Project Report

Production practices, storage and sprouting conditions affecting number of stems per seed tuber and the grading of potato crops

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Summary

The dormancy and re-growth of seed tubers of several varieties from a range of production cycles was investigated over a wide range of replanting dates in 2001-2003. The experiments in all years have quantified the effect of duration of storage period on the numbers of stems produced by seed tubers and examined how these effects are modified by sprout development prior to planting and by environmental conditions following planting. In 2003 experiments also examined variation that may be attributed to differences between seed tubers within a seed crop and effects of seed cutting and modified atmospheres on seed from different production cycles. Density experiments were also carried out in 2003 to determine the relationship between stem density, yield and tuber size distribution for contrasting seed stocks.

Results over the three years showed that the interval from emergence of seed to date of apparent dormancy break was relatively conservative. The data also show that for unsprouted seed planted into warm soil there was a predictable increase in number of stems with delay in planting up to *c*. 450 days from the emergence of the seed crop followed by a decrease in productivity. Differences in sprouting during storage for seed stocks from different production cycles were consistent but the variation observed in stem production from planting sprouted seed requires further investigation.

The density experiments showed that differences in stem populations resulting from planting contrasting seed stocks at the same plant density could have substantial effects on tuber size distribution. Application of these findings should enable seed to be used more efficiently and experiments with a greater number of varieties are planned for 2004.

Differences in the number of stems produced by seed stocks were almost invariably consistent but plantings into cold soil tended to result in a greater number of stems than expected and quantifying this effect will be important to enable predictable stem populations to be established under these conditions. Experiments planned for 2004 will provide data to better quantify the effects of sprouting and soil temperature on the underlying change in stem production resulting from differences in seed production cycle.

Introduction

This project investigates the effects of production practice, storage temperatures and sprouting of seed on number of mainstems and tubers per seed tuber and began in 2000 with the production of contrasting seed crops. It will continue in 2004 with planting seed stocks of a wider range of varieties than in 2001-2003. This report covers the results of the third year of experiments replanting seed from different sites and production cycles and the body of data available for Charlotte, Hermes and particularly Estima is now quite comprehensive. The research findings have already been recognised to be of commercial value and several commercial seed crops have been produced. The project should continue to provide information that enables growers to make better use of seed through using the most physiologically appropriate seed for their specific objectives.

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Materials and Methods

Seed production

Seed crops of Estima, Charlotte and Hermes were planted over a wide range of dates in 2000 and 2001 at various sites throughout the UK and in Jerez, Spain. In 2002, seed production also included Maris Piper at three sites. In 2003, Hermes was omitted, but three varieties were added, Maris Peer, Shepody and Saturna, which were produced, along with Estima and Charlotte, at four UK sites (with the exception of Shepody in Northumberland) and Estima was again produced in Jerez, Spain. Crops in the UK were all grown from a common source of seed and were planted and harvested mechanically. Regular counts of plant emergence were made for all crops to establish the date of 50 % emergence. Details of the 2003 seed crops are given in Table 1 (2000-2002 seed crops have been reported previously in the 2002 and 2003 Project Reports).

Seed from all sites was graded in 5 mm increments soon after harvest and placed in boxes or nets. Seed from all sites was initially stored at ambient temperatures and weights of boxes and nets were recorded prior to transfer to cold stores or storage regimes according to treatments, at the end of June in the case of the seed from Spain, or October to November for seed from all other sites.

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Table 1. Timing of key events in the seed crops in 2003

		Date of			
Variety	Site	Planting	Emergence	Defoliation	Harvest
Estima	Spanish	12 Feb	18 Mar	30 Apr	22 May
	Welsh P1	28 Mar	4 May	3 Jul	10 Aug
	Northumberland	23 Apr	26 May	10 Jul	3 Sep
	Wiltshire	11 Apr	25 May	10 Jul	29 Aug
	Welsh P2	25 Jun	10 Jul	27 Aug	1 Oct
Charlotte	Welsh P1	28 Mar	6 May	3 Jul	10 Aug
	Northumberland	23 Apr	26 May	25 Jul	3 Sep
	Wiltshire	11 Apr	28 May	10 Jul	29 Aug
	Welsh P2	25 Jun	12 Jul	27 Aug	1 Oct
Maris Piper	Welsh P1	28 Mar	4 May	3 Jul	10 Aug
	Northumberland	23 Apr	26 May	4 Aug	3 Sep
	Wiltshire	11 Apr	25 May	10 Jul	29 Aug
	Welsh P2	25 Jun	10 Jul	27 Aug	1 Oct
Maris Peer	Welsh P1	28 Mar	4 May	3 Jul	10 Aug
	Northumberland	23 Apr	26 May	4 Aug	3 Sep
	Wiltshire	11 Apr	28 May	10 Jul	29 Aug
	Welsh P2	25 Jun	10 Jul	27 Aug	1 Oct
Saturna	Welsh P1	28 Mar	6 May	3 Jul	10 Aug
	Northumberland	23 Apr	24 May	4 Aug	3 Sep
	Wiltshire	11 Apr	26 May	10 Jul	29 Aug
	Welsh P2	25 Jun	10 Jul	27 Aug	1 Oct
Shepody	Welsh P1	28 Mar	12 May	3 Jul	10 Aug
	Wiltshire	23 Apr	27 May	10 Jul	29 Aug
	Welsh P2	25 Jun	12 Jul	27 Aug	1 Oct

Assessment of dormancy

Weekly observations were made of *c.* 100, 35-45 mm tubers held at 15 ºC, and the mean date of dormancy break was estimated as the first date when ≥ 50 % of tubers had sprouts ≥ 3 mm. For Maris Peer and Maris Piper grown in Wiltshire and Wales P1, samples of *c.* 100, 35-45 mm tubers dug from the crop were placed in the test chamber in early July, August and September. Following grading, samples were obtained from all stocks and placed at 15 ºC. For Maris Peer and Maris Piper grown in Wiltshire and Wales (P1 & P2), and Estima grown in Spain, further samples obtained at grading were retained and held at *c.* 2 ºC, then placed in the 15 ºC controlled temperature cabinet at approximately monthly intervals.

