REPORT FOR
HORTICULTURAL DEVELOPMENT COUNCIL

CALABRESE MATURITY PREDICTION

Contract No: FV57a

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SUMMARY

In 1991, shortly after head initiation, twenty commercial crops of calabrese were sampled in Fife and a further twenty were sampled in Lincs. Predictions of when crops would mature were made using five different Wellesbourne Calabrese Models. The predictions were adjusted according to the plant density used and show that for the Scottish crops one model was best for all varieties while in Lincs the best model varied according to variety. The accuracy of predictions was good in Shogun, Marathon, Skiff and Cruiser and was more accurate than the commercial evaluation of the Wellesbourne Cauliflower Model in 1987. Use of the models for predictions of Caravel, Arcadia and Greenbelt is not recommended. A commercial prediction system could be operated in 1992, once funding for the necessary computer software is made available.

INTRODUCTION

It is increasingly important to be able to predict when calabrese heads will reach the required market size because of demands for continuity of supply from supermarkets. UK calabrese production has expanded considerably in recent years but continuity of supply throughout the growing season is difficult to maintain because our unpredictable climate affects both the time of head initiation and the rate of head growth. However, it is possible to smooth out these fluctuations in supply by cold storing calabrese for up to three weeks, if it is known that a peak of supply is likely to be followed by undersupply. Other marketing decisions can also be aided by predictions of when crops will be ready to cut. An example of the practical use of such a prediction technique is the ADAS Cauliflower Prediction Service, based on the Wellesbourne Cauliflower Model, developed at HRI, Wellesbourne. Similar work on calabrese was funded by MAFF at Wellesbourne between 1986 and 1990 and is described in two papers:

WURR, D.C.E., FELLOWS, J.R. & HAMBIDGE, A.J. (1991). The influence of field environmental conditions on calabrese growth and development. Journal of Horticultural Science **66** 495-504.

WURR, D.C.E., FELLOWS, J.R. & HAMBIDGE, A.J. (1992). The effect of plant density on calabrese head growth and its use in a predictive model. Journal of Horticultural Science **67** In Press.

This work has resulted in several different models, which predict when a required percentage of the crop will reach a specified head diameter, and are based on mathematical relationships between head size and effective day-degrees. Effective day-degrees incorporate both temperature and solar radiation and are important because the crop responds to both factors and is grown in parts of the UK with different temperature/solar radiation balances. Because calabrese may be grown at a wide range of densities for both spear and crown production, the Wellesbourne models adjust predictions according to the plant density in the field, since the time taken for a head to reach a specified size will differ according to crop density.

MATERIALS AND METHODS

In 1991, twenty commercial calabrese crops grown in Fife, Scotland and a further twenty grown in Lincolnshire, were used to test the accuracy of the Wellesbourne Calabrese Models. The prediction system involved sampling the crop when the head diameter was approximately 10 mm and measuring head diameters in two directions at 90° to one another on a sample of 25 representative plants. Crop sampling was arranged by David O'Connor and was carried out in Fife by The Scottish Agricultural College and in Lincolnshire through Old Leake Growers Association. Sample data, including the actual plant density and the specified target size, were sent to Wellesbourne.

Predictions can be made for any percentage of the crop reaching a specified size and in order to test properly the accuracy of predictions it was necessary to measure head size at cutting and to estimate the percentage of crop cut. These data were also sent to Wellesbourne, together with information on variety and soil type. The meteorological data used for predictive purposes were from Leuchars in Fife and from Kirton in Lincolnshire.

The Wellesbourne Calabrese Model has several versions (Wurr et al., 1991, 1992) and in order to determine which model was most appropriate in the circumstances used here, five models were run for data grouped according to:

- Site (Fife or Lincolnshire)
- Variety

These models were those based on data from all previous crops (Model 1) and those based on different varieties (Models 2 to 5). It was originally intended to run each model in four different ways as follows:

(1) Using the specified target diameter and average weather. This is how the model would initially be used in practice.

(2) Using the specified target diameter and observed weather to take account of differences between observed and average weather.

(3) Using the actual diameter at the time of cutting and average weather.

(4) Using the actual diameter at the time of cutting and observed weather.

The latter is a true test of the accuracy of the model because it accounts for variation due to observed weather differing from average and to the grower cutting the crop at a different diameter from that which he had stated was the target. The original intention was to predict when 10% and 50% of the crop would reach the target diameter. However, since the percentage of the crop that was actually cut when the maturity sample was taken varied from 5% to 80% a different approach needed to be adopted using :

(1) Target diameter, average weather and 50% cut.

