. Only 84 crop samples were subsequently used, because two growers in Cornwall failed to supply dates of 50% crop cut. Samples of up to twenty plants were taken from the crops after curd initiation and two measurements of the diameter of curds were taken at 90^{o} to one another. The prediction system was used to indicate when these crops would reach a specified target size under average temperature conditions and the predictions of production were sent to the growers. Figure 16 shows the overall predicted patterns of production for the three regions.

Of these 84 crops, 42 were from Cornwall, 5 from Kent and 37 from Lincolnshire. Sixty-two of the crops were Roscoff types, 10 were Roscoff x Walcheren crosses and 12 were Walcheren types. The growers indicated when crops reached 50% cut and as near to this time as possible, a sample of 20 curds was taken from a protected area of crop to determine the actual size at which curds were cut. These ‘check’ maturity samples were taken on 71 of the 84 crops.

Throughout the season, current weather data were supplied from a weather station located at Gwithian in Cornwall and from a remote recording system at Old Leake in Lincolnshire. No observations were available for Kent, so Met Office data for Manston airport were used. Table 8 shows average daily mean temperatures for the three regions.

Fig. 16. Predicted pattern of production of the varieties sampled in Cornwall, Lincolnshire and Kent

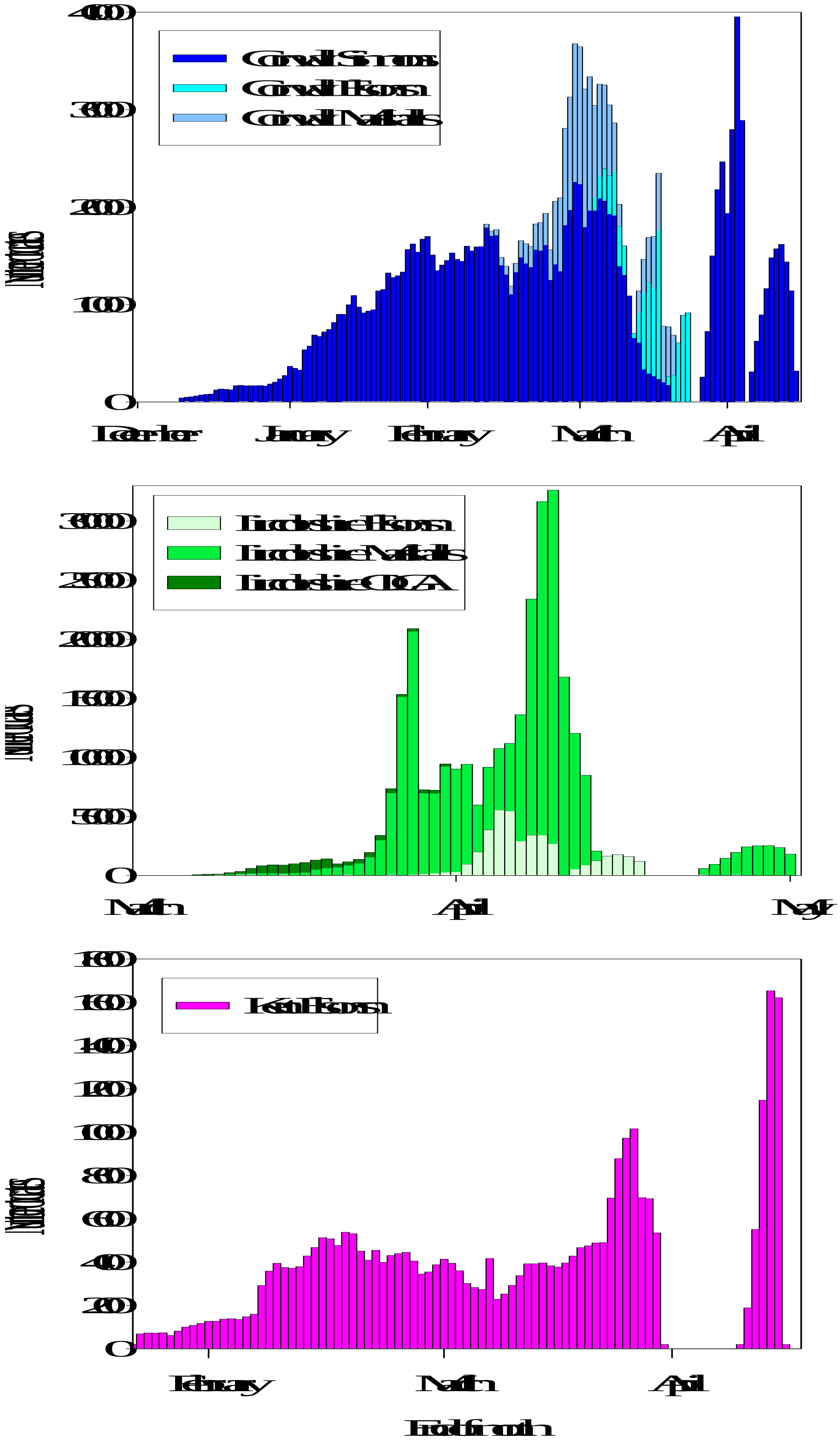


Table 8. Monthly average daily mean air temperature (^oC).