Field experiments in 2003

Using seed from the 2001 and 2002 seed crops, a series of experiments (Table 2) was conducted at Cambridge. The experiments consisted of all combinations of the factors listed in Table 2. Where planting date was a treatment (Expts 5-8), a split-plot design with three replicates was used with planting dates as main plots and other treatment combinations as sub-

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plots. Pre-emergence herbicide was applied to the appropriate main plots following each planting. In these experiments, and Expts 16 and 17, seed was held at *c.* 2 ºC up to planting. For the ageing experiments (Expts 9-12), seed was held at the appropriate treatment temperature (see below) or at *c.* 2 ºC. Seed for other experiments was held at *c.* 3 ºC within 1 t boxes in a commercial cold store. Experiments in which planting date was not a treatment were arranged in randomized blocks with three replicates, except Expts 9-12 where four replicates were used.

All experiments were planted by hand into 76 cm rows and most were planted at a within-row spacing of 30 cm. Exceptions to this were Expt 18, planted at 20 cm within-row spacing and the density experiments (Expts 13-15), in which plant spacing was a treatment. No fertilizer P or K was used and fertilizer N was applied at a rate of 200 kg N/ha as liquid pre-planting. Plots consisted of single rows of 20 plants in Expts 1-7, four rows of 10 plants in Expt 8-12 and 18-19. In Expts 13-15, the number of plants differed between densities (see Table 2) with three 12 m rows in Expts 13-14 and five 2 m rows in Expt 15. Plots consisted of single rows of 16 plants in Expt 16 and four rows of 9 plants in Expt 17. At planting, boxes and nets of seed were weighed to establish weight loss during storage and a record of any decayed tubers was made. Emergence and final number of stems was recorded for all experiments, ground cover recorded regularly for Expts 8-15 and graded yield determined for Expts 8-19. Emergence of stems was recorded regularly for Expts 5-12. Experiments at Cambridge were harvested as follows (Expt nos in parentheses following date): 18 Sep, 29 Sep (8); 13 Aug (9); 23 Jul (10); 22 Sep (11); 23 Sep (12); 3 Jul, 17 Sep (13); 3 Jul, 23 Sep (14, 15); 23 Sep (16); 31 Jul (17); 22 Sep (18); 1 Aug (19).

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Table 2. List of field experiments in 2003

Expt	Variety	Seed size (mm)	Seed stock	Planting date	Other treatments
1	Estima	25-30, 30-35, 35-40, 40-45, 45-50, 50-55	Welsh (P1 & P2), Wiltshire, Cambridge, Northumberland, Spanish	16 Apr	
2	Charlotte	As Expt 1	Welsh P1, Wiltshire, Northumberland, Cambridge	14 Apr	
3	Hermes	As Expt 1	As Expt 2	15 Apr	
4	Maris Piper	As Expt 1	Welsh (P1 & P2), Wiltshire	16 Apr	
5	Estima	30-35, 45-50	Spanish, Welsh (P1 & P2), Wiltshire, Cambridge, Scottish (2001) / Northumberland (2002)	12 Mar, 30 Apr, 18 Jun, 6 Aug	2001 and 2002 seed stocks
6	Charlotte	30-35, 45-50	Northumberland	As Expt 5	2001 and 2002 seed stocks
7	Hermes	30-35, 45-50	Northumberland	As Expt 5	2001 and 2002 seed stocks
8	Estima, Charlotte, Hermes	30-35	Northumberland, Cambridge	22 Apr, 23 Jul	Pre-sprouted 2001 and 2002 seed stocks
9	Estima	35-40	Northumberland, Cambridge	28 Apr	5 seed ages
10	Charlotte	35-40	Northumberland	28 Apr	5 seed ages
11	Hermes	35-40	Northumberland	28 Apr	5 seed ages
12	Maris Piper	35-40	Northumberland	28 Apr	5 seed ages
13	Estima	35-45	Welsh (P1 and P2)	15 Apr	5 within-row spacings (19, 24, 31, 44, 80 cm)
14	Maris Piper	35-45	Welsh (P1 and P2)	16 Apr	As Expt 13
15	Charlotte	35-45	Welsh P1, Cambridge	14 Apr	5 within-row spacings (14, 17, 20, 25, 33 cm)
16	Estima	40-45	Cambridge	16 Apr	2 dates of seed emergence, 2 number of stem categories of mother plant, non-factorial 'control'
17	Estima	Various	Cambridge	16 Apr	2 seed 'zones', 2 dates of seed emergence, 2 sprouting treatments
18	Hermes	30-35	Welsh P1, Northumberland, Welsh (commercial), Cambridge	11 Apr	2 sprouting treatments, 2 cutting treatments
19	Maris Piper, Estima, Hermes	35-45	Early: Welsh P1 except Estima, Wiltshire Late: Welsh P2, except Hermes Wiltshire	11 Apr	2 controlled atmosphere treatments (by GVAP)

Experiments 1-7, 13-15

For these experiments, boxes or nets of seed were removed from cold storage immediately prior to planting, weighed and planted. Separate individual plastic boxes were allocated to sequential plantings in Expts 5-7 so that this seed could be held undisturbed at 2 ºC.

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Experiment 8

Following planting of P1 and P3 of Expts 5-7, 30-35 mm seed of selected stocks (2001 and 2002 produced Cambridge Estima, Northumberland/Scottish Estima, Northumberland/Scottish Hermes, Northumberland/Scottish Charlotte) was placed at 15 ºC. Weekly observations were made and the experiment planted once all stocks had ≥ 50 % of tubers with sprouts ≥ 3 mm.

Experiments 9-12

Trays of 35-40 mm seed were allocated to one of five storage treatments; 2 ºC, 4 ºC, 15 ºC from 1 November to accumulate 300 degree days > 4 ºC (early 300 ºC d), 15 ºC from 21 March to accumulate 300 degree days (late 300 ºC d) or 15 ºC from 1 November until planting. Seed from the early 15 ºC treatment was held at 2 ºC following treatment. During sprouting, the length of the longest sprout was recorded weekly from each treatment and at planting the length of all sprouts on 20 tubers was recorded.

Experiment 16

An area of the 2002 Cambridge Estima seed crop was observed at least every 2-3 days, and individual plants labelled with date of emergence. Once emergence was complete, two contrasting emergence dates were chosen (29 Jul and 5 Aug) and 40-45 mm seed was hand dug from marked plants from these emergence dates and further separated according to the number of stems on the mother plant (≤ 3 stems and ≥ 7 stems per plant). Seed of 40-45 mm for the 'control' treatment was taken at the same time from the machine-harvested crop which emerged on 30 July. Seed was stored at 2 ºC at Cambridge and removed from cold storage immediately prior to planting.

