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Extension of the production season in leeks by understanding vernalization and early growth
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I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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PRACTICAL SECTION FOR GROWERS

The variety Prelina was sown on 3 October, 17 October, 31 October, 14 November, 28 November and 12 December 1995 in 308 module trays and on 31 October in 3.2 cm peat blocks. Plants were raised at 18°C for six weeks and at day/night temperatures of 15/10°C for a further three weeks before transfer to frost protection until planting. Plants were transplanted at Gwithian, Cornwall on 22/23 February and 28 March and at Wellesbourne on 19 March. Plants were either covered with fleece or left uncovered. Samples of the crop were taken weekly from the time of fleece removal (Gwithian-19 May, Wellesbourne-3 June) until late June/early July. The leeks were trimmed, weighed and measured and the height of the flowering stalk determined.

There were treatment effects of time of sowing and crop cover which were consistent between the two sites and between the two transplantings at Gwithian. There the second transplanting was consistently behind the first in all characters. The block-raised plants followed the same pattern of development as module-raised plants but were ahead in their development, producing larger plants whose progress towards flowering was also more advanced. The percentage of plants with flower stalks decreased with later sowing and unlike 1995 there was no benefit from fleece cover. There were differences between the two transplantings at Gwithian and at Wellesbourne in percentage of flowering plants and percentage of bolters, showing that the effect of the environment during the latter stages of plant raising and in the field is important in determining the level of bolters. These results suggest that while the main stimulus for vernalization comes during the latter part of the raising period the early conditions in the field were insufficiently warm in 1996 to prevent the completion of vernalization or to devernalize plants. Marketable yields increased with time to a maximum, which occurred later with later sowings. Thus the timing of harvest to maximise marketable yields is crucial. It seems likely that there is a strong case for increasing plant raising temperatures during the later stages of raising in order to delay bolting relative to the development of marketable yield.

SCIENCE SECTION

Introduction

The production of leeks in the UK has expanded considerably in recent years but is still not possible over a full 12-month period. There tends to be a gap in production of about six weeks during May and early June because of bolting in overwintered leeks. The aim of any production system targeting this particular market must be to do everything possible to delay flower initiation and to slow the rate of flower stalk extension while encouraging vegetative growth.

- The objective of this work is to study the effect of plant raising conditions and the field environment on early growth, vernalization and bolting to determine whether it is possible to grow earlier crops in Cornwall to fill the production gap and provide the consumer with all year round leeks which do not bolt.

At present, the effects of temperature, solar radiation and day length on plants sown at different times are unclear and need resolving in order to determine whether it is possible to manipulate growing conditions during plant raising and early field growth in order to minimise bolting and maximise vegetative growth. It is possible that the conditions causing flower initiation (vernalization) are distinct from those causing extension of the flowering stalk (bolting).

Outline of materials and methods

The experiment was conducted with the variety Prelina. There were six sowing dates (3 October, 17 October, 31 October, 14 November, 28 November and 12 December

1995) and two covering treatments in the field (covered with fleece or left open). Plants were transplanted in experiments at two sites: Wellesbourne and Gwithian, Cornwall. At Wellesbourne there were four replicates of the twelve treatments while in Cornwall, where there were two planting dates, there were two replicates of the 24 treatments. Seeds were sown into 308 module trays and for the 31 October sowing 3.2 cm peat blocks were also used to provide a simple comparison with module-raised plants. Seeds were germinated and raised at 18°C for six weeks and at day/night temperatures of 15/10°C for a further 3 weeks before transfer to frost protection in which the temperature did not fall below 2.4°C. Trays were watered as necessary throughout growth and were fed initially fortnightly and later weekly with a feed containing 200 mg l^{-1} N, 30 mg l^{-1} P and 150 mg l^{-1} K, starting four weeks after sowing. On 14 February plants were moved to Cornwall, where they were kept in a glasshouse with frost protection and fed as previously described until transplanted.

