PC/12 Development of interrupted-lighting schedules for AYR spray chrysanthemum cultivars. FINAL REPORT - IHR, Littlehampton.

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Location: IHR, Littlehampton and Efford EHS
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The work at the two centres has been fully integrated, with complementary objectives being pursued. Each centre will submit a separate final report on its component of the work. This report is that for IHR, Littlehampton.

OBJECTIVE:

To derive quantitative relationships between the average daily light integral during short days (SD) and the number of SD required for complete commitment to flowering* for a range of 'key' cultivars. These relationships are designed to enable the calculation of when long-day (LD) interruptions should begin, taking account of prevailing natural winter-light conditions.

BACKGROUND:

The technique of interrupted lighting consists of the intercalation of a period of long days into the short-day phase of chrysanthemum growing. A major effect is to elongate the peduncles giving a more attractive presentation of the flowers. Final harvest is expected to be delayed by up to the length of the period of interruption and, presumably as a result of increased dry weight from the extended growing period, stem strength, flower number and flower size can be increased.

However, the timing of the start of interruption is critical and should be as soon as possible after all flower buds are initiated (this is before they become visible without microscope dissection). The later the start after this stage is reached, the less is the effect of the interruption. On the other

* 'Initiation' although strictly incorrect will, for convenience, be used instead of 'commitment to flowering' in the text that follows.

hand, if it is started before all lateral flowers are initiated, compound 'double-decker' sprays result which can have reduced commercial value. In practice, a calendar approach is usually adopted with the length of the initial inductive short-day period being varied according to the time of year. Calendar recommendations reflect past experience, take account of widely differing cultivar responses and are given for 'usual' temperature regimens. However, they cannot allow for uncontrollable variation in daily light receipt which, for a given cultivar and with maintained conditions of temperature, is the most important factor determining the time taken to flower initiation. Increasingly large delays in bud initiation have been shown to occur below light integrals of 1.25 MJ m^{-2} d^{-1} PAR measured inside the glasshouse. This means that calendar-based recommendations have to include considerable margins for error so that interruptions are frequently given later than necessary: without such margins, interruptions will often be given too early.

Earlier work at IHR, Littlehampton to improve the precision of timing explored the possibility of direct microscopic dissection of apices and of using light-integral monitoring. The former procedure was dismissed since there is a time lag of some days between the irreversible commitment of lateral buds to flower and the visual detection, using a microscope, of morphological changes indicating that initiation has occurred, and this time lag varies considerably depending on the prevailing light climate. The second approach, light-integral monitoring, proved much more useful and empirical relationships between average daily radiation integral and speed of initiation were derived, and have been used routinely by ADAS to provide a prediction service. This approach is based on the concept that chrysanthemum plants are able to integrate fluctuating levels of light both within and between successive days to determine the time taken to initiation.

The relationships derived in the earlier work were obtained with a mean 24h temperature of 15.6°C. They were also derived using plants 'pinched' to give a single side shoot. The purpose of the present HDC sponsored work has been to refine the relationships by growing plants at c. 17°C, the commercial norm for leading growers, and by using 'mature' unpinched plants given initial long-day periods corresponding to commercial practices. It was felt that plants grown in this way would require shorter durations of SD before interruption.

PROCEDURES:

Cultivars. Snowdon, Pink Gin, Snapper, Delta, Daymark and Pale Salmon Snapper were used. Rooted cuttings were bought in as required from Messrs. Yoder Toddington Ltd., Littlehampton.

Experimental protocol. Rooted cuttings were planted in 13cm pots of GCRI peat-sand compost and maintained initially in LD given by a 5h night-break (21.30 - 02.30 GMT) from incandescent lamps at a minimum illuminance of 120 lux. Each trial utilised 90 plants per cultivar, 45 of these being shaded using black 'rokolene' netting, giving approximately 50% light transmittance. At the end of the initial LD period, five plants per cultivar from each shading treatment (shaded and unshaded) were dissected to give early warning of 'premature budding'. A further batch of five plants per cultivar from each shading treatment were retained in LD conditions (as controls), but with no further shading. The remaining 35 plants per cultivar per shading treatment were transferred to SD with black polythene covers being drawn over the plants from 19.00 to 08.00 (trial 1) and 17.00 to 08.00 (other trials). The plants shaded in LD continued with shading in SD so that each trial simultaneously monitored initiation in two light climates. One batch of five plants per cultivar per shading treatment remained in SD throughout the trial; six other batches were transferred back to LD (without shading) at intervals depending on time of year, and remained in LD until final scoring. The progression of initiation in these plants, having experienced varying periods of SD, was determined by direct comparison with plants in continuous SD. Light levels experienced by those plants in SD were recorded using Kipp solarimeters positioned on the shaded and unshaded benches. Temperatures were maintained at a minimum 17°C day and night with venting at 21°C. CO_2 enrichment was given to a nominal 1000 p.p.m. during SD.

Scoring and subsequent computations. Complete initiation was taken to mean the initiation of the terminal and of the top five lateral buds per plant. In low light conditions, one rarely gets more than five flowering laterals on many cultivars, and the extra time required for initiation of further laterals on those cultivars which do develop more than five laterals is very short, if measurable.

Plants were scored when the terminal and the lateral buds were clearly visible. Leaf counts were made on the main stem and on the uppermost five laterals of each plant, with bracts being ignored. Initiation of the terminal bud was judged to have occurred in SD prior to transfer to LD when the leaf number on the main stem was no more than two greater than that of the highest leaf count in the continuous SD sample. Initiation of a lateral was judged to have occurred when the leaf count on that lateral was no more than one greater than the highest count on equivalent laterals in the continuous SD sample. Plants judged to be prematurely budded were ignored - these have low numbers of leaves on the main stem and have leafy lateral shoots in treatments where these would not be expected.