Experiment 17

Zones were defined by partitioning the below ground stem into three equal lengths by eye, zone 1 being closest to the soil surface and zone 3 closest to the mother tuber. Tubers were harvested from zones 2 and 3 from plants with the early and late emergence dates as in Expt 16 and individual tuber weights were recorded. Seed was stored at 2 ºC at Cambridge and unsprouted seed removed from cold storage immediately prior to planting. Sprouted seed was placed at 15 ºC until all tubers had sprouts ≥ 3 mm and then stored at 2 ºC until planting. During sprouting, the length of the longest sprout was recorded weekly from each treatment. At planting, numbered tubers were planted in order, so that the individual weight of each seed tuber was known.

Experiment 18

The cut treatment separated the rose and heel ends and these pieces were placed in separate trays. The sprouted seed (cut and uncut) was held at 15 ºC from 2 April until planting. The length of the longest sprout, and the number of sprouts was recorded for 20 tubers at planting. Unsprouted seed was stored at 2 ºC at Cambridge and removed from cold storage immediately prior to planting. Cut tubers were planted alternating between rose and heel end pieces, so that differences in emergence and number of stems could be recorded.

Experiment 19

The controlled atmosphere treatment was performed by Greenvale AP (GVAP), on seed detailed in Table 2 and supplied to GVAP in January. Nets of untreated seed were held in cold storage until immediately prior to planting, shortly after seed was returned following treatment.

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Results and Discussion

Dormancy

The interval from emergence of the seed crop to dormancy break was within the same range found in the previous three years, for the varieties previously examined (Table 3). The varieties new to the project (Maris Peer, Saturna and Shepody) had a similar interval of *c*. 28 weeks on average. Analysis of sprouting of samples placed sequentially at 15 ºC from both before and after grading showed that the interval to dormancy break was slightly shorter for samples from early test digs (*c*. 6-8 weeks after emergence) than subsequent samples possibly associated with inevitable scuffing of skin of these initial samples (Figure 1). Apart from the very early samples, the apparent dormancy period (weeks from emergence to onset of sprouting) remained relatively consistent until samples were placed in the test chamber > *c*. 25 weeks after emergence. After this time, the apparent (i.e. enforced) dormant period increased following the end of the natural dormant period.

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Table 3. Date of dormancy break and interval from emergence to dormancy break for seed from different sites in 2003

Variety	Site	Date	Weeks from emergence
Estima	Spanish	8 Sep	25
	Welsh P1	1 Dec	30
	Northumberland	8 Dec	28
	Wiltshire	24 Nov	26
	Welsh P2	26 Jan	29
	Mean		28
Charlotte	Welsh P1	17 Nov	28
	Northumberland	1 Dec	27
	Wiltshire	24 Nov	26
	Welsh P2	22 Dec	23
	Mean		26
Maris Piper	Welsh P1	1 Dec	30
	Northumberland	1 Dec	27
	Wiltshire	1 Dec	27
	Welsh P2	26 Jan	29
	Mean		28
Maris Peer	Welsh P1	17 Nov	28
	Northumberland	1 Dec	27
	Wiltshire	1 Dec	27
	Welsh P2	19 Jan	28
	Mean		28
Saturna	Welsh P1	1 Dec	30
	Northumberland	1 Dec	27
	Wiltshire	1 Dec	27
	Welsh P2	2 Feb	30
	Mean		29
Shepody	Welsh P1	1 Dec	29
	Wiltshire	8 Dec	28
	Welsh P2	9 Feb	30
	Mean		29

January and February dates are for the year subsequent to that of seed production.

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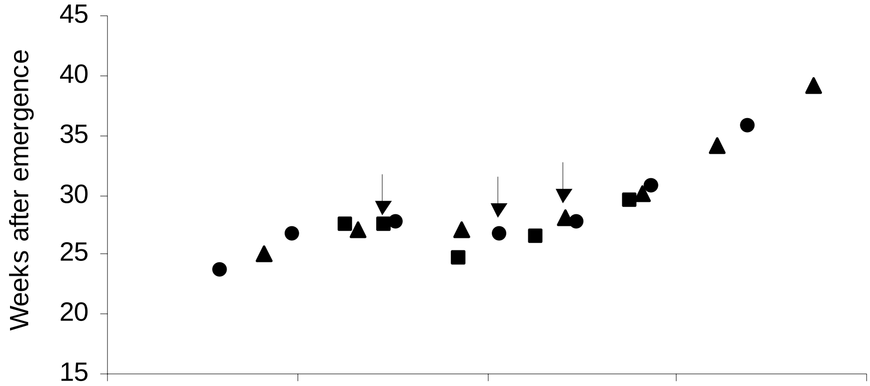
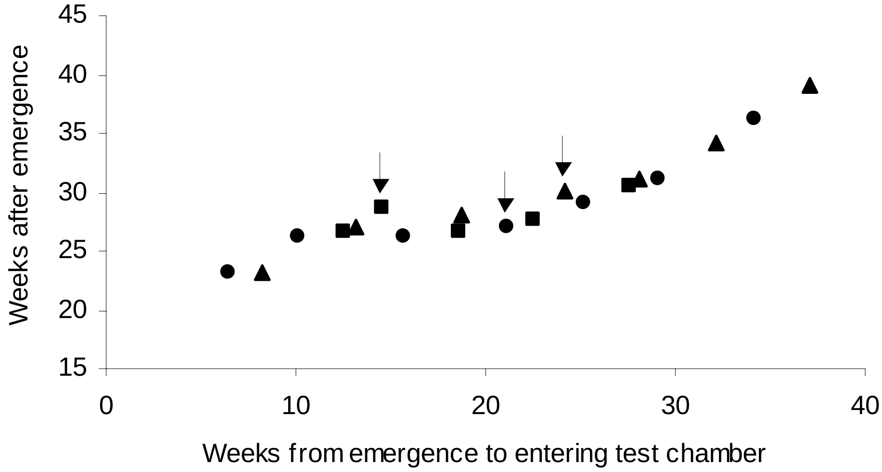
Figure 1. Interval from emergence to dormancy break for (a) Maris Peer and (b) Maris Piper seed from different sites in 2003, placed into the test chamber at different times. ▲, Welsh P1; ●, Wiltshire; ■, Welsh P2. Arrows indicate 'standard' test times, following grading of harvested seed.