Plants were transplanted at Gwithian on 22 and 23 February 1996 and 28 March into a prepared seedbed to which 50 kg N, 105 kg P and 200 kg K ha^{-1} had been applied and incorporated. At Wellesbourne plants were transplanted on 19 March into land which had been prepared similarly. On both sites transplants were spaced 12.5 cm apart in four 40 cm rows in 1.83 m wide beds. At Gwithian the crop was top-dressed with 100 kg N ha^{-1} on 26 March and a further 50 kg N ha^{-1} on 21 May and a total of 52 mm of irrigation was applied on 16 May, 14 June and 20 June. Fleece was laid on 26 February and 16 April and removed on 19 May. Samples of plants were taken at transplanting and weekly from 19 May to 30 June. At Wellesbourne irrigation was applied as necessary throughout growth to keep the soil moisture deficit below 25 mm and a top dressing of 50 kg N ha^{-1} was applied on 4 June. Fleece was laid on 25 March and removed on 3 June. Samples of plants were taken at transplanting and weekly from 3 June to 8 July. Measurements included shank length and diameter, total plant weight, trimmed weight, the height of the flowering stalk above the base plate and visible bolters.

Results so far

The temperatures and accumulated solar radiation during the later stages of plant development are shown in Table 1 together with 1995 data for comparison.

Table 1. Conditions during plant raising

Week number (beginning)	Mean temperature frost protection (°C) Wellesbourne		Glasshouse mean (°C) Gwithian	Accumulated solar radiation($MJm^{-2}w^{-1}$) Wellesbourne	
	1994/5	1995/6	1996	1994/5	1995/6
49 (4-12-95)	-	4.7	-	19.0	16.5
50 (11-12)	-	5.8	-	14.7	10.4
51 (18-12)	7.0	6.1	-	12.5	10.2
52 (25-12)	9.4	4.4	-	5.2	15.9
1 (1-01-96)	7.4	6.7	-	16.6	8.3
2 (8-01)	8.5	9.2	-	16.1	15.9
3 (15-01)	7.6	7.0	-	10.9	10.3
4 (22-01)	7.8	4.7	-	16.9	11.1
5 (29-01)	8.9	5.0	-	27.1	17.0
6 (5-02)	8.7	5.7	-	19.0	24.5
7 (12-02)	8.5	7.0	10.3	36.1	27.9
8 (19-02)	8.8	5.9	9.3	41.7	36.4
9 (26-02)	8.7	7.3	10.6	57.8	51.0
10 (4-03)	9.0	6.9	10.7	58.9	42.7
11 (11-03)	9.6	5.9	11.5	76.6	44.6
12 (18-03)	10.7	-	10.2	77.0	30.1

Temperatures in the field at Gwithian and Wellesbourne from covered and uncovered plots are shown in Table 2. **The main objective of the first two years of this work has been to determine the effect of plant raising regimes on bolting in the early leek crop.** Analyses of variance were carried out on all the characters measured at each sample but for simplicity the results are restricted to percentage visible bolters, percentage flowering stalks above the base plate, percentage of marketable leeks and marketable yield.

Table 2. Field met data. Mean temperatures (^{0}C)