Scoring plants in this way allowed, for each cultivar in each shading treatment in each trial, calculations of percentage initiation for given numbers of SD. Graphical presentation of these data gave extrapolated estimates of when 100% initiation had been achieved. These estimates were then related to the average daily light integral actually experienced and, when all trials had been completed, were brought together to derive for each cultivar, a quantitative relationship between SD for initiation and average light integral.

RESULTS:

Trials 1 (unshaded) and 1A (shaded):

- Plants potted: 5 August
- Transfer to SD: 21 August (after 16 LD) - all cultivars and both shade treatments
- Transfer intervals: 4, 6, 8, 10, 12, and 14 SD
- Average 24h temp. - LD: 21.5°C
- Average 24h temp. - SD: 21.1°C (21 Aug. - 3 Sept. incl.)

Number of days for 100% initiation and, in brackets, the average daily light integral during these periods (MJ m^{-2} d^{-1} PAR):

Cultivar	Unshaded (1)	Shaded (1A)
Snowdon	08 (2.62)	08 (1.20)
Pink Gin	09 (2.60)	10 (1.18)
Snapper	07* (2.63)	07* (1.21)
Delta	10 (2.59)	10 (1.18)
Daymark	08 (2.62)	08 (1.20)
P.S. Snapper	07* (2.63)	07* (1.21)

* Estimated on the basis of initiation of sub-laterals; severe premature budding (a consequence of using unpinched plants) at 24-30 leaves.

Trials 2 and 2A:

- Plants potted: 30 September

Trials aborted due to plant and glasshouse gale damage on 16 October.

Trials 3 and 3A:

- Plants potted: 4 November
- Transfer to SD: unshaded plants, 25 November (Snappers), and 2 December (others), - shaded plants, 27 November (Snappers) and 4 December (others)
- Transfer intervals: 8, 11, 14, 17, 21 and 25 SD
- Average 24h temp. - LD: 15.4°C
- Average 24h temp. - SD: 17.4°C (25 November - 29 December incl.).

Number of days for 100% initiation and, in brackets, the average daily light integral during these periods (MJ m^{-2} d^{-1} PAR):

Cultivar	Unshaded (3)	Shaded (3A)
Snowdon	14 (0.56)	20 (0.26)
Pink Gin	15 (0.54)	26 (0.25)
Snapper	13 (0.57)	28* (0.28)
Delta	17 (0.52)	26 (0.25)
Daymark	12 (0.62)	17 (0.26)
P.S. Snapper	15 (0.65)	28* (0.28)

* Estimates; lower laterals were still not fully initiated at the final transfer after 25 SD.

Trials 4 and 4A:

- Plants potted: 17 December
- Transfer to SD: unshaded plants, 11 January (Snappers), and 18 January (others), - shaded plants, 18 January (Snappers) and 25 January (others)
- Transfer intervals: 8, 11, 14, 17, 21, and 25 SD
- Average 24h temp. - LD: 17.5°C
- Average 24h temp. - SD: 17.2°C (11 January - 18 February incl.)

Number of days for 100% initiation and, in brackets, the average daily light integral during these periods (MJ m^{-2} d^{-1} PAR):

Cultivar	Unshaded (4)	Shaded (4A)
Snowdon	- ǂ	- ǂ
Pink Gin	11 (0.64)	15 (0.50)
Snapper	11 (0.77)	16 (0.38)
Delta	15 (0.75)	17 (0.54)
Daymark	11 (0.64)	13 (0.43)
P.S. Snapper	12 (0.80)	17* (0.38)

ǂ Snowdon data excluded from final analyses since these were Kenya clone plants which are known to have aberrant flowering characteristics.

* Estimate; scores based on terminal and top 3 laterals only since there was excessive leaf production on the 4th and 5th laterals of plants in continuous SD.

Trials 5 and 5A:

- Plants potted: 20 January
- Transfer to SD: unshaded plants, 3 February (Snappers), and 10 February (others), - shaded plants, 10 February (Snappers), and 17 February (others)
- Transfer intervals: 8, 10, 12, 15, 18, and 21 SD for unshaded Snappers and shaded others; 8, 10, 12, 15, 19 and 21 SD for remainder
- Average 24h temp. - LD: 16.8°C
- Average 24h temp. - SD: 17.3°C (3 February - 8 March incl.)

Number of days for 100% initiation and, in brackets, the average daily light integral during these periods (MJ m^{-2} d^{-1} PAR):

Cultivar	Unshaded (5)	Shaded (5A)
Snowdon	10 (1.82)	11 (0.90)
Pink Gin	10 (1.82)	12 (0.89)
Snapper	12 (1.39)	-
Delta	12 (1.77)	12 (0.89)
Daymark	10 (1.82)	10 (0.90)
P.S. Snapper	11 (1.35)	-

Snapper and P.S. Snapper in 5A showed excessive vegetative growth and were not fully initiated at the end of the trial. There was no obvious reason for this.

Trials 6 and 6A:

- Plants potted: 24 February (to replace those lost in trials 2 and 2A)
- Transfer to SD: unshaded plants, 9 March (Snappers) and 14 March (others), - shaded plants, 16 March (Snappers) and 21 March (others)
- Transfer intervals: 6, 8, 10, 12, 15 and 18 SD
- Average 24h temp. - LD: 17.1°C
- Average 24h temp. - SD: 18.0°C (9 March - 7 April incl.)

Number of days for 100% initiation and, in brackets, the average daily light integral during these periods (MJ m^{-2} d^{-1} PAR):

Cultivar	Unshaded (6)	Shaded (6A)
Snowdon	09 (1.53)	09 (0.99)
Pink Gin	11 (1.62)	10 (0.98)
Snapper	08 (1.50)	09 (0.86)
Delta	10 (1.52)	12 (1.00)
Daymark	08 (1.41)	08 (1.05)
P.S. Snapper	-	-

A yellow coloured Snapper was delivered instead of Pale Salmon Snapper; results with this were 09 (1.53) for trial 6 and 08 (0.82) for 6A.