(a)



(b)



Expt 1. Seed size and stock (Estima)

Emergence was on average 5 days later for the late-produced Welsh P2 and Cambridge seed stocks (33 ± 0.84 days after planting) than other stocks (28 days; Table 4). Late emerging seed suffered from damage by rooks, resulting in incomplete plots, particularly for the smallest seed sizes (final emergence 82 % Welsh P2, 88 % Cambridge and 85 % Northumberland for 25-30 mm seed). Some secondary stems were produced (0.14 per plant, on average) but no differences were found between stocks or seed size. The relationship between number of mainstems and seed weight was analysed using linear regression with stock as a factor ($R^2 \geq 0.93$ for all varieties). Number of mainstems was generally least for the later-produced seed stocks, the smallest seed of which produced virtually all single-stemmed plants and most for the earliest stocks, with the largest Spanish seed producing eight stems per plant. For each of the stocks, the number of mainstems increased progressively with increase in seed size, although this increase was least for the late-produced stocks and most for the early-produced Spanish stock (Figure 2). These results are very similar to those found in 2001 and 2002, with the

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addition of the very early-produced Spanish seed producing the most marked increase in number of mainstems as would be predicted.

Table 4. Effect of stock and seed size on interval from planting to emergence (weeks) for Estima in Expt 1

	Stock					
Seed size (mm)	Welsh P1	Wilts	Northumberland	Welsh P2	CUF	Spanish
25-30	27.2	31.2	30.5	34.4	34.9	27.0
30-35	28.8	28.0	27.4	34.0	34.2	26.8
35-40	29.0	29.8	27.7	33.7	33.3	26.4
40-45	26.8	27.0	28.7	33.3	33.7	25.7
45-50	28.7	27.2	28.8	30.5	33.8	26.2
50-55	26.7	26.8	28.2	32.1	32.0	29.0
S.E.			0.84			

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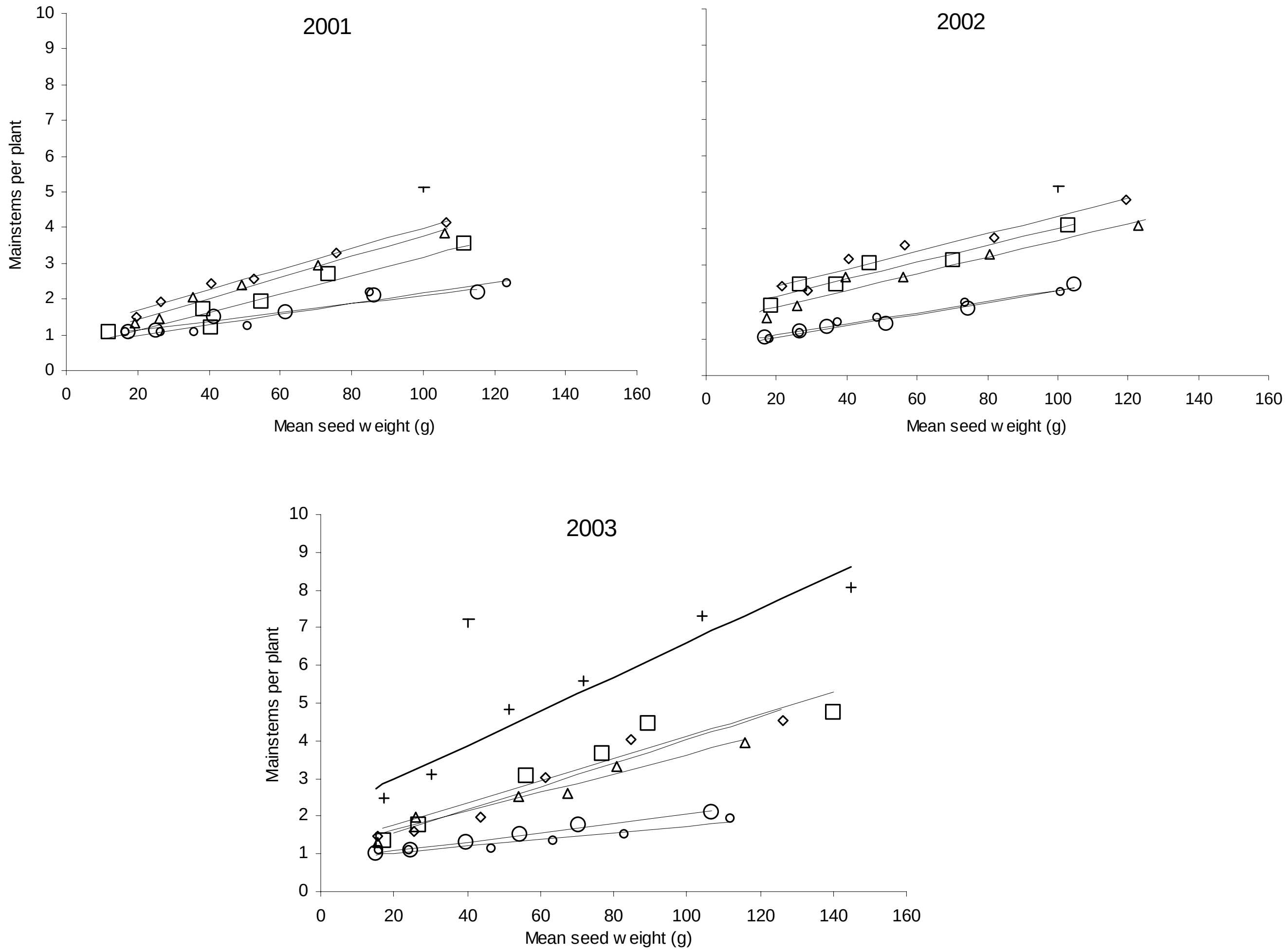
Figure 2. Linear relationships between number of mainstems per plant and seed weight in Estima over three years in Expt 1. Seed stocks: ○, Cambridge; Δ, Scottish/Northumberland; ◇, Welsh P1; ◯, Welsh P2; □, Wiltshire; +, Spanish. Bar indicates S.E.