Year	Month	Average daily mean temperature (^oC)		
		Cornwall	Lincs	Kent
2001	August	16.4	17.2	17.8
	September	14.5	12.9	13.6
	October	13.6	13.4	14.5
	November	9.7	6.7	8.2
	December	6.6	2.6	4.9
2002	January	8.6	5.3	6.1
	February	8.7	6.8	7.9
	March	8.7	7.2	8.2
	April	9.2	9.0	9.9
	May (part)	10.0	11.0	11.7

In order to check how accurate the prototype prediction system was and to determine what correction factors might be needed to refine the accuracy of the system analyses were carried out on the data. Tables 9 and 10 show the mean apex diameter at the time of sampling, the number of days from sampling to 50% crop cut, an estimate of curd diameter at maturity and the difference between this size and that used as a target for predictions. Tables 9 and 10 also show the deviation in days between the actual and predicted dates of cutting. These were calculated as predicted minus observed so that a positive value indicated that the crop was cut earlier than predicted while a negative value indicated that the crop was cut later than predicted.

Predictions supplied to the growers were made using average weather, but actual weather may have been quite different and a truer test of the accuracy of the curd growth models was to re-run the predictions using observed temperatures and then calculate the deviations between predicted and actual dates of cutting. Tables 9 and 10 show that the use of observed weather data consistently reduced the deviations and Fig. 17 illustrates why this was so, indicating the effect of higher than average temperatures from mid-January on predicted curd diameter. It shows that the simulated curd growth proceeded more rapidly when using observed data and therefore the crop was cut earlier than predicted using average weather. Therefore in practice, after the initial sample, the model needs to be re-run periodically incorporating observed temperatures to update predictions.

In order to provide a more complete illustration of the opportunities provided by the indicator system, estimates of scheduled production, two prediction scenarios and real production quantities were produced. P E Simmons and Son provided daily records of the number of crates of 6 or 8 curds which the gangs cut for two of the crops sampled (S31 and W4BRODEN) for the varieties Medaillon and Broden respectively. Fig. 18 then demonstrates how the accuracy of prediction increased as the indicator system was re-run with more refined inputs for these two crops. Firstly, predictions of scheduled production were made from the date of planting using historic weather data from Camborne and an estimate of possible plant to plant variation in the crop. Secondly, predictions were made using a crop sample to determine both the starting point and the true crop variation, together with historic weather data from Camborne. Thirdly, predictions were made using the same crop sample and observed weather data from Gwithian, which was closer to where the crops were grown and finally, the numbers of curds taken off the field by the cutting gang are shown at the bottom of the figure.

Fig. 17. Simulating curd growth using the Roscoff model for a sample of Madiot (Code H12MADE)