All Trials - Summary of Responses:

Cultivar	1	1A	3	3A	4	4A	5	5A	6	6A
Snowdon										
days	08	08	14	20	-	-	10	11	09	09
LI	2.62	1.20	0.56	0.26	-	-	1.82	0.90	1.53	0.99
Pink Gin										
days	09	10	15	26	11	15	10	12	11	10
LI	2.60	1.18	0.54	0.25	0.64	0.50	1.82	0.89	1.62	0.98
Snapper										
days	(07)	(07)	13	(28)	11	16	12	-	08	09
LI	2.63	1.21	0.57	0.28	0.77	0.38	1.39	-	1.50	0.86
Delta										
days	10	10	17	26	15	17	12	12	10	12
LI	2.59	1.18	0.52	0.25	0.75	0.54	1.77	0.89	1.52	1.00
Daymark										
days	08	08	12	17	11	13	10	10	08	08
LI	2.62	1.20	0.62	0.26	0.64	0.43	1.82	0.90	1.41	1.05
P.S. Snapper										
days	(07)	(07)	13	(28)	12	(17)	11	-	-	-
LI	2.62	1.21	0.57	0.28	0.80	0.38	1.35	-	-	-

LI = Light integral (MJ m^{-2} d^{-1} PAR, inside the glasshouse)
() = Estimate

LIGHT-INTEGRAL RELATIONSHIPS - RESULTS AND DISCUSSION

Figures 1-5 show numbers of SD for complete initiation plotted against average daily light integrals during these periods of SD for Snowdon, Pink Gin, Snapper, Delta and Daymark respectively. There were no indications from the trials that the responses of Pale Salmon Snapper differ significantly from those of Snapper and so Figure 6 shows a combined data plot for these two cultivars. It should be noted that, because of the tendency for Snapper and its sports to bud prematurely under high light conditions and to be excessively vegetative under low light conditions, seven of the 16 values are estimated and need to be treated with caution.

The form of the relationship for each cultivar appears to follow an exponential increase in the time for initiation as the light integral falls below 1.0 - 1.25 MJ m^{-2} d^{-1} (PAR). Time for initiation appears to approach a constant value (asymptote) at higher light levels. Accordingly, a line of best fit was constructed for each cultivar (see Figures) using the relationship

$$y = A + B\exp\,[-kx]$$

with A as the asymptotic value, A + B as the hypothetical number of days for initiation in continuous darkness (x = 0), and k as a constant. These 'fitted' lines have values of 'percentage variance accounted for' of 93.5, 96.1, 89.5, 96.3, 90.1 and 91.4 respectively. It should be noted, however, that the extreme low-light datum point in each case has a very strong influence (leverage) in determining the rate of exponential increase in time for initiation below 0.5 MJ m^{-2} d^{-1}. Several further trials under extreme low-light conditions would be desirable to improve the predictive values of the fitted line relationships.

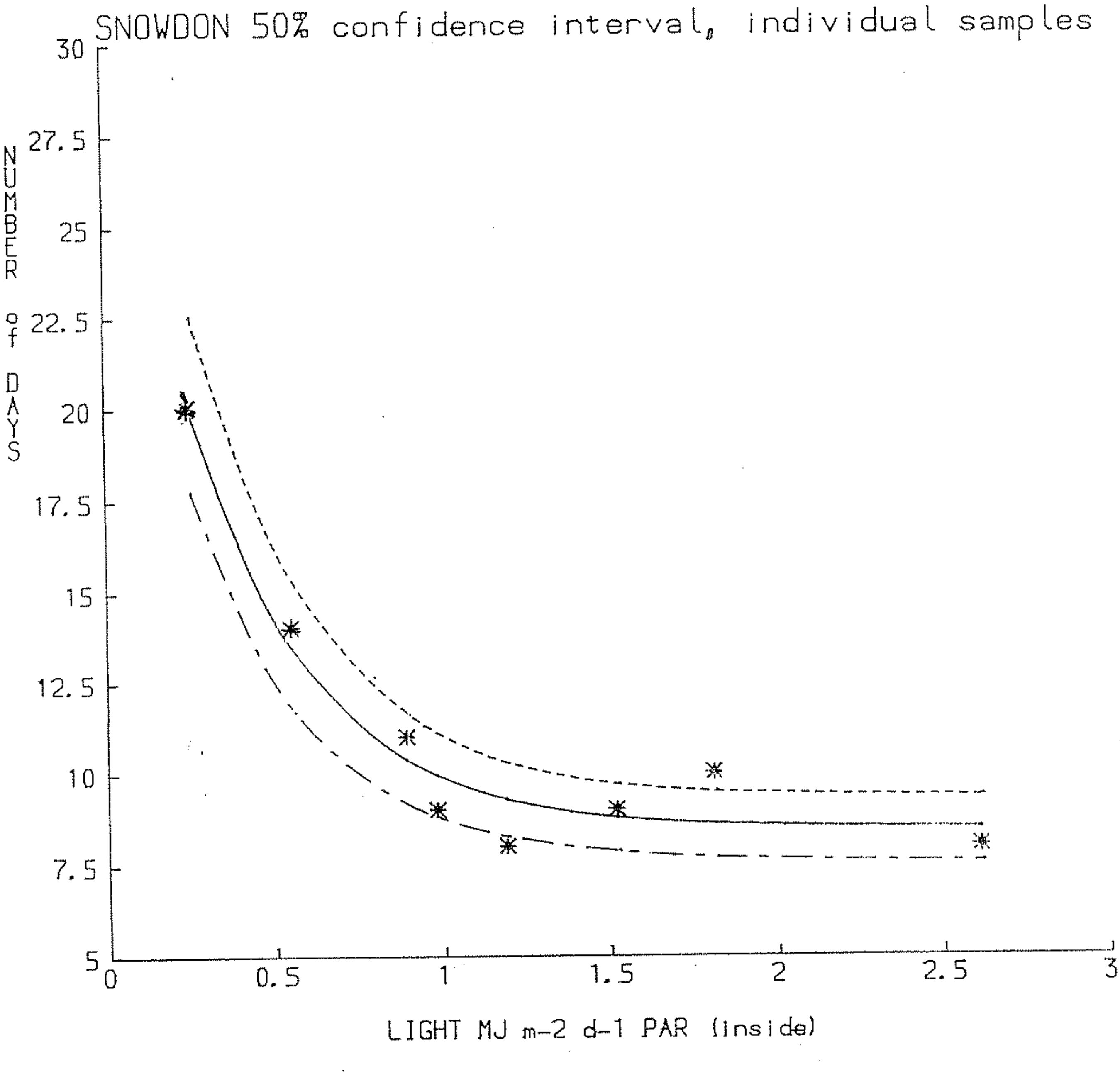
It appears that Snowdon requires slightly fewer SD than Pink Gin for initiation at both high and low light levels. Daymark initiates faster than Snowdon at low light levels, and Delta initiates appreciably more slowly than Snowdon at all light levels. These results confirm the cultivar rankings observed in practice. The results for Snapper and Pale Salmon Snapper show unexpectedly large delays in initiation at light levels below 0.5 MJ m^{-2} d^{-1} (PAR) which possibly confirms the correctness of the Dutch practice of using late interruptions on these cultivars. It should be noted that the variability of response at given average light levels is far greater in the Snappers than in any of the other cultivars used.