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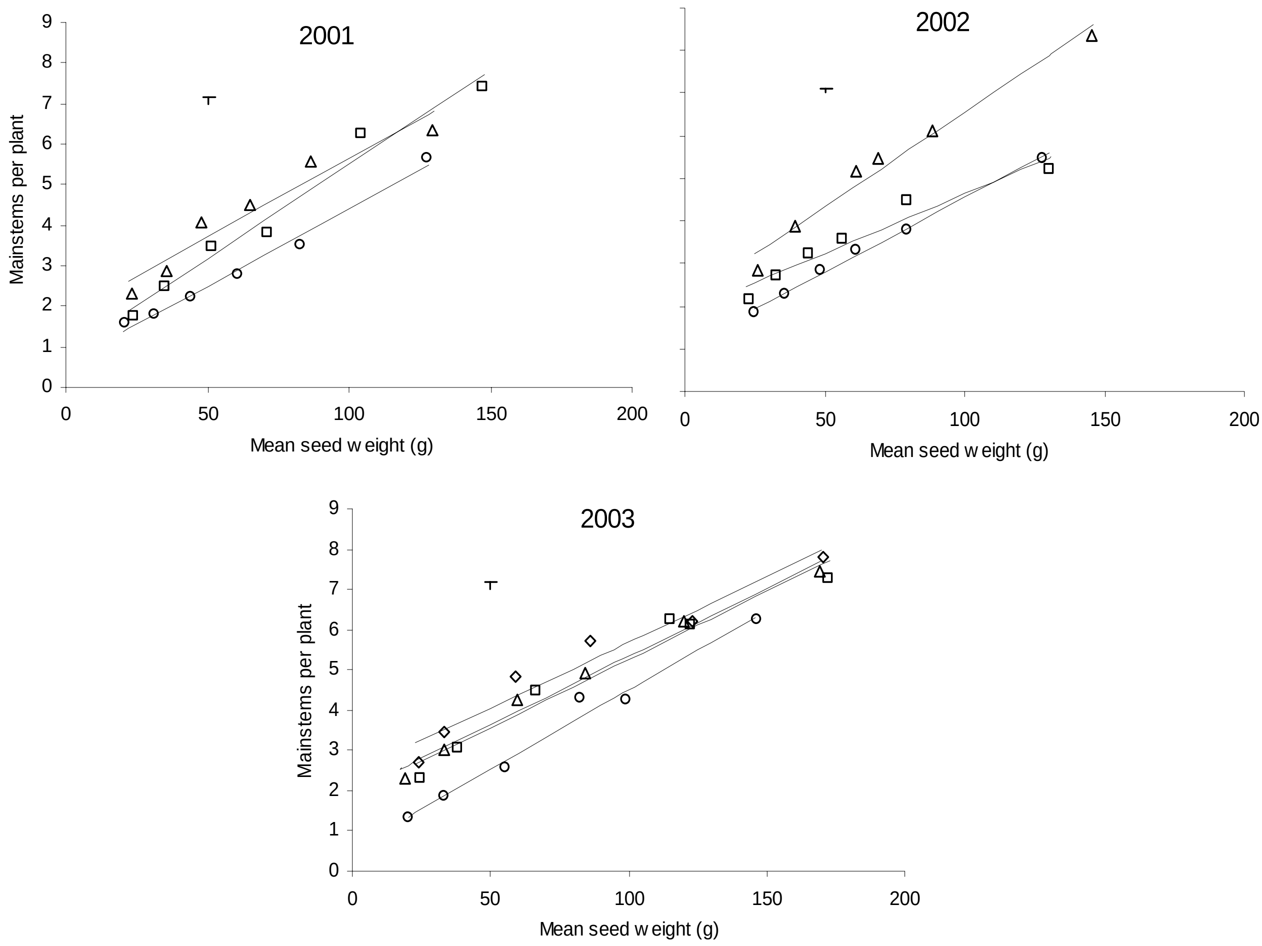
Expt 2. Seed size and stock (Charlotte)

Emergence was on average later for the Cambridge stock (48 ± 0.37 days after planting) than other stocks (42 days) but there was little difference (< 2 days) between seed sizes, and all plots reached near complete emergence. There were few secondary stems in any treatment. The rate of increase in number of mainstems with increase in seed size was similar for all stocks. The number of mainstems was on average greatest for early-produced Welsh P1 seed and least for Cambridge seed. Although the Cambridge seed consistently produced fewer stems than the other stocks, differences between the stocks were less marked than for Estima, with the late-produced large Cambridge seed producing 6.3 stems per plant (compared with 2.1 stems per plant in Estima). Similar effects were generally shown in 2001 and 2002
(Figure 3).

Figure 3. Linear relationships between the number of mainstems per plant and seed weight in Charlotte over three years in Expt 2. Seed stocks: ○, Cambridge; Δ, Scottish/Northumberland; □, Wiltshire; ◇, Welsh P1. Bar indicates S.E.



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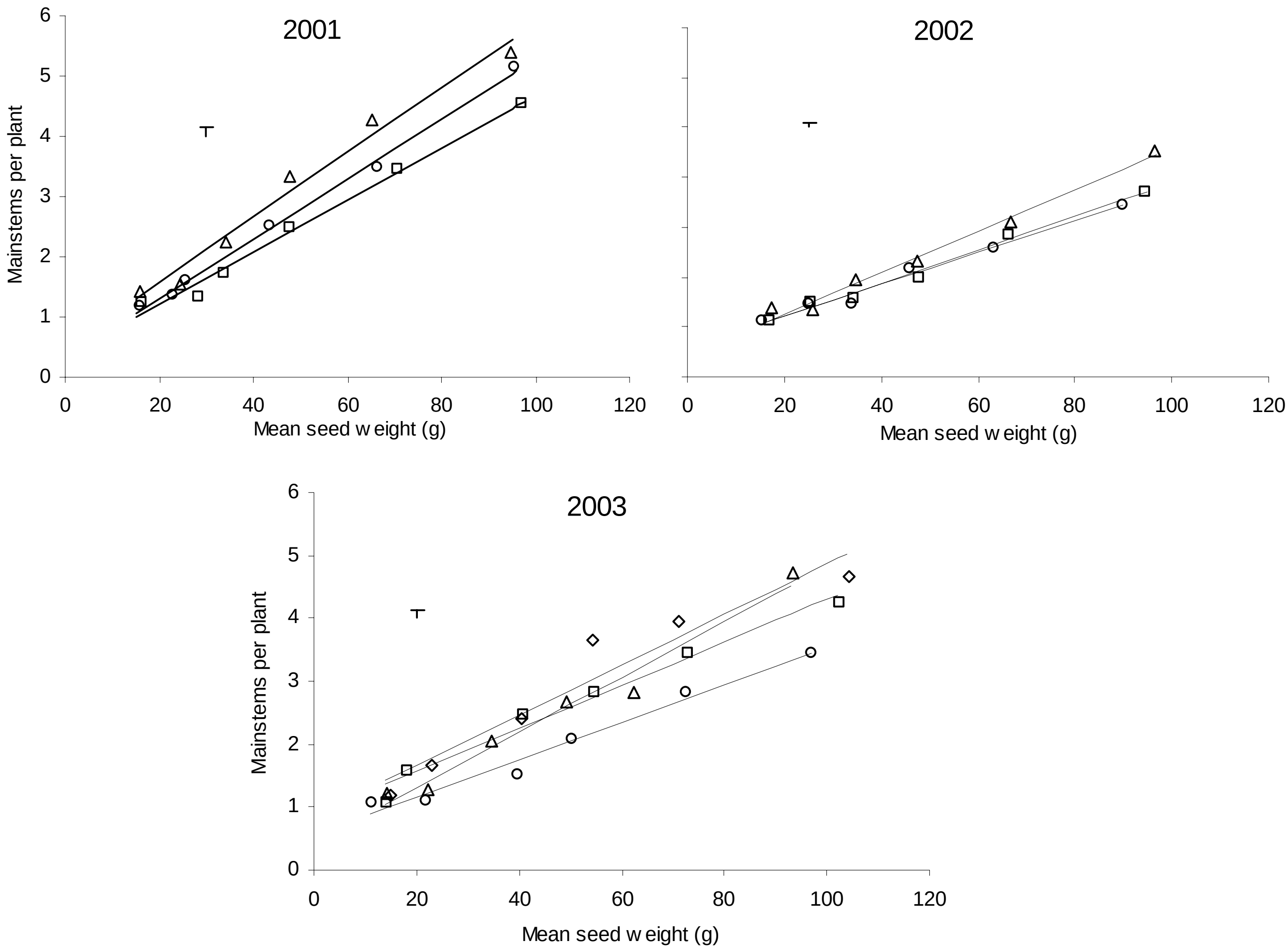
Expt 3. Seed size and stock (Hermes)