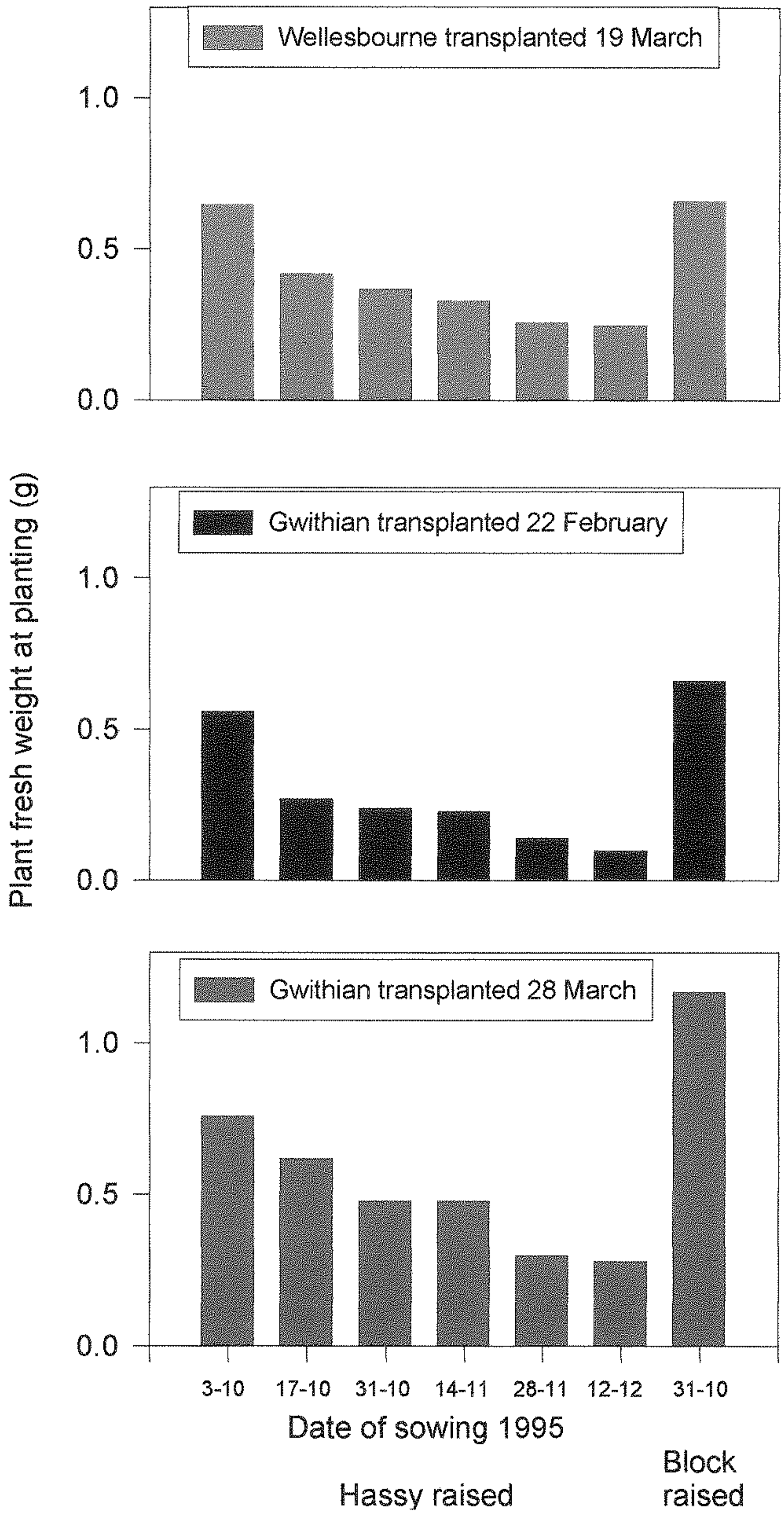
Week number (beginning)	Gwithian		Wellesbourne	
	Open	Fleece	Open	Fleece
9 (26-02)	5.7	6.6	-	-
10 (4-03)	6.1	6.9	-	-
11 (11-03)	6.1	6.1	-	-
12 (18-03)	7.9	8.3	6.5	6.5
13 (25-03)	5.6	6.6	4.0	5.5
14 (1-04)	6.0	7.4	5.2	6.8
15 (8-04)	9.4	10.6	8.0	9.9
16 (15-04)	10.2	11.6	11.9	12.9
17 (22-04)	10.6	12.8	11.2	13.8
18 (29-04)	8.6	11.1	8.3	11.0
19 (6-05)	8.8	11.4	8.2	10.5
20 (13-05)	9.1	11.6	8.1	10.6
21 (20-05)	10.9	-	11.5	12.6
22 (27-05)	12.9	-	14.4	15.4
23 (3-06)	14.0	-	17.9	-
24 (10-06)	15.5	-	17.0	-
25 (17-06)	16.9	-	15.7	-
26 (24-06)	16.3	-	16.1	-
27 (1-07)	-	-	14.1	-

General observations

The weather in 1996 was not conducive to the early production of leeks with particularly low light levels during plant raising from early January onwards. Indeed for the month of January average solar radiation was 27% down on that for the previous year and for January and February it was 16% lower than 1995. Tables 1 and 2 show that temperatures in the glasshouse at Gwithian were higher than in the field, that temperatures in the field at Gwithian were slightly higher than at Wellesbourne immediately after transplanting at Wellesbourne and that temperatures under fleece exceeded those in the open. Once plants were transplanted temperatures were lower than normal with ground frosts still occurring in Cornwall as late as mid-May.

The analyses indicate that significant treatment effects were largely confined to those of time of sowing and crop cover. Relevant data are presented as means across other treatments. The effects of sowing date were similar between Gwithian and Wellesbourne and between transplantings at Gwithian. The second transplanting at Gwithian behaved like the first but was consistently behind it in all characters. The criteria for marketability were diameter greater than 15 mm and flower stalk less than the break in the pseudostem but other options are possible because data are available for individual leeks. For comparable dates of harvest the leek plants in Cornwall were smaller than those at Wellesbourne primarily as a result of differences in soil type and irrigation regime. The block-raised plants grown at Gwithian and Wellesbourne followed the same pattern of development as the module-raised plants from the same sowing date (31 October) but were consistently ahead in their development as can be seen in Figure 1 which shows plant weight at transplanting. They produced larger plants in the field that were initially more than two weeks ahead of module-raised

Fig. 1. Plant fresh weight at planting



plants. However the percentage of flowering plants was also greater suggesting that the critical phase of growth, when temperatures influence vernalization, was reached earlier in these plants and that later sowing of block-raised plants would probably have been highly beneficial.