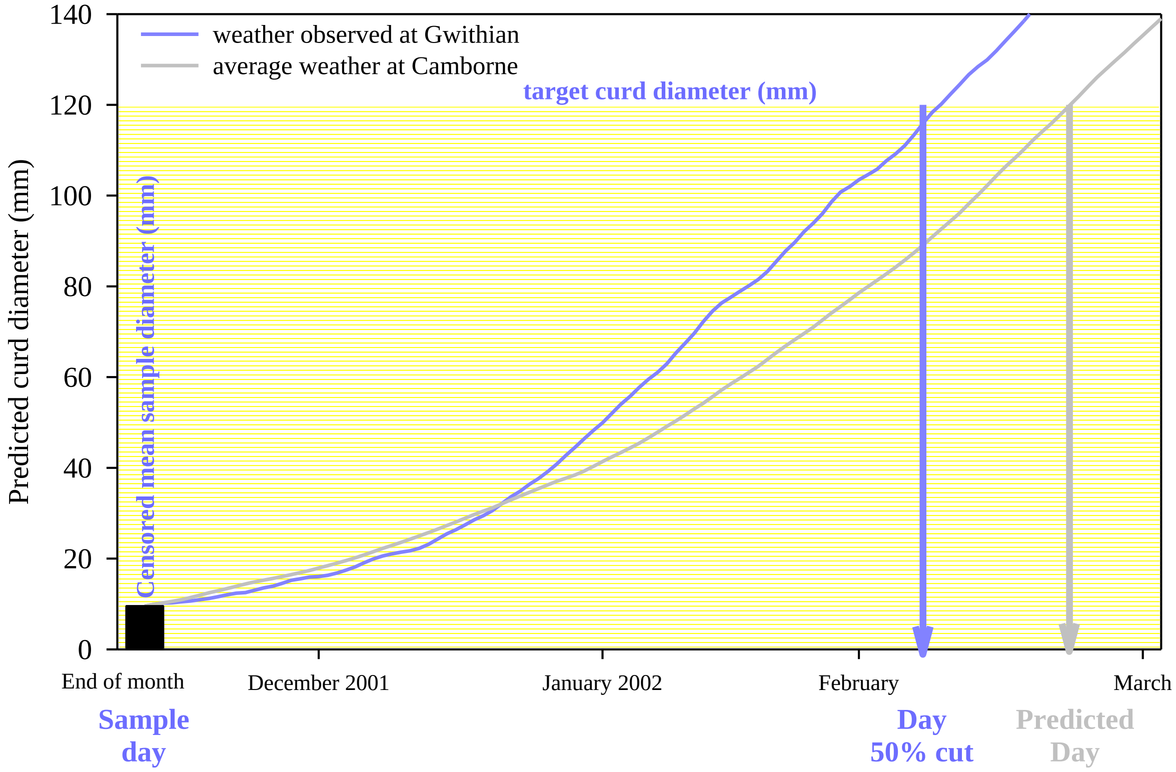


Fig. 18. Using the 'WINTER CAULIFLOWER' indicator system to output estimates of scheduled production and two prediction scenarios. Also shown is recorded production for two crops grown by P E Simmons & Son