Emergence was on average 5 days later for the Cambridge stock than the other stocks, and although the smallest seed size tended to take the longest to emerge, there was no systematic change with seed size. There were few secondary stems (average 0.05 per plant) in any treatment. The number of mainstems was greatest for early-produced Welsh P1 seed and least for Cambridge seed. A greater difference between stocks in the increase in number of mainstems with increase in seed size was observed than had been seen in the previous two years, which was similar to that observed for Charlotte, though less marked than observed for Estima. The increase began at a smaller seed size for the earlier-produced Welsh P1 seed than for the later-produced Cambridge seed (Figure 4).

Figure 4. Linear relationship between the number of mainstems per plant and seed weight for Hermes over three years in Expt 3. Seed stocks: ○, Cambridge; Δ, Scottish/Northumberland; □, Wiltshire; ◇, Welsh P1. Bar indicates S.E.



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Expt 4. Seed size and stock (Maris Piper)

Emergence was, on average, nearly 4 days later for the Wiltshire stock than the two Welsh stocks and although statistically significant differences were shown between seed sizes, there was no systematic change of emergence with seed size. Smaller seed produced more secondary stems than larger seed and both Welsh stocks produced more secondary stems than the Wiltshire-produced stock with small seed (Figure 5). The number of mainstems tended to be greater for early-produced Welsh P1 seed than the other two stocks and the number of mainstems increased with seed size at a similar rate for all stocks (Figure 6).

Figure 5. Relationship between the number of secondary stems per plant and seed size and for 3 stocks of Maris Piper in Expt 4. Seed stocks ■, Welsh P1; ■, Welsh P2; □, Wiltshire. Bar indicates S.E. for comparison across stocks.

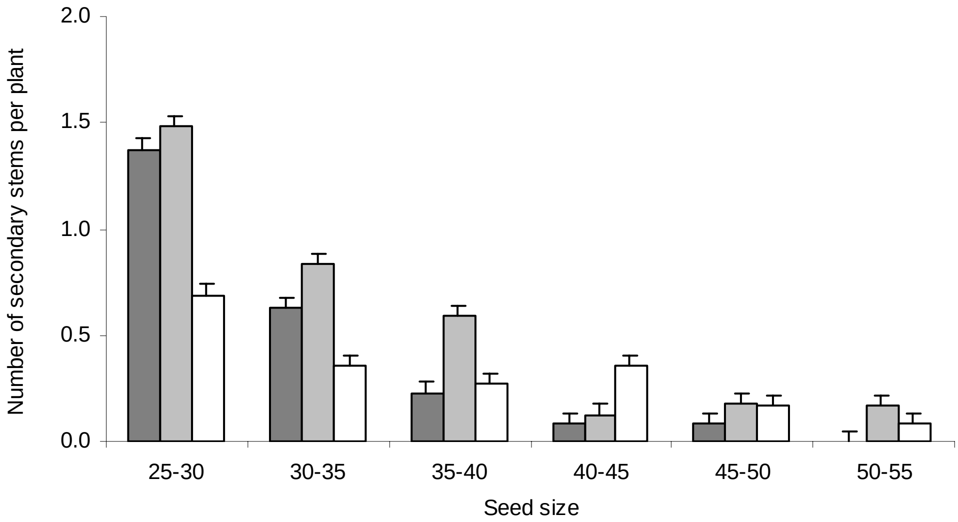
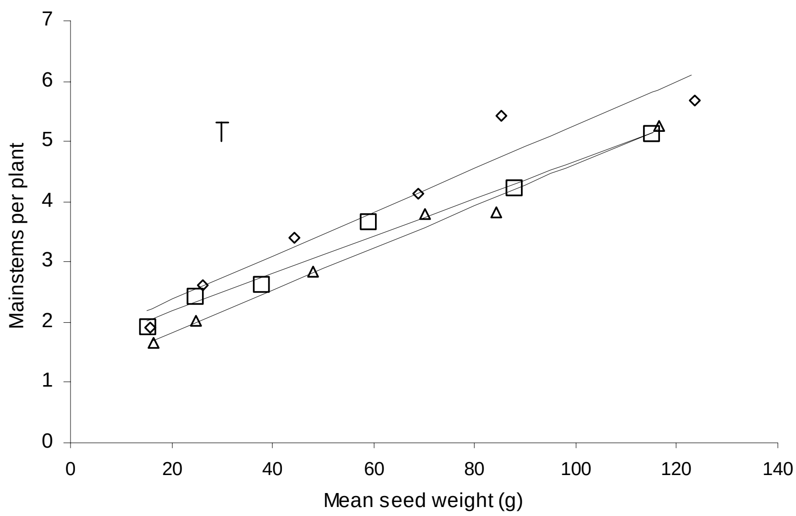


Figure 6. Linear relationship between the number of mainstems per plant and seed weight for Maris Piper in Expt 4. Seed stocks: ◇, Welsh P1; Δ, Wiltshire; □, Welsh P2. Bar indicates S.E.