The problem of basing predictions on values taken directly from the fitted curves, is that up to 50% of these predictions can be expected to underestimate the time required for initiation and lead to impairment of quality. Confidence intervals were, therefore, calculated such that there is a given percentage likelihood of individual values for days to initiation lying between the upper (maximum) and lower (minimum) limit lines. In Figures 1-6, the upper and lower limits of the 50% confidence interval are shown. The extent of their separation from the fitted line reflects the degree of scatter of observed values about the fitted line. In practice, the use of a 50% interval means that 25% of predictions, based on the upper limit line, will underestimate the number of SD needed for flower commitment. This is probably an acceptable level of risk, bearing in mind that the degree of underestimate is likely to be small and, at most, affect only one or two lower lateral buds. Higher percentage confidence intervals can be computed at will but, whilst the use of upper limit lines based on these will reduce the proportion of underestimates, they will correspondingly increase the number of overestimates. It should be noted that the vertical separation of the upper and lower confidence lines from the fitted line increases as light integral declines. This is particularly noticeable in Figure 3 for Snapper.

Table 1 gives rounded values for numbers of days for complete initiation against a range of average light integrals based on fitted and on upper confidence limit (50%) lines. This is useful in giving a quick indication of how the speed of initiation declines with reducing light integral. Using this Table one can compare predictions with actual numbers of days for initiation in the complementary Efford trials, where average light integrals in the glasshouse were about 0.4 MJ m^{-2} d^{-1} (PAR). The closeness of fit (Table 2) appears encouraging.

Table 3 is presented as the basis for predictive monitoring. It is based on the upper 50% confidence line for each cultivar and could replace tables developed earlier by IHR,L and currently used by ADAS. Growers planning to use the data in conjunction with their own outdoor-mounted light monitoring equipment should note that corrections will need to be made to take account of transmission losses into the glasshouse. In many cases the measured light levels will need to be reduced by c. 30%. The figures presented in Table 3 are for photosynthetically active radiation (PAR) and are 50% of the values recorded directly using Kipp solarimeters. Growers using other types of light sensor need to ensure their comparability with Kipp solarimeters. As an aid for growers, Table 4 presents equivalent data to those in Table 3 but adjusted to represent total radiation (as measured using a Kipp) and for equipment mounted out of doors above a glasshouse with 30% transmission loss characteristics.

Figure 1



SNOWDON 50% confidence interval, individual samples

minimum DAYS v LIGHT
maximum DAYS v LIGHT
fitted DAYS v LIGHT
actual values DAYS v LIGHT