Percentage flowering stalks above the base plate

These were determined by cutting each leek in half down the stem and looking for apical development above the baseplate. In the absence of time-consuming plant dissections at the apex, this is the best indicator of floral initiation. The percentage of plants with flower stalks (Table 3) decreased with later sowing and like 1995 at Wellesbourne did not increase after early July. This suggests that the environmental conditions triggering flowering occur during the later stages of plant raising or during early field growth. It is likely that the plant will not respond to potentially vernalizing conditions until it has reached a particular size or weight. Thus later sowings reach this critical phase later when plant raising temperatures for plants held under frost protection are gradually increasing and are more favourable for vegetative growth. The second transplanting at Gwithian with a lower percentage of flowering plants may have simply been at an earlier stage of growth. Alternatively, the temperatures in the glasshouse, which were higher than in the field, may have partially prevented vernalization or actually been responsible for some devernalization. Unlike 1995 there was no benefit from fleece cover in terms of suppressing flower stalk development, suggesting that the early season field temperatures were insufficiently high to prevent the completion of vernalization. The level of flower stalk development from Gwithian transplanting 1 was greater than at Wellesbourne which in turn was greater than from

Gwithian transplanting 2, again suggesting that the conditions triggering flower initiation had probably been largely satisfied by mid-February but that some influence of the early field environment remained.

Table 3. Percentage flowering stalks above the base plate. (Sowings are a mean over covering treatments and covering treatments are a mean over sowings)

	Sown						Cover	
Sampled	3-10	17-10	31-10	14-11	28-11	12-12	Open	Fleece
Wellesbourne transplanted 19 March								
3-06	50	21	20	4	6	0	7	27
10-06	88	84	71	41	26	8	48	58
17-06	78	76	54	33	23	5	39	50
24-06	96	83	70	43	46	13	53	63
1-07	93	85	89	75	56	30	69	74
8-07	94	80	84	68	43	23	65	65
Gwithian transplanted 22 February								
19-05	8	0	0	0	0	0	0	3
26-05	43	20	18	0	0	0	8	19
2-06	80	55	30	5	0	3	26	32
9-06	85	73	58	33	33	3	51	43
16-06	93	93	80	60	38	18	63	63
23-06	95	93	88	78	68	23	75	73
30-06	95	98	58	88	65	50	79	72
Gwithian transplanted 28 March								
19-05	0	0	0	0	0	0	0	0
26-05	3	0	0	8	3	0	2	3
2-06	15	18	8	0	0	0	6	8
9-06	48	35	38	25	0	0	18	30
16-06	60	60	38	30	13	0	34	33
23-06	88	68	70	58	23	10	53	53
30-06	78	83	70	58	23	65	64	61

Percentage visible bolters

These are those plants where the flowering stalk has emerged from the pseudostem. They decrease with later sowing (Table 4) but, at both sites, in contrast to 1995, fleece

Table 4. Percentage visible bolters. (Sowings are a mean over covering treatments and covering treatments are a mean over sowings)

	Sown						Cover	
Sampled	3-10	17-10	31-10	14-11	28-11	12-12	Open	Fleece
Wellesbourne transplanted 19 March								
3-06	0	0	0	0	0	0	0	0
10-06	1	0	0	0	0	0	0	0
17-06	5	1	0	0	0	0	0	2
24-06	29	15	11	3	0	0	6	13
1-07	51	31	31	15	6	1	20	26
8-07	79	53	44	30	11	1	36	36
Gwithian transplanted 22 February								
19-05	0	0	0	0	0	0	0	0
26-05	0	0	0	0	0	0	0	0
2-06	0	0	0	0	0	0	0	0
9-06	43	13	3	3	3	0	8	13
16-06	13	0	3	0	0	0	1	4
23-06	53	35	23	5	8	0	18	23
30-06	73	35	15	25	8	0	36	16
Gwithian transplanted 28 March								
19-05	0	0	0	0	0	0	0	0
26-05	0	0	0	0	0	0	0	0
2-06	0	0	0	0	0	0	0	0
9-06	8	0	0	0	0	0	0	3
16-06	0	0	0	0	0	0	0	0
23-06	18	0	5	5	0	0	4	5
30-06	10	18	13	0	0	18	7	13