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Expt 5. Stock and planting date (Estima)

Weight loss between loading seed into boxes and the first planting was relatively low for most stocks of 2002 seed (< 2.5 % from grading before storage until planting), although it was slightly higher for the large Spanish seed (5 %). As expected, weight loss was greater for 2001 seed planted in 2003, particularly the small seed (> 9 % for most stocks) and the large Wiltshire and early Welsh P1 seed (10-15 %). Further weight loss from 2001 seed up to the final planting was no more than an additional 2 % for any stock and there was little difference in percentage weight loss between seed sizes. Soft rotting was evident in all 2001 stocks; *c.* 5 % of small seed and *c.* 10 % of the larger seed had rotted at the first planting (rotten seed was not planted). By the final planting, the incidence of soft rotting had increased to *c.* 25 % for the larger seed, and *c.* 15 % for most stocks of the small seed, although 52 % rotting was observed for the small late Welsh P2 seed. Tubers with symptoms of decay were not planted but tubers with latent infection may not have been excluded.

Whilst 2002 produced seed generally emerged well at all plantings, for 2001 produced seed emergence varied from near complete to very poor (Figure 7). At the first planting, near complete emergence was achieved in some 2001 produced stocks, but emergence was poor for Welsh P1, Cambridge and Spanish stocks. The poor emergence of the Welsh P1 and the Cambridge stocks may be associated with planting into cold soil, but emergence improved for the second planting (an average across stocks of 83.5 %, with the exclusion of the Spanish seed). Poor emergence of Spanish seed was consistent with its chronological age, as there was a progressive decrease in final % emergence with interval from emergence to replanting across all stocks (Figure 7). The mean interval from planting to emergence decreased progressively with delay in planting from the first to the third planting although this decrease did not continue to the final planting (Table 5). At all plantings, 2002 seed emerged more rapidly than the 2001 seed. The 2001 large Spanish seed was the slowest to emerge, followed by the Welsh P1 and Wiltshire seed, whilst emergence was generally similar between the 2002 stocks. Differences in emergence between seed sizes were generally < 1 day.

Table 5. Effect of seed stock and planting date on days from planting to 50 % emergence (mean of two seed sizes) in Estima in Expt 5

	Stock					
Planting date	Spanish†	Welsh P1	Wiltshire	Scottish	Welsh P2	Cambridge
2001 seed						
12 Mar	*80.5*	68.7	71.8	66.6	54.0	69.4
30 Apr	*60.7*	47.5	49.3	45.3	35.5	37.1
18 Jun	*49.8*	46.3	40.8	38.5	30.5	31.7
6 Aug	*66.8*	56.0	45.9	45.9	37.9	37.7
2002 seed						
12 Mar	50.9	48.6	49.4	47.9	52.8	52.7
30 Apr	30.0	30.4	28.9	28.7	30.0	30.9
18 Jun	20.0	18.7	18.2	21.2	20.7	19.9
6 Aug	24.2	17.9	17.3	17.3	18.1	18.3
S.E.‡	(a) 1.14 (1.04*) (b) 1.55 (1.45*)					

† Data for Spanish seed are for large seed only for 2001 seed (data in italics excluded from analysis of variance)
‡ S.E.s (a) for comparisons with Spanish stock within 2002 stocks (b) for comparing all except Spanish stock at all plantings
* S.E. for comparisons at the same planting date

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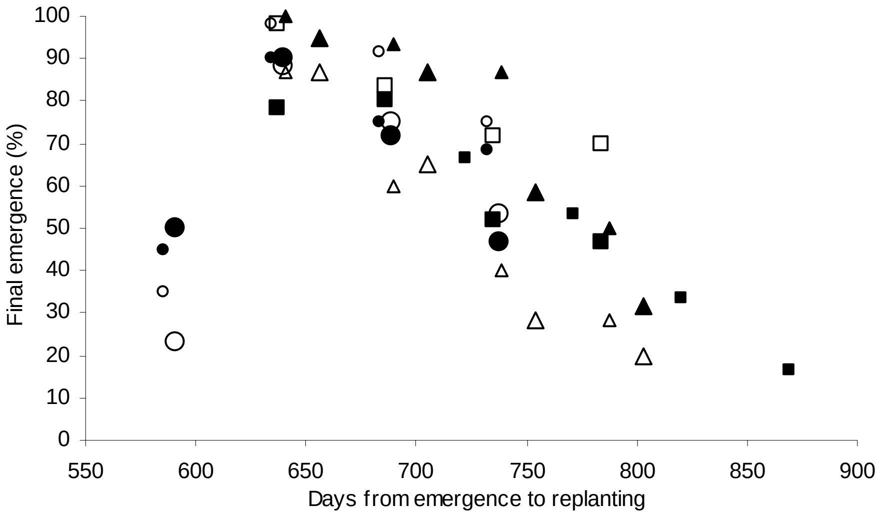
Figure 7. Effect of time from emergence of seed crop on the final % emergence for seven seed stocks of 2001 produced Estima replanted in 2003, in Expt 5 Seed stocks: ○ Cambridge; □ Spanish; ▵ Scottish; Δ Welsh P1; ○ Welsh P2; □ Wiltshire. Open symbols 30-35 mm seed, closed symbols 45-50 mm seed.



The relationship between accumulated soil temperature from planting to 50% emergence and the interval from emergence to replanting for 2001 produced seed demonstrates that the influence of temperature on emergence changes according to the age of the seed at planting (Figure 8a). The accumulation of day degrees slightly decreased for later-planted seed, until the seed was replanted more than *c*. 450 days after emergence (the outliers shown are from Spanish-produced seed). A similar effect was seen for 2002 produced seed replanted in 2003 (Figure 8b). It is unlikely that these results were affected by planting before natural dormancy break, as the earliest planting was more than 28 weeks after emergence of the mother crop (Table 3). Even at the early plantings, the daily mean soil temperature was not below 5 ˚C in either the 2002 or 2003 experiments. A base temperature of 0 ˚C was used in this analysis, and it is possible that the plantings into cold soil may have accumulated 'ineffective' day degrees, thus overestimating the accumulation required for emergence. In addition, it has been shown that early sprout growth, and hence emergence, is not linearly related to temperature, with elongation of spouts characterized by a period of slow growth until sprouts reach *c*. 10 mm (Firman *et al*., 1992). The length of this lag period has been shown to be affected by temperature (Firman *et al*., 1992), and would therefore be longer for plantings into cold soil than later plantings. For plantings more than *c*. 450 days after emergence of the seed crop, there was a rapid increase in accumulated day degrees required for 50 % emergence (Figure 8a), reflecting the more protracted emergence observed in the field for older seed.