Figure 2

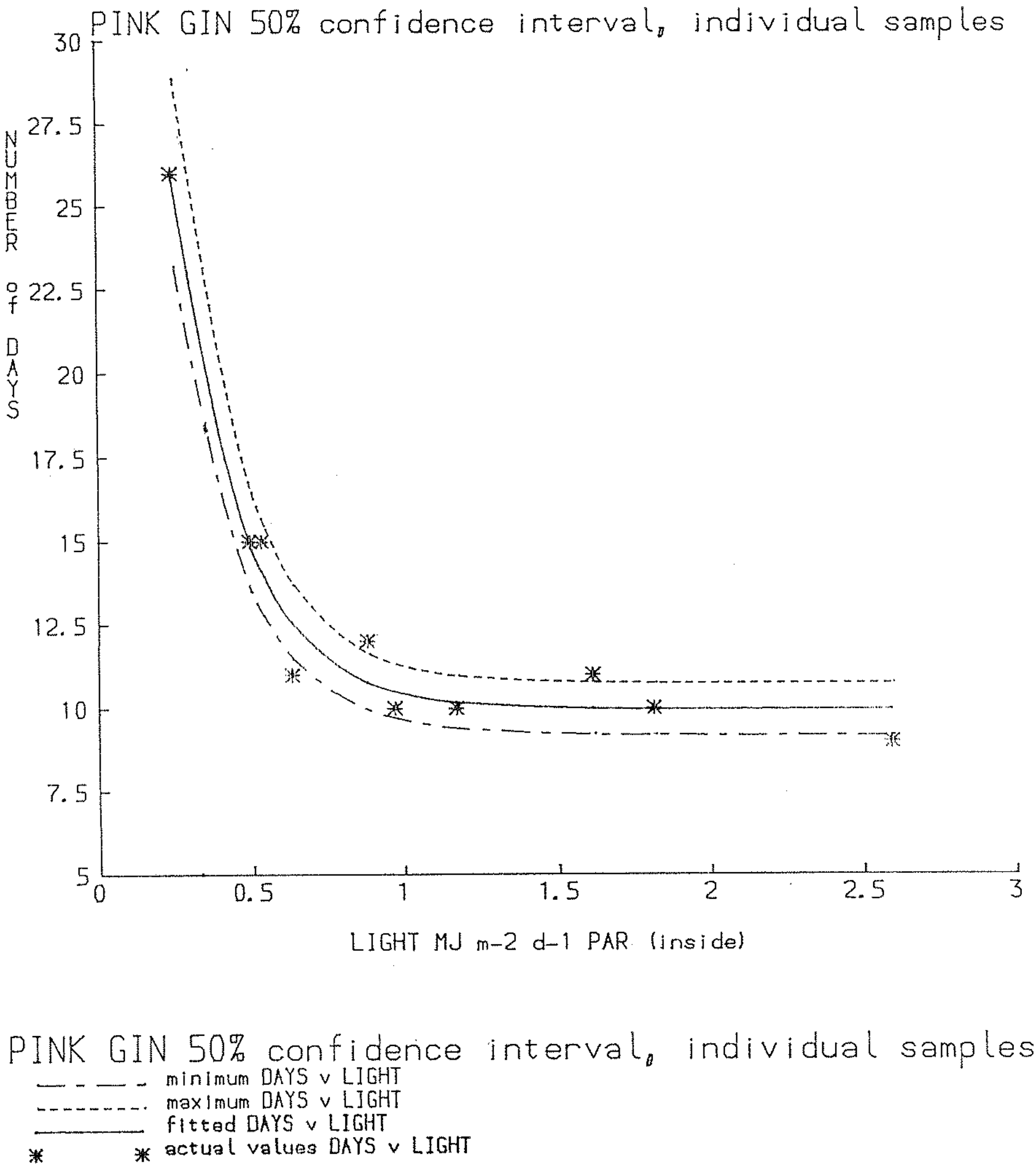

PINK GIN 50% confidence interval, individual samples
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
NUMBER of DAYS
0
0.5
1
1.5
2
2.5
3
LIGHT MJ m-2 d-1 PAR (inside)
PINK GIN 50% confidence interval, individual samples
minimum DAYS v LIGHT
maximum DAYS v LIGHT
fitted DAYS v LIGHT
actual values DAYS v LIGHT

Figure 3

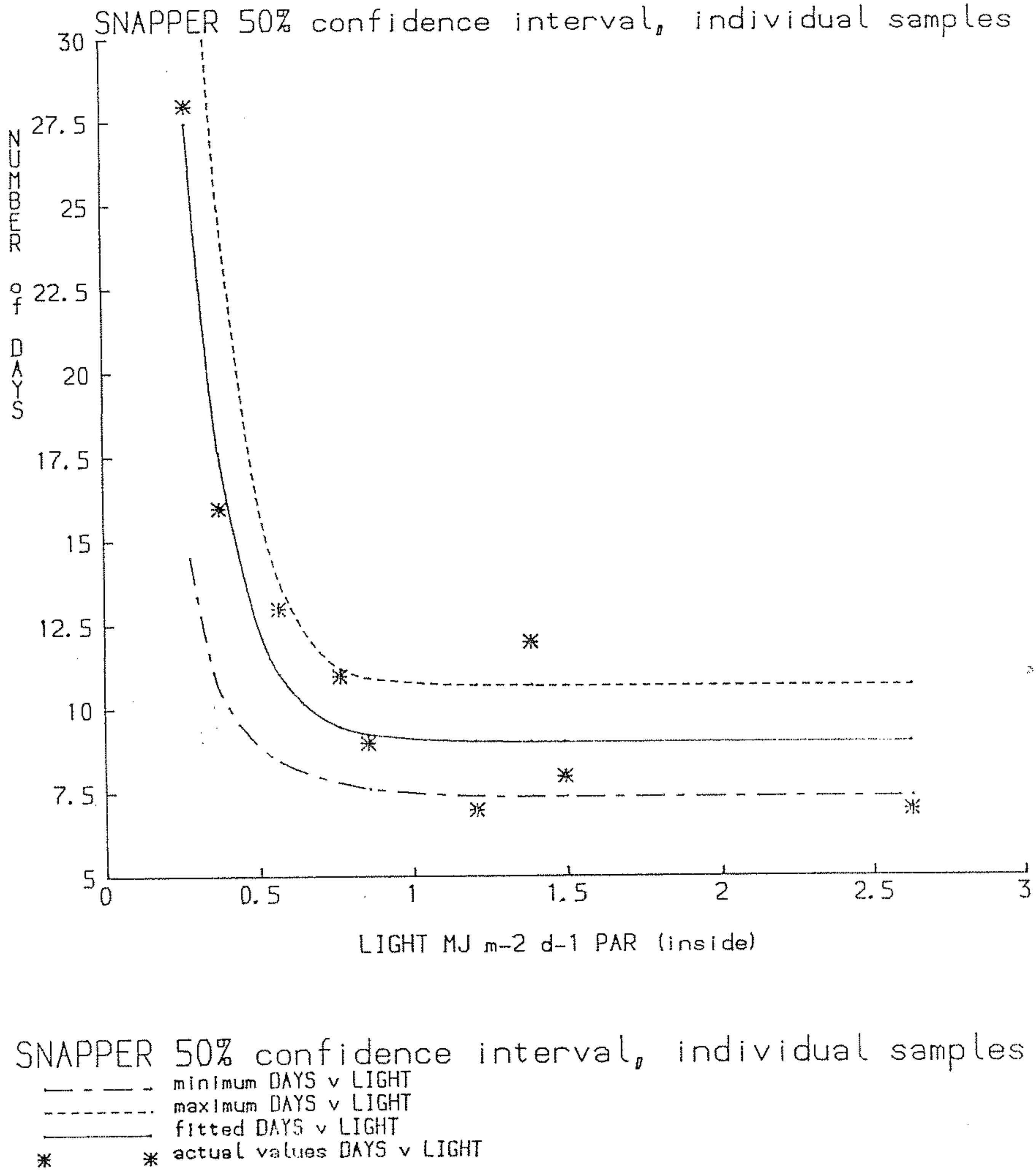

SNAPPER 50% confidence interval, individual samples
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
NUMBER of DAYS
0
0.5
1
1.5
2
2.5
3
LIGHT MJ m-2 d-1 PAR (inside)
SNAPPER 50% confidence interval, individual samples
minimum DAYS v LIGHT
maximum DAYS v LIGHT
fitted DAYS v LIGHT
actual values DAYS v LIGHT