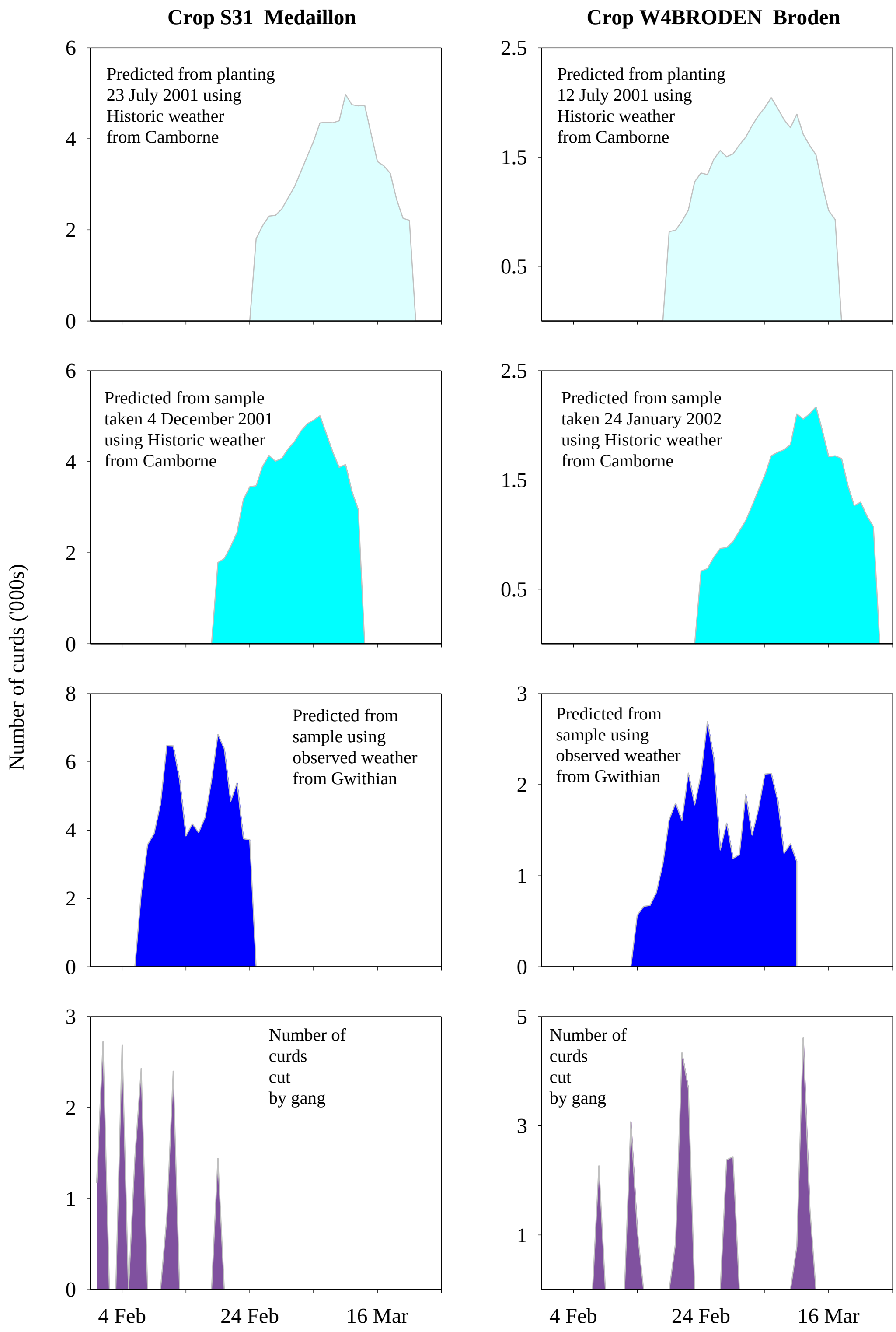


Table 9. Deviations for varieties with a single crop sample only.

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Roscoff types									
Alpen	Cornwall	Simmons	J31Alp	45	49	137	17	3	-1
April	Cornwall	Simmons	P18APRIL	4	88	114	-7	17	*
Boulen	Cornwall	Simmons	G09BOUL	29	67	122	2	3	-8
CadalNS	Cornwall	Simmons	S23CADAL	45	25	137	17	23	13
Evita	Lincs	Marshalls	W22CBEVI	29	27	*	*	14	*
Luxor	Kent	Elsoms	Mont60	21	51	87	-44	48	21
Nomad	Cornwall	Simmons	R30NOMAD	8	75	110	-10	17	5
No6	Cornwall	Simmons	H13No6	4	87	90	-30	18	*
Redoubtable	Cornwall	Simmons	RedPry	13	73	123	3	20	4
Overall mean								**18.1**	**5.7**
Roscoff x Walcheren types									
Passion	Lincs	Marshalls	W4302PAS	51	18	*	*	2	1
Protector	Lincs	Elsoms	LODPROT	19	38	*	*	7	5
Picasso	Lincs	Marshalls	W39TIPIC	56	21	153	33	-2	-3
Overall mean								**2.3**	**1.0**
Walcheren types									
Arthur	Lincs	Elsoms	LODART	18	40	131	11	5	4
Bejo_1880	Lincs	Marshalls	W41TIBEJ	33	29	*	*	-1	-1
Bejo_1881	Lincs	Marshalls	W4525BEJ	32	27	*	*	0	0
Overall mean								**1.3**	**1.0**

* Where the deviation using observed weather is missing, the model ran out of observed weather data

Table 10. Deviations summarised by variety and by region where applicable. Overall mean for variety in red, mean for Cornwall in blue, mean for Lincolnshire in green.

Roscoff Types

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Broden	Cornwall	Simmons	Ar21Bro	26	46	138	18	21	7
Broden	Cornwall	Simmons	W4BRODEN	49	29	112	-8	19	5
Overall mean								**20.0**	**6.0**
Buren	Cornwall	Simmons	ColeBur	49	46	101	-19	2	-1
Buren	Cornwall	Simmons	J21Bur	30	46	104	-17	23	13
Cornwall mean								**12.5**	**6.0**
Buren	Kent	Elsoms	Mont59	64	27	134	4	33	8
Overall mean								**19.3**	**6.7**
Cadal	Cornwall	Simmons	CadPry	9	75	135	15	26	12
Cadal	Cornwall	Simmons	Ar31Cad	20	45	126	6	29	13
Cadal	Cornwall	Marshalls	KesCad	45	18	119	-1	27	22
Overall mean								**27.3**	**15.7**
Invicta	Cornwall	Elsoms	Lang2Inv	19	54	122	-3	21	9
Invicta	Cornwall	Marshalls	OsbInv	47	24	128	8	19	13
Cornwall mean								**20.0**	**11.0**
Invicta	Lincs	Marshalls	W3409INV	21	34	120	0	30	26
Invicta	Lincs	Marshalls	W3710INV	49	18	116	-4	20	17
Lincs mean								**25.0**	**21.5**
Overall mean								**22.5**	**16.3**

Table 10. Deviations summarised by variety and by region where applicable contd.