(2) Target diameter, observed weather and 50% cut.

(3) Actual diameter, average weather and 50% cut.

(4) Actual diameter, observed weather and 50% cut.

(5) Actual diameter, average weather and actual % cut.

(6) Actual diameter, observed weather and actual % cut.

The accuracy of prediction of each model was then tested by examining the differences between the predicted and actual dates of cutting using both the mean deviation and the prediction error (Spre). This was calculated as the square root of (the difference between the predicted and actual cuts)^2 divided by the number of crops. The merit of Spre is that positive and negative differences of equal value do not cancel each other out and both contribute equally to the error. The prediction error is therefore more appropriate than the mean deviation, which could be zero yet composed of equally large positive and negative differences.

RESULTS

Basic summarised data for all forty crops (Table 1) show for both sites, the sample identity code, the variety, plant density, specified target size, dates of transplanting, sampling and cutting, the actual % cut and the mean head diameter of the crop when sampled and when cut. Additional sample data were supplied but only the sample with a mean head diameter closest to 10 mm was used. The soil type is not shown because all Fife samples were from sandy loam soils and all Lincolnshire samples were from silt soils.

The data show that of the 40 samples, 6 were of Shogun, 6 of Skiff (all in Fife), 12 of Marathon, 6 of Cruiser (all in Lincs), 5 of Caravel, 2 of Greenbelt, 2 of Arcadia and 1 of SG1. Plant densities ranged from 3.4 to 5.5 plants/m^2 in Fife and from 5.5 to 16.0 plants/m^2 in Lincs. Target head diameters ranged from 130 to 220 mm in Fife and from 80 to 150 mm in Lincs. The earliest transplanting in Fife was 15 March and in Lincs 4 April while the latest transplanting in Fife was 1 July and in Lincs 23 July. The actual % of crop cut when the maturity samples were taken was much wider than expected and ranged from 9% to 75% in

Table 1. <u>Experimental details.</u>

(a) <u>Fife</u>

Identity code	Variety	Density (plants/m^2)	Target size (mm)	Date of transplanting	Date of sampling	Mean sample diameter (mm)	Actual date cut	Actual % cut	Mean diameter (mm)
1	Shogun	3.5	220	24 March	28 May	11.9	23 June	10	185
2	Skiff	5.5	130	15 March	28 May	11.9	25 June	51	111
3	Skiff	5.0	130	26 March	31 May	15.4	24 June	45	129
4	Greenbelt	4.1	220	6 April	31 May	11.2	24 June	12	146
5	Caravel	5.2	130	11 April	4 June	9.6	26 June	45	108
6	Marathon	3.9	220	8 April	4 June	12.4	1 July	28	187
7	Shogun	3.9	220	8 April	7 June	9.3	4 July	55	183
8	Caravel	5.1	130	15 April	7 June	11.4	28 June	60	104
9	Skiff	5.1	130	15 April	13 June	13.1	4 July	65	119
10	Skiff	5.0	130	19 April	13 June	13.0	3 July	57	117
11	Skiff	5.5	130	2 May	20 June	8.9	10 July	59	107
12	Marathon	3.8	220	21 April	25 June	13.1	12 July	28	195
13	Skiff	4.8	130	2 May	25 June	4.4	22 July	41	119
14	Marathon	3.5	220	14 May	25 June	3.5	25 July	75	201
15	Marathon	3.5	220	29 April	26 June	9.7	17 July	36	179
16	Marathon	3.4	220	22 April	26 June	11.9	16 July	28	189
17	Marathon	3.5	220	28 May	19 July	10.0	1 Aug	48	155
18	Marathon	3.7	220	20 June	5 Aug	9.2	28 Aug	13	204
19	Marathon	3.5	220	1 July	21 Aug	11.6	13 Sep	9	177
20	Shogun	3.4	220	1 July	21 Aug	9.8	17 Sep	29	184