Figure 4

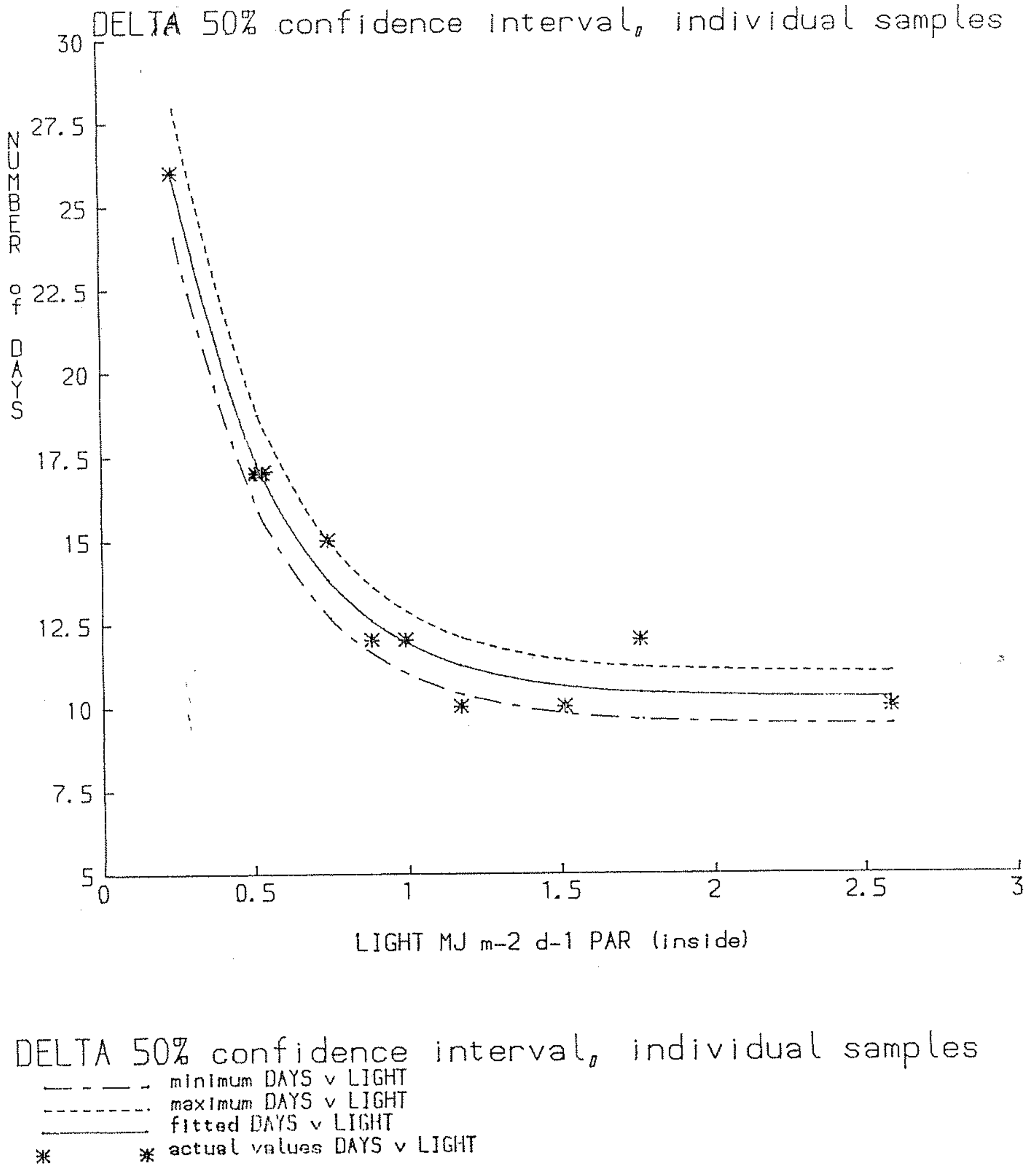