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Madiot	Cornwall	Simmons	ColeMad	5	91	111	-9	21	6
Madiot	Cornwall	Simmons	H12MADE	9	85	91	-30	16	1
Madiot	Cornwall	Simmons	H12MADL	6	90	135	15	20	6
Madiot	Cornwall	Simmons	Ar41Mad	20	49	143	23	26	10
Madiot	Cornwall	Simmons	J51Mad	61	32	146	26	6	1
Madiot	Cornwall	Elsoms	Lang3Mad	27	49	114	-11	17	5
Madiot	Cornwall	Marshalls	KesMad	39	27	137	17	23	17
Madiot	Cornwall	Marshalls	OsbMad	72	11	109	-12	16	13
Cornwall mean								**18.1**	**7.4**
Madiot	Lincs	Marshalls	W3401MAD	26	39	120	0	27	20
Madiot	Lincs	Marshalls	W3402MAD	22	32	119	-2	33	28
Madiot	Lincs	Marshalls	W3403MAD	62	8	122	2	24	21
Madiot	Lincs	Marshalls	W3407MAD	24	32	*	*	32	25
Lincs mean								**29.0**	**23.5**
Overall mean								**21.8**	**12.8**

Table 10. Deviations summarised by variety and by region where applicable contd.

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Medaillon	Cornwall	Simmons	G9	25	61	126	6	13	1
Medaillon	Cornwall	Simmons	G10	25	48	118	-2	25	14
Medaillon	Cornwall	Simmons	S31	15	62	116	-4	28	12
Medaillon	Cornwall	Simmons	S32	23	64	104	-16	13	1
Medaillon	Cornwall	Simmons	M09	15	66	103	-17	23	7
Medaillon	Cornwall	Simmons	Dr11Med	18	67	133	13	16	1
Medaillon	Cornwall	Simmons	J11Med	14	67	126	6	25	10
Cornwall mean								**20.4**	**6.6**
Medaillon	Kent	Elsoms	Mont54	25	67	98	-32	42	20
Medaillon	Lincs	Marshalls	W3205MED	28	28	132	12	34	27
Medaillon	Lincs	OLGA	KM01	19	77	113	-17	46	24
Medaillon	Lincs	OLGA	WT20	13	86	112	-18	44	22
Lincs mean								**41.3**	**24.3**
Overall mean								**28.1**	**12.6**
Miracle	Lincs	Marshalls	W3104MIR	29	34	112	-9	37	30
Miracle	Lincs	Marshalls	W3107MIR	36	34	117	-4	32	22
Miracle	Lincs	Marshalls	W3101MIR	32	32	*	*	37	29
Overall mean								**35.3**	**27.0**

Table 10. Deviations summarised by variety and by region where applicable contd.

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Mystique	Cornwall	Simmons	Ar51Mys	16	48	90	-31	32	15
Mystique	Cornwall	Marshalls	KesMys	42	28	126	6	19	14
Mystique	Cornwall	Marshalls	OsbMys	59	18	119	-2	16	12
Overall mean								**22.3**	**13.7**
Twilight	Cornwall	Simmons	ColeTwi	7	99	92	-28	9	-6
Twilight	Cornwall	Simmons	P21TWI	6	83	101	-19	26	11
Twilight	Cornwall	Elsoms	Lang1Twi	21	55	122	-3	17	6
Twilight	Cornwall	Marshalls	KesTwi	46	28	129	9	17	11
Overall mean								**17.3**	**5.5**
Vogue	Cornwall	Simmons	JB5VOGUE	9	36	127	7	56	41
Vogue	Cornwall	Simmons	S25VOGUE	7	71	131	11	23	11
Cornwall mean								**39.5**	**26.0**
Vogue	Kent	Elsoms	Mont84	22	40	*	*	22	17
Vogue	Lincs	Marshalls	W0002VOG	55	17	*	*	13	12
Overall mean								**28.5**	**20.3**

Table 10. Deviations summarised by variety and by region where applicable contd.

Roscoff x Walcheren types

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Jerome	Kent	Elsoms	Mont75	15	57	136	6	6	-4
Jerome	Lincs	Elsoms	LODJER	25	33	98	-22	7	4
Jerome	Lincs	Marshalls	W4010JER	55	20	*	*	-1	-2
Lincs mean								**3.0**	**1.0**
Overall mean								**4.0**	**-0.7**
Renoir	Cornwall	Elsoms	WindRen	19	57	113	-12	23	11
Renoir	Cornwall	Marshalls	OlivRen	35	32	131	11	23	16
Cornwall mean								**23.0**	**13.5**
Renoir	Lincs	OLGA	SS19	57	17	115	-5	4	2
Renoir	Lincs	OLGA	JW03	51	23	113	-7	2	-1
Lincs mean								**3**	**0.5**
Overall mean								**13.0**	**7.0**
Sidor	Lincs	Marshalls	W3404SID	22	31	112	-8	19	14
Sidor	Lincs	Marshalls	W3409SID	22	28	125	5	20	16
Sidor	Lincs	Marshalls	W3407SID	26	25	110	-10	20	16
Sidor	Lincs	Marshalls	W3408SID	26	25	110	-10	20	16
Overall mean								**19.8**	**15.5**

Table 10. Deviations summarised by variety and by region where applicable contd.