(b) <u>Lincs</u>

Identity code	Variety	Density (plants/m^2)	Target size (mm)	Date of transplanting	Date of sampling	Mean sample diameter (mm)	Actual date cut	Actual % cut	Mean diameter (mm)
1	SG1	14.5	80	4 April	5 June	11.1	27 June	80	88
2	Greenbelt	6.0	150	17 April	21 June	8.0	11 July	45	137
3	Cruiser	15.0	85	13 May	9 July	28.0	17 July	60	86
4	Caravel	16.0	85	7 June	1 Aug	28.5	7 Aug	75	95
5	Arcadia	6.0	150	17 June	9 Aug	10.5	28 Aug	15	173
6	Marathon	6.0	150	17 June	9 Aug	6.1	30 Aug	5	158
7	Cruiser	15.5	85	17 June	9 Aug	12.1	29 Aug	75	82
8	Caravel	15.0	85	17 June	9 Aug	6.3	29 Aug	40	95
9	Marathon	5.5	150	2 July	15 Aug	6.2	12 Sep	20	169
10	Cruiser	15.5	85	2 July	22 Aug	9.1	11 Sep	20	107
11	Cruiser	16.0	85	1 July	23 Aug	16.7	12 Sep	40	108
12	Marathon	6.0	150	26 June	15 Aug	10.0	6 Sep	10	164
13	Cruiser	15.0	85	15 July	4 Sep	20.9	12 Sep	5	101
14	Shogun	6.0	150	4 July	4 Sep	26.4	18 Sep	10	173
15	Arcadia	6.0	150	9 July	4 Sep	13.0	18 Sep	30	172
16	Caravel	15.0	85	4 July	29 Aug	4.1	24 Sep	40	98
17	Shogun	6.0	150	18 July	4 Sep	4.8	14 Oct	20	170
18	Shogun	6.0	150	17 July	5 Sep	7.6	5 Oct	20	180
19	Cruiser	15.0	85	17 July	5 Sep	5.0	7 Oct	10	158
20	Marathon	6.0	150	23 July	11 Sep	3.7	16 Oct	20	146

Fife and from 5% to 80% in Lincs. A further inconsistency in the data is shown in Table 2 which highlights the differences between the target head diameter and the actual head diameter which were as great as 74 mm (51% of the actual head diameter). All the Fife crops were cut when smaller than the target diameter, while in Lincs, 17 of the 20 crops were cut with heads larger than the target diameter. Some of these differences were considerable and inevitably result in initial predictions using target head diameters and 50% maturity being largely inappropriate. Thus in order to simplify the presentation of results (Table 3) the accuracy of predictions is shown using only two of the six calculated criteria:

(1) Target diameter, average weather and 50% cut.
This represents what happens in practice when making a prediction based on the target diameter specified by the grower, using projected weather and assuming that the crop will be cut when 50% of the heads reach the specified size. In practice the % cut could be set to any required level.

(6) Actual diameter, observed weather and actual % cut.
This is a true test of the accuracy of a model because it represents what actually happened to the crop.

Table 3 shows the number of crops tested, the best model using actual diameter, observed weather and actual % cut and the performance of the same model using target diameter, average weather and 50% cut. Performance may be

Table 2. Difference between target and actual head diameters at maturity expressed as a percentage of the actual head diameter.

Site	Identity code	Difference (mm)	Difference %
Fife	1	35	19
	2	19	17
	3	1	1
	4	74	51
	5	22	20
	6	33	18
	7	37	20
	8	26	25
	9	11	9
	10	13	11
	11	23	21
	12	25	13
	13	11	9
	14	19	9
	15	41	23
	16	31	16
	17	65	42
	18	16	8
	19	43	24
	20	36	20
Lincs	1	-8	-9
	2	13	9
	3	-1	-1
	4	-10	-11
	5	-23	-13
	6	-8	-5
	7	3	4
	8	-10	-11
	9	-19	-11
	10	-22	-21
	11	-23	-21
	12	-14	-9
	13	-16	-16
	14	-23	-13
	15	-22	-13
	16	-13	-13
	17	-20	-12
	18	-30	-17
	19	-73	-46
	20	4	3

Table 3. The deviation, in days, of predicted cutting from actual cutting calculated as predicted day minus actual day.

			No. crops	Model No.	Predictions based on: Target diameter, Average weather, 50% cut		Actual diameter, Observed weather, Actual % cut	
					Spre	Mean	Spre	Mean
(1)	All crops		40	1	5.0	0.5	4.9	-0.6
(2)	Fife		20	4	4.9	0.7	3.3	-1.4
	Lincs		20	3	4.4	0.8	4.2	0.5
(3)	Shogun	All	6	4	4.2	2.2	3.2	-0.8
		Fife	3	4	3.7	1.0	3.4	-3.0
		Lincs	3	2	4.2	2.0	2.2	0.0
	Caravel	All	5	3	4.2	0.0	5.4	0.8
		Fife	2	4	2.0	-2.0	1.0	-1.0
		Lincs	3	3	3.6	3.3	5.3	5.0
	Marathon	All	12	1	4.8	2.5	3.8	-0.2
		Fife	8	4	6.3	4.4	3.5	0.3
		Lincs	4	1	4.4	3.0	2.9	0.3
	Skiff		6	4	4.4	-3.3	3.2	-2.5
	Cruiser		6	3	3.8	-0.2	2.3	-0.7
	Arcadia/Greenbelt		4	3	5.9	1.7	7.2	1.0

assessed by the prediction error (Spre) and the mean deviation, both expressed in days. Data are presented for:

(1) All 40 crops together

(2) Fife and Lincolnshire

(3) Each variety separately, except SG1 which had only 1 crop and Arcadia and Greenbelt which are combined.

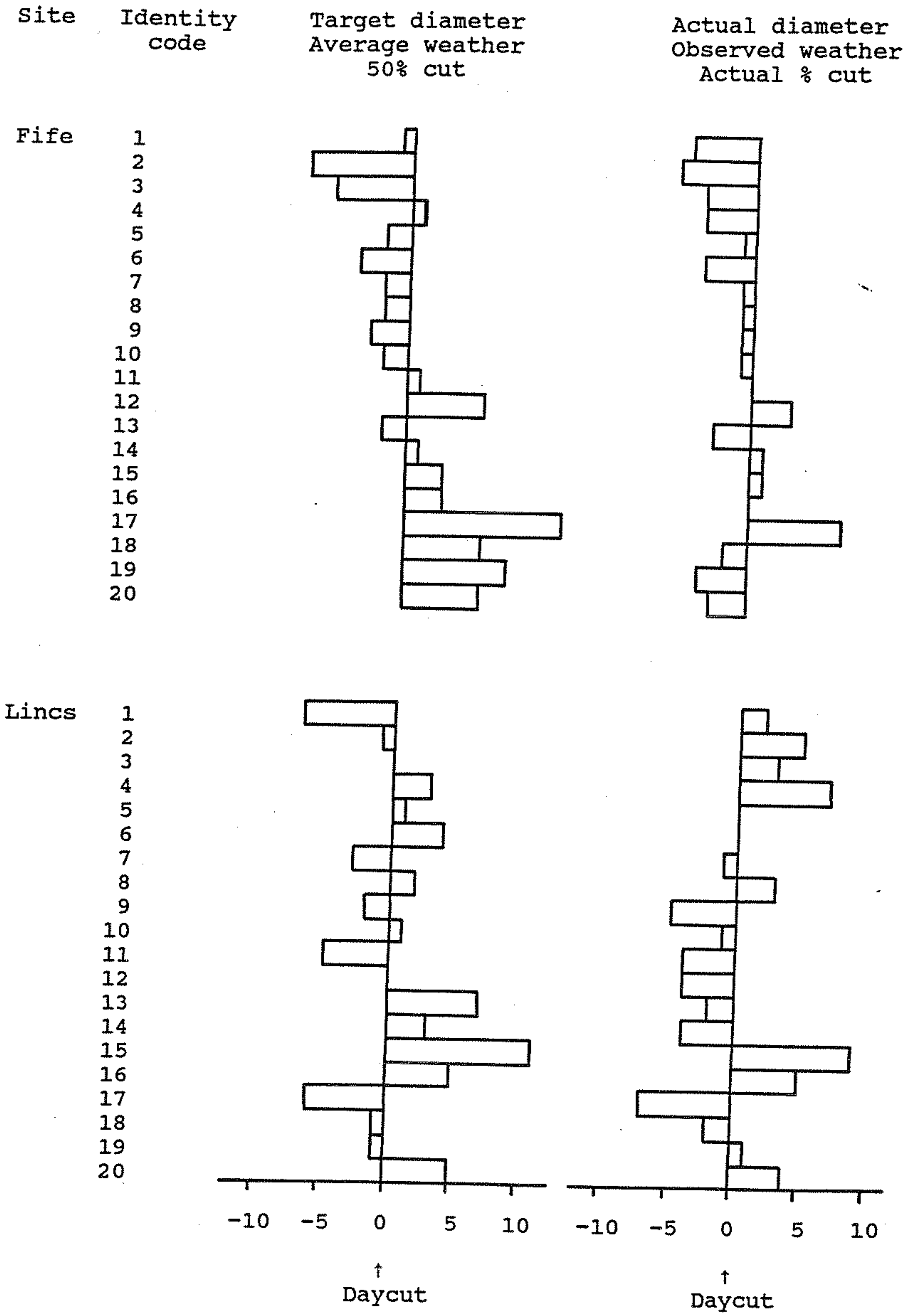
A single model (Model 1) applied to all crops gave a reasonable prediction error (Spre = 4.9 days) for actual diameter, observed weather and actual % cut with a mean deviation of -0.6 day. Deviations are calculated as predicted minus actual so a negative value means that the prediction was early and a positive value means that the prediction was late. When using different models for Fife (Model 4) and Lincs (Model 3) the prediction error was reduced with mean deviations still being small. The tendency for Fife crops to be predicted early (a negative deviation) may be largely due to the use of estimated solar radiation for Leuchars because only data on sunhours were available. It is known from previous experience that estimated radiation tends to be greater than observed, hence predicting cutting slightly too early.