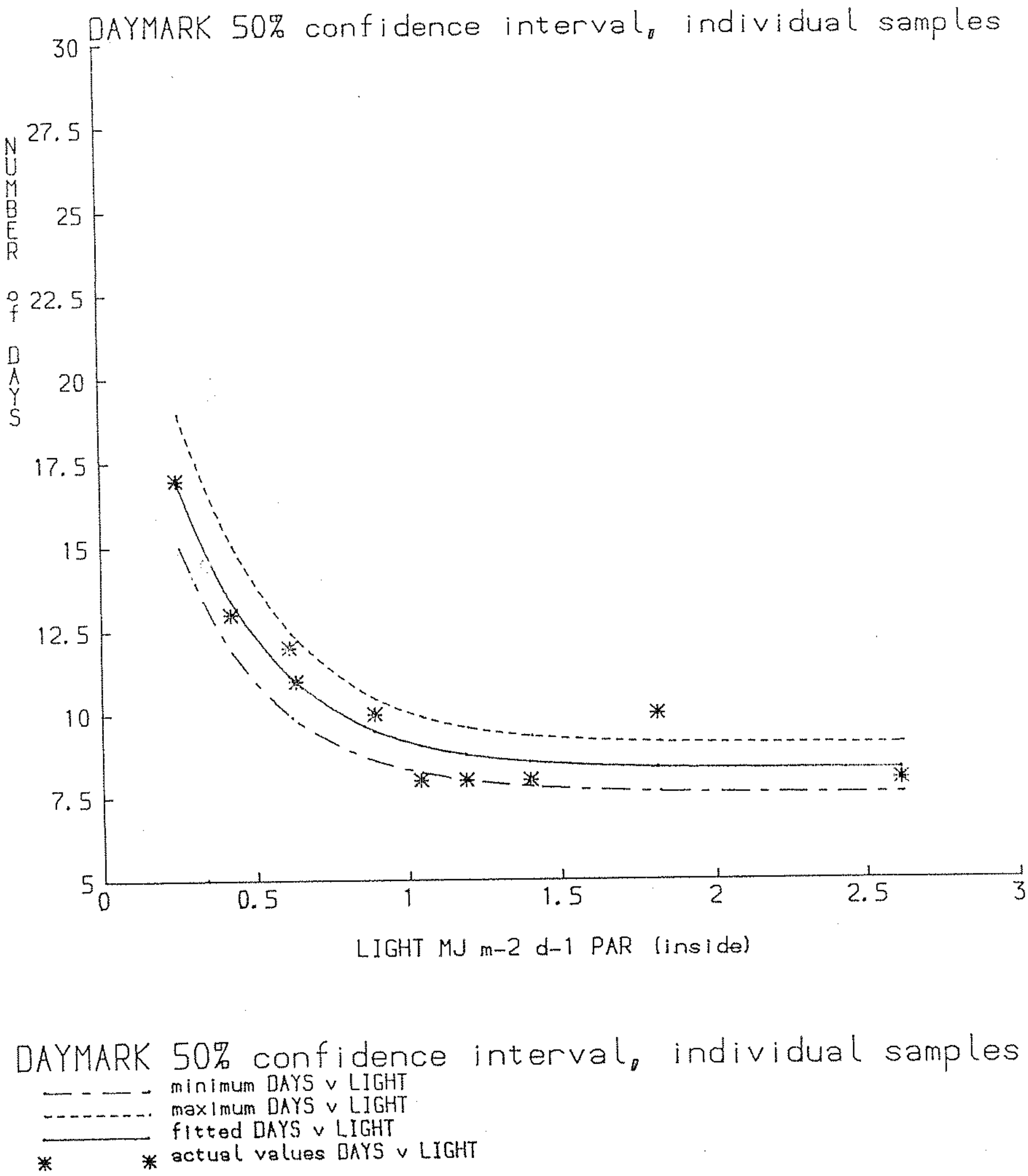
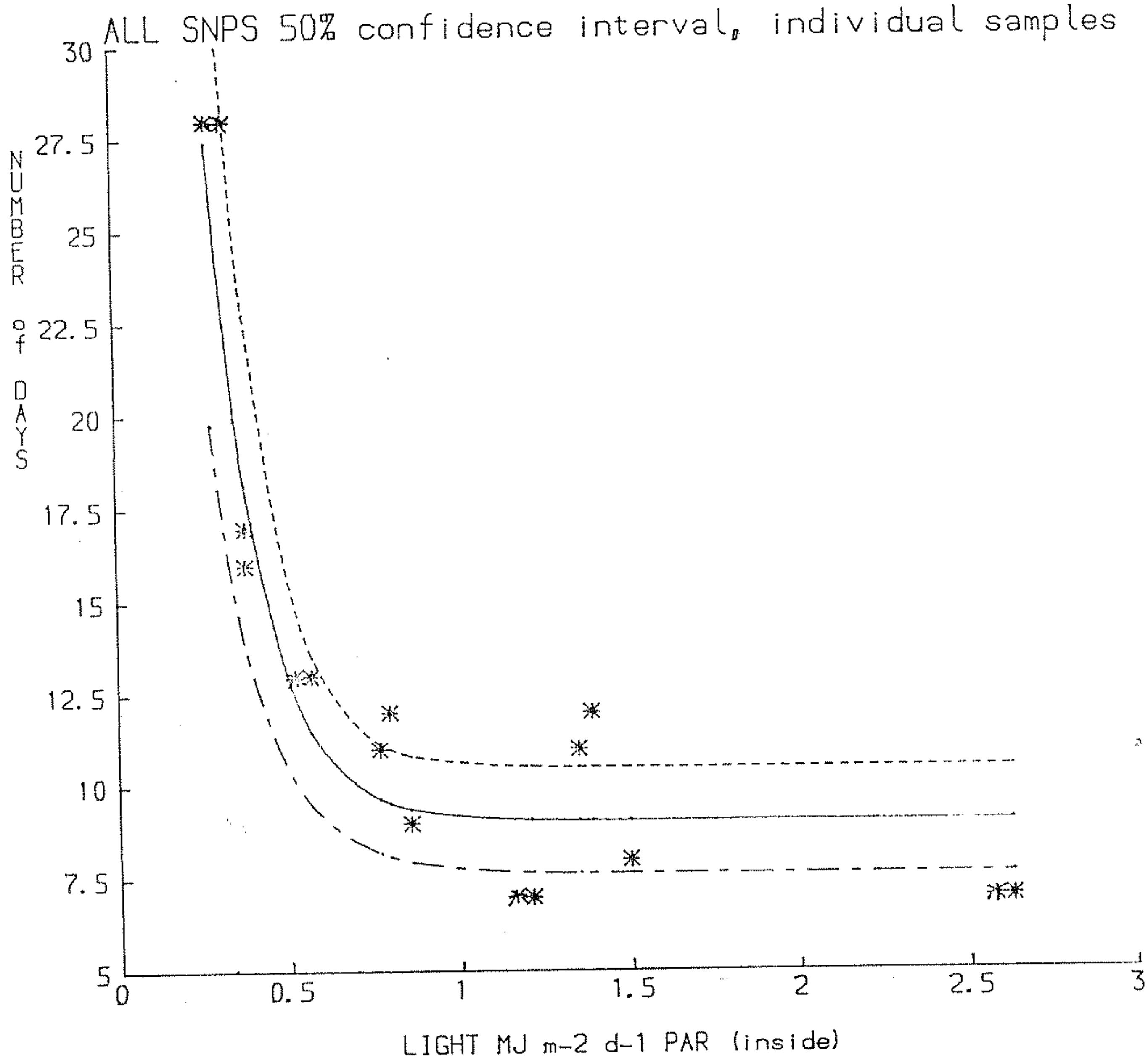