Walcheren types

Variety	Region	Company	Code	Mean censored apex diameter at sample (mm)	Days from sample to 50% cut	Estimated mean curd diameter at 50% cut (mm)	Difference in curd size from target (mm)	Deviation average weather (days)	Deviation observed weather (days)
Maverick	Lincs	Elsoms	LODMAV	21	40	128	8	2	-1
Maverick	Lincs	Marshalls	W4402MAV	52	20	*	*	-1	-3
Overall mean								**0.5**	**-2.0**
Mayfair	Lincs	Elsoms	LODMAY	12	48	132	12	5	3
Mayfair	Lincs	Marshalls	W0002MAY	30	29	115	-5	0	-1
Mayfair	Lincs	Marshalls	W4601MAY	30	30	136	16	-1	-2
Mayfair	Lincs	Marshalls	W21CBMAY	30	24	107	-13	4	4
Mayfair	Lincs	Marshalls	W21TBMAY	30	26	116	-4	2	2
Mayfair	Lincs	Marshalls	W46TCMAY	29	30	*	*	-1	-2
Mayfair	Lincs	Marshalls	W4602MAY	35	21	*	*	4	4
Overall mean								**1.9**	**1.1**

* Where the deviation using observed weather is missing, the model ran out of observed weather data

A second factor to consider was the need to make adjustments for local conditions by considering the whole crop and its aspect and these were provided locally for three of the commercial crops (Table 11) and consistently improved the accuracy of the predictions.

Table 11. Three examples of the efficacy of subjective adjustments made on the basis of knowledge of local conditions in Cornwall by Alan Edmond (Elsoms).

Variety	Code	Deviation in days for the prediction using observed weather at Gwithian	Adjustment in days suggested by Alan Edmond	Deviation in days for the prediction using observed weather at Gwithian corrected by the adjustment
Invicta	Lang2Inv	9	-2	7
Madiot	Lang3Mad	5	-4	1
Twilight	Lang1Twi	6	-5	1

There may also be considerable differences between local weather conditions and the weather at the recording site. Figure 19 shows a map of Western Cornwall with the location of the weather stations indicated. Of eight crops sampled by Marshalls in Cornwall, half were sited at Lamorna on the south coast and half at Constantine near the Helford River and it is likely that the temperatures at these locations differed from the observed temperatures at Gwithian and the average temperatures at Camborne. This emphasizes the importance of local weather data when running predictions.

A further factor to be considered is that crops were not necessarily cut at the target size. Where a ‘check’ maturity sample was available, estimates of mean curd diameter at 50% cut were made and Tables 9 and 10 show the difference between the target and the actual diameter. In the varieties Buren, Madiot, Medaillon, Miracle, Mystique and Twilight the accuracy of predictions was adversely affected by not cutting crops at the target diameter. Nevertheless, it is accepted that cauliflower cutting is not a precise science and that, because of commercial pressures, crops will not always be cut at the intended target diameter.

Fig. 19. The relative locations of the Cornwall crops provided by Marshalls together with sites used for average and observed weather data.

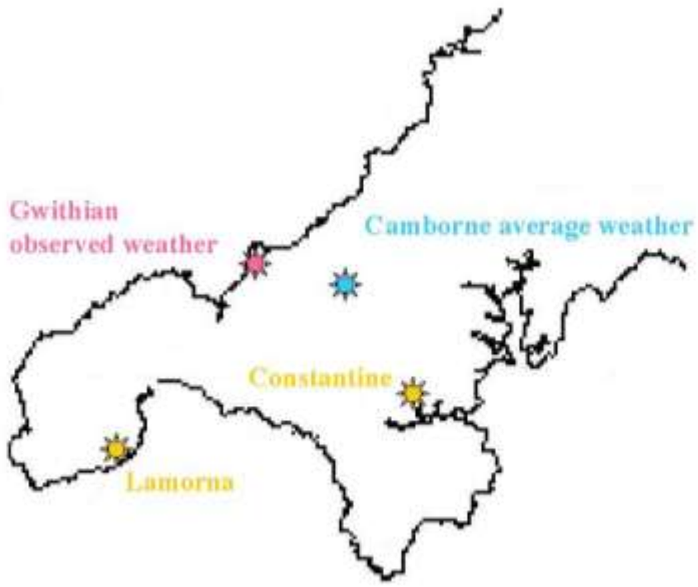


Table 9 presents data for 15 varieties for which only one crop sample was provided aggregated by varietal type. On average the deviations using observed weather were less than one day, which is extremely accurate. However the predictions were poor for the variety Luxor.