When splitting predictions up by variety accurate results were obtained with Shogun (Spre = 3.2 days), Marathon (Spre = 3.8 days), Skiff (Spre = 3.2 days) and Cruiser (Spre = 2.3 days). However predictions were not very accurate with Caravel (Spre = 5.4 days) and Arcadia/Greenbelt (Spre = 7.2

days). The best model for Fife crops of Shogun, Caravel and Marathon was Model 4 whereas in Lincs the best models for Shogun, Caravel and Marathon respectively were Models 2, 3 and 1. In all cases, except Caravel and Arcadia/Greenbelt, predictions using target diameter, average weather and 50% cut were less accurate than using actual diameter, observed weather and actual % cut. Although predictions using target diameter, average weather and 50% cut with Caravel were better than with Marathon and Shogun this is likely to be a chance result and the true test of accuracy, using actual diameter, observed weather and actual % cut, suggests that predictions should not be made for Caravel, Greenbelt and Arcadia with these models.

A better indication of how accurate the predictions are is given by Figure 1. This presents the deviations of predicted cutting from actual cutting for all crops but using just two of the models: Model 4 for Fife crops and Model 3 for Lincs crops. A negative value means that the crop was cut after the predicted date of cutting while a positive value means that the crop was cut before the predicted date. The data are shown using target diameter, average weather and 50% cut on the left and actual diameter, observed weather and actual % cut on the right. The deviations are reduced with the latter, particularly with the Fife data. The change in deviations using Lincs data was not so great because the same model was used for

Figure 1. <u>Deviation of predicted cutting from actual cutting, in days, using Model 4 for Fife crops and Model 3 for Lincs crops.</u>



all varieties and the results have shown that the best model varies with variety.

DISCUSSION

The accuracy of predictions made here has been generally good and more accurate than the commercial evaluation of the Wellesbourne Cauliflower Model (Wurr et al., 1990). This is pleasing considering the different areas, sites, varieties and cultural techniques used and the fact that the models assume that crops are grown without stress whereas the stress to which the crops sampled here were subjected, is not known. Furthermore, the sampling technique was being used on commercial crops for the first time and experience with cauliflower suggests that taking an appropriate sample of a commercial crop is not simply a mechanical exercise and improves with practice. Thus there is good reason to believe that the calabrese models can be used to give reasonable estimates of the time that the crop will be cut.

There does not seem to be any merit in using only one model for all crops, though in Fife Model 4 was always best. In Lincs the best model varied according to variety. Predictions for Shogun, Marathon, Skiff and Cruiser appeared to be sound but those for Caravel, Arcadia and Greenbelt were not. It is suggested that the Wellesbourne Calabrese Models are not used for these varieties. With only one crop of SG1 it was not possible to test the suitability of the various models adequately.

The major problem that occurred in the work described was the disparity between on the one hand, target diameters and 50% cut, and on the other actual diameters and actual % cut. Predictions made with target diameters that are unrealistic in practice and differ markedly from the size at which the crop is cut will cause inaccuracies of prediction. This is where in future, experience of the grower or the agronomist in choosing a realistic target diameter will improve results considerably. In addition, more appropriate predictions can be made if an accurate estimate of the % of crop to be cut can be made initially. Inevitably these features will become easier to 'get right' with experience and the difference between predictions made using 50% cut of target diameters and actual % cut of actual diameters will be reduced. In addition the effect of updating predictions made using average weather, by incorporating observed weather can easily be done now and is a sensible use of any prediction system.

Further refinement of the models used here to take account of the effect of moisture stress on crop growth is possible with further experimental and modelling work and would improve the accuracy of predictions in those crops that are not stress free.

22 November 1991