DELTA 50% confidence interval, individual samples
NUMBER of DAYS
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
0
0.5
1
1.5
2
2.5
3
LIGHT MJ m-2 d-1 PAR (inside)
DELTA 50% confidence interval, individual samples
minimum DAYS v LIGHT
maximum DAYS v LIGHT
fitted DAYS v LIGHT
actual values DAYS v LIGHT

Figure 5



DAYMARK 50% confidence interval, individual samples
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
NUMBER of DAYS
0
0.5
1
1.5
2
2.5
3
LIGHT MJ m-2 d-1 PAR (inside)
DAYMARK 50% confidence interval, individual samples
minimum DAYS v LIGHT
maximum DAYS v LIGHT
fitted DAYS v LIGHT
actual values DAYS v LIGHT

Figure 6



ALL SNPS 50% confidence interval, individual samples

- — - — - minimum DAYS v LIGHT
- - - - - - maximum DAYS v LIGHT
- ——— fitted DAYS v LIGHT
- * * actual values DAYS v LIGHT

Table 1. Predictions for days to complete initiation based on fitted lines and on upper limit lines of the 50% confidence interval (ci).

Light integral $MJ\ m^{-2}\ d^{-1}$ PAR	Days to complete initiation					
	Snowdon		Pink Gin		Snapper	
	Fitted	50% ci	Fitted	50% ci	Fitted	50% ci
1.00	10	11	11	12	10	11
0.90	11	12	11	12	10	11
0.80	11	13	12	13	10	12
0.70	12	14	12	13	10	12
0.60	13	15	14	15	11	14
0.50	15	17	15	17	13	17
0.40	17	19	18	20	17	23
0.30	19	22	23	25	25	36
0.20	23	25	30	34	42	>50
	Delta		Daymark		All Snappers	
	Fitted	50% ci	Fitted	50% ci	Fitted	50% ci
1.00	12	13	10	10	10	11
0.90	13	14	10	11	10	11
0.80	14	15	10	11	10	12
0.70	15	16	11	12	10	12
0.60	16	18	12	13	11	13
0.50	18	20	13	14	13	16
0.40	21	22	14	16	17	21
0.30	24	26	16	18	25	32
0.20	29	31	19	21	41	>50

Table 2. Predictions of numbers of days for complete initiation based on IHR,L data and actual values derived from Efford EHS trials (0.4 $MJ\ m^{-2}\ d^{-1}$ PAR).

	Cultivars			
	Pink Gin	Delta	Daymark	All Snappers
Prediction - fitted	18	21	14	17
Prediction - 50% ci	20	22	16	21
Efford - actual	17	22	16	16-17

Table 3. Predictive relationships between numbers of SD for complete initiation and average light integral (MJ m^{-2} d^{-1} PAR) measured within the glasshouse. These are based on upper limit lines of the 50% confidence interval.

No SD	Snowdon	Pink Gin	Snapper	Delta	Daymark	All Snappers
9	-	-	-	-	-	-
10	1.33	-	-	-	1.02	-
11	1.01	1.15	0.85	2.52	0.79	0.81
12	0.84	0.82	0.69	1.21	0.66	0.67
13	0.73	0.70	0.61	0.98	0.56	0.60
14	0.64	0.62	0.57	0.84	0.49	0.55
15	0.57	0.56	0.53	0.74	0.43	0.52
16	0.51	0.52	0.51	0.67	0.38	0.49
17	0.46	0.48	0.48	0.61	0.33	0.47
18	0.42	0.45	0.47	0.55	0.29	0.45
19	0.38	0.42	0.45	0.51	0.26	0.43
20	0.34	0.39	0.43	0.47	0.23	0.41
21	0.31	0.37	0.42	0.43	0.20	0.40
22	0.28	0.35	0.41	0.40	0.17	0.39
23	0.25	0.33	0.40	0.37	0.15	0.38
24	0.22	0.32	0.39	0.34	0.12	0.36
25	0.20	0.30	0.38	0.32	0.10	0.35

Table 4. Predictive relationships between numbers of SD for complete initiation and average total solar radiation (MJ m^{-2} d^{-1}) measured outside the glasshouse. These are based on upper limit lines of the 50% confidence interval.

No SD	Snowdon	Pink Gin	Snapper	Delta	Daymark	All Snappers
9	-	-	-	-	-	-
10	3.80	-	-	-	2.91	-
11	2.89	3.29	2.43	7.20	2.26	2.31
12	2.40	2.34	1.97	3.46	1.89	1.91
13	2.09	2.00	1.74	2.80	1.60	1.71
14	1.83	1.77	1.63	2.40	1.40	1.57
15	1.63	1.60	1.51	2.11	1.23	1.49
16	1.46	1.49	1.46	1.91	1.09	1.40
17	1.31	1.37	1.37	1.74	0.94	1.34
18	1.20	1.29	1.33	1.57	0.83	1.29
19	1.09	1.20	1.28	1.46	0.74	1.23
20	0.97	1.12	1.23	1.34	0.66	1.18
21	0.89	1.06	1.20	1.23	0.57	1.14
22	0.80	1.00	1.17	1.14	0.49	1.11
23	0.71	0.94	1.14	1.06	0.42	1.08
24	0.63	0.90	1.11	0.97	0.35	1.04
25	0.57	0.86	1.09	0.91	0.29	1.00