Table 10 shows data for varieties with multiple crop samples again aggregated by varietal type. The mean deviations for a variety are shown in red, and where applicable, regional mean deviations are shown for Cornwall, in blue, and for Lincolnshire in green. On average, the accuracy of predictions was good in Broden, Buren, Madiot in Cornwall, Medaillon in Cornwall, Twilight, Jerome, Renoir in Lincolnshire, Maverick and Mayfair. Specific varietal adjustments seem to be needed for Cadal and Mystique in Cornwall and for Invicta and Vogue.

There appeared to be a systematic deviation associated with Lincolnshire crops of Madiot (24 days), Medaillon (24 days), Miracle (27 days) and Sidor (16 days) which may need to be built into 'WINTER CAULIFLOWER'.

Thus the validation data suggest that:

- The use of observed weather data improved the accuracy of predictions.
- Where local grower adjustments were provided they improved the accuracy of predictions.
- It is important to use local weather data.
- If crops had been cut at the size that the grower suggested the accuracy of predictions would have been further improved in Buren, Madiot, Medaillon, Renoir, Miracle, Mystique and Twilight.
- The model worked exceptionally well with some varieties in particular locations.

- It appears that, as expected, specific adjustments to predictions will be needed for certain varieties.

While there is a strong tendency to look at the accuracy of prediction for individual crops it is important to remember that ‘WINTER CAULIFLOWER’ is a tool which provides a grower with information which he will then use in making management and marketing decisions. It was designed to indicate the overall pattern of supply of winter cauliflower throughout the production season and all the ‘tools’ required for this are now available. A full test of the system’s ability to indicate the overall pattern of supply will be the prime function of future work during the exploitation phase of this project.

Conclusions

Objectives 1 and 2

- Light and temperature conditions in Cornwall and Lincolnshire are quite different and influence crop growth and development.

- Complex models of curd induction driven by temperature were developed to estimate the time of curd initiation. However simple linear models using date of planting were found to be more suitable and were incorporated into ‘WINTER CAULIFLOWER’.

- Curd sizes at maturity were normally distributed. This will enable predictions of the spread of maturity in ’WINTER CAULIFLOWER’ to be estimated simply.

- The pattern of curd growth differed between varieties. Separate models for each variety based on day-degrees described curd growth much better than those using solar radiation and were incorporated into ‘WINTER CAULIFLOWER’.

Objective 3

- Data on the time of crop maturity relative to Medaillon and Renoir were collected for 62 varieties from three locations and are being used in ‘WINTER CAULIFLOWER’ to adjust model predictions run from planting where no curd samples are taken after curd initiation.

- In order for ‘WINTER CAULIFLOWER’ to take account of new varietal introductions, adjustments relative to the standard varieties were averaged for each site of production and varieties were aggregated into half-monthly groupings based on time of maturity.

Objective 4

- A single frost model based on combined data from Alpen, Medaillon and Renoir was devised to adjust crop volumes following severe frosts.

Objective 5

- A prototype software indicator system called 'WINTER CAULIFLOWER' was developed to run within the MORPH system to take account of weather, location and varietal type to indicate patterns of supply of winter cauliflower.

- Validation testing in 84 commercial crops during the 2001/02 winter showed that :
  - The use of observed weather data improved the accuracy of predictions.
  - In every case where local grower adjustments were provided they improved the accuracy of predictions.
  - It is important to use local weather data.
  - If crops had been cut at the size that the grower suggested, the accuracy of predictions would have been further improved in seven varieties.
  - The model worked exceptionally well with some varieties in particular locations.
  - It appears that, as expected, specific adjustments to predictions will be needed for certain varieties.

ACKNOWLEDGEMENTS

The use of meteorological data owned and supplied by the Meteorological Office is gratefully acknowledged.

TECHNOLOGY TRANSFER

During the course of this project the consortium agreed to limited publicity being given on a number of occasions:

- John Constable of Elsoms Seeds included information in a talk to Cornish growers in February 2000.
- A poster on the project featured on the HDC/ MAFF HortLINK stand at VEGEX in September 2000.
- David Wurr gave a specific talk on the project to Cornish growers in January 2001.
- David Wurr included features of 'WINTER CAULIFLOWER' in a talk at the Brassica Growers Association Conference in January 2002.
- Richard Reader of HRI mentioned features of 'WINTER CAULIFLOWER' in a talk at the joint HDC/HRI Modelling Day in March 2002.
- Information from the project will be further publicised within the UK by a Grower article, an article in HDC Project News and by a Demonstration Workshop.