had no effect on the number of bolters. This again suggests that the level of vernalization was largely fixed before plants were transplanted. The level of bolters was however lower in Gwithian transplanting 2 than at Wellesbourne which suggests that elongation of the flowering stalk was slightly suppressed in Cornwall or perhaps that plant raising and/or field conditions there enabled some devernalization to occur. Work in Germany by Wiebe has shown that devernalization can occur in leeks. Since transplants were moved to Cornwall in February, temperatures there in the glasshouse were higher than at Wellesbourne and Table 2 shows that in general field temperatures were slightly higher than at Wellesbourne.

Marketable yield

This has two controlling features. As the leeks grow they increase in diameter to gradually exceed 15 mm and thus become marketable. At the same time many leeks have flowering stalks which are getting longer and when these exceed the length to the break in the pseudostem the plants become unmarketable. Thus the key to early leek production is to delay flower stalk extension as much as possible and to encourage vegetative growth so that more leeks reach 15 mm diameter before flower stalks have reached an unacceptable length. The use of fleece not surprisingly increased marketable yields. At Gwithian marketable leeks were available in late May although yields were low. At Wellesbourne for each sowing date marketable yields increased to a maximum and then declined as the level of bolters increased (Table 5). The sample at which maximum yields were achieved increased by a week per sowing from sowing 1 to sowing 4. The highest yields of 15 t/ha were still achieved on 1 July from 12 December sowing with fleece cover. The yields achieved in Cornwall were not as high as this because many of the leeks were not large enough but later sowings gave higher yields with the highest yield from the 28 November sowing with fleece cover harvested on 30 June.

Table 5. Marketable yield (t/ha) based on leeks greater than 15 mm in diameter and with flower stalks below the break in the pseudo stem

	Sown					
Sampled	3-10	17-10	31-10	14-11	28-11	12-12
Wellesbourne transplanted 19 March, fleece cover						
3-06	0.6	0.4	0.5	0.5	0.5	0.5
10-06	4.0	2.8	2.7	3.3	3.4	1.8
17-06	3.9	4.5	5.7	4.7	6.1	5.2
24-06	2.1	2.1	6.7	8.8	10.9	8.3
1-07	2.3	2.9	3.3	11.7	10.3	15.0
8-07	2.8	2.8	3.5	4.3	4.2	1.7
Gwithian transplanted 22 February, fleece cover						
19-05	-	-	-	-	-	-
26-05	1.8	1.0	-	-	0.3	-
2-06	4.6	0.9	2.1	-	1.2	0.3
9-06	2.4	1.2	2.3	2.1	1.7	-
16-06	5.0	2.7	7.3	1.8	3.9	3.5
23-06	2.4	4.2	6.2	2.5	7.8	5.5
30-06	5.6	5.8	5.3	7.0	8.9	8.2

CONCLUSIONS

1. Early leek production requires flower stalk extension to be delayed as long as possible while maximising increase in plant diameter. The timing of harvest to maximise marketable yields is critical.

2. Later sowing gives fewer plants with a flowering stalk and fewer bolters. There seems no point in sowing in module trays earlier than the end of October while December is too late for plants which might be transplanted in February unless a lot of heat is used in plant raising.

3. The indications are from 1995, when early raising temperature differences did not affect bolting, and from this year, when later sowing reduced the level of flowers and bolters, that it is the conditions during the later stages of plant raising that affect the ability to flower.

4. Fleece cover increased marketable yields but did not reduce percentage flowering. The latter suggests that either the sensitive phase for flower development had completely passed by transplanting or that temperatures during early field growth under fleece in 1996 were just not high enough to produce devernalization of plants. Fleece cover is essential for early production.

5. As in 1995 by early July plants had either reached a growth stage at which they did not respond to vernalizing temperatures or long days prevented further floral initiation or the temperatures achieved exceeded those allowing vernalization.

6. The sowing date with the highest marketable yield was 12 December at Wellesbourne and 28 November at Gwithian.

7. The use of block-raised plants produces bigger transplants and bigger plants in the field but also produces earlier bolters suggesting that sowing after the end of October will be advisable.

8. The data from 1995 and 1996, with a range of raising and field temperatures, have shown considerable effects on percentage flowering stalks and bolters. Extensive 'environmental data analyses' are now needed to determine when plants are susceptible to vernalizing temperatures and what those temperatures are.