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EXPLOITATION

- **TCS scheme**
  The University of Plymouth Teaching Company Centre have entered into a two-year Teaching Company Scheme with P.E. Simmons and Son with effect from October 2001. The proposal is supported in part by DEFRA and has already placed a graduate in the company. Approximately half of the time of the graduate will be spent implementing the output of LINK 195 into the company.

- **Monitoring and modelling cauliflower production in Brittany**
  The consortium has been approached by the Director of the CATE experimental trials station at St Pol de Leon (M. Michel Leroux) to express interest in the work done in this project because the cauliflower industry in Brittany is well aware of the advantages of being able to predict crop maturity. Future collaboration is envisaged in three stages:

- HRI analysis of French cauliflower growth data to develop algorithms describing curd growth and driven by environmental data.
- HRI validation of the accuracy of using these algorithms on independent French crops to predict crop maturity.
- Agreement by the exploitation consortium to incorporate these algorithms into WINTER CAULIFLOWER and make it available to Brittany growers.

EXPLOITATION PLAN

Discussions about the development of an Exploitation Agreement were held on 18 July and 7 November 2001, and 15 January and 18 June 2002 and this exploitation plan sets out the Consortium's strategy for the full exploitation of the output from the HortLINK 195.

Objective
A formalised document enabling the participants of the Link Project 195 to satisfy the exploitation and commercialisation requirements laid out in the DEFRA (previously MAFF) offer of Grant Letter reference CSA 4462 dated 30th March 1998.

Consortium Membership and Voting Rights

Horticultural Development Council	28.3
Horticulture Research International	39.5
PEP Research & Consultancy	9.5
Elsoms Seeds	7.0
Old Leake Growers Association	7.0
Marshall Bros (Butterwick) Limited	4.7
P.E. Simmons	4.0
	100.0%

Control
In accordance with the Collaboration Agreement all matters relating to exploitation, dissemination and commercialisation of foreground Intellectual Property will remain wholly subject to approval from the Consortium.

All decisions made by the Consortium regarding the commercial uptake will be reached in accordance with the voting arrangements specified above.

Timescale
It is envisaged that this plan will cover a period of 27 months and will be reviewed at set intervals throughout this period. If the Consortium deems it necessary, a further Exploitation Plan will be made towards the end of the period.

Review Meetings
Review meetings will be held in conjunction with the following milestones.

Date	Milestone
18 June 2002	Review of Model's performance 2001/2 and recommendation to HDC for subsequent validation project Final Meeting of Link Project completion
29 Oct 2002	Sampling Strategy for 2002/3 Season
June 2003	Review of Model's performance 2002/3
October 2003	Sampling Strategy for 2002/2003 Season
June 2004	Final Evaluation of Model's Performance

Exploitation Components
The consortium has identified the following areas of exploitation:-

1. Crop physiological data generated out of the project
    - Cauliflower growth habits.
    - Varietal frost tolerance.
    - Variety maturity/physiological behaviour patterns with particular reference to parent type/genetic origin as an aid to both growing and programming cauliflower crops.
    - Planting date comparisons.

2. Fully commissioned Winter Cauliflower Prediction software.

- For use by Consortium Members.
- For use by HDC levy payers/Consultants.
- For use by European growers eg. France, Spain, Italy.
- HDC have agreed funding of additional work to fully validate 'WINTER CAULIFLOWER' and develop it into commercial software for the benefit of all HDC members in the UK.

3. Supply of prediction data/models to European Science Establishments.

4. There is an opportunity for the provision of predictions as a service by one or more consortium members

5. The establishment of a Market Intelligence Scheme providing a flow of data on the likely pattern of supply will enable participants to make judgements about market strategy and promotions to enhance the value of their product. Data could be pooled from individual Production Areas or countries.

6. Wider use of the software framework
   There are opportunities for wider use of the software framework:
   - As a basis for a prediction system in:
     - Early summer cauliflower
     - Summer/autumn cauliflower
     - Any other crop requiring continuity of supply whose progress to maturity can be described mathematically.
   - To expand a winter cauliflower predictor to include crop programming and risk management components.

7. Training Arrangements with respect to software.

The foregoing represents a full list of potential exploitation/commercialisation areas which have been identified by the Consortium. It is envisaged that more detailed strategies for each component will be formulated over the period of this Exploitation plan.