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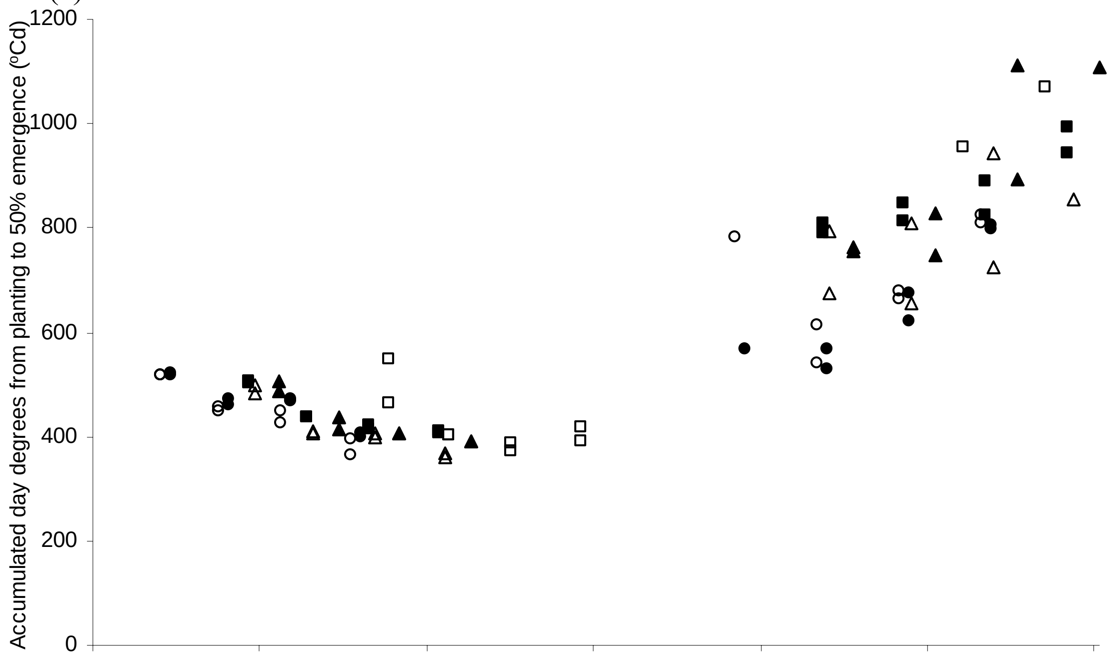
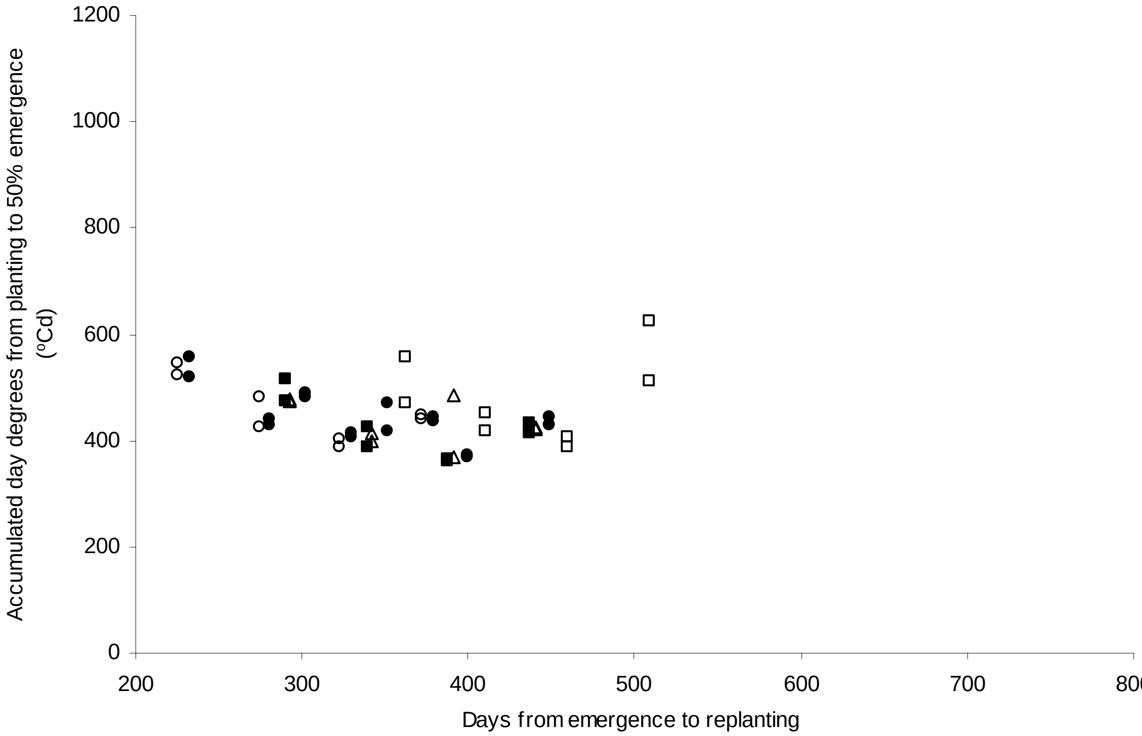
Figure 8. Effect of time from emergence of seed crop on the accumulated soil temperature until 50% emergence for seven seed stocks of (a) 2001 produced Estima replanted in 2002 and 2003, (b) 2002 produced Estima replanted in 2003 in Expt 5 Seed stocks: ○ Cambridge; □ Spanish; Δ Scottish/Northumberland; ▲ Welsh P1; ● Welsh P2; ■ Wiltshire.

(a)



For 2002 seed replanted in 2003, there was an overall trend for an increase in number of stems with delayed replanting (Figure 9). This effect is consistent with a reduced effect of apical dominance when replanting is delayed beyond natural dormancy break, just as the number of

(b)



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sprouts which develop increases with the period of storage at low temperature (Goodwin, 1963). The number of mainstems was greater for early–produced than late–produced seed and the increase in number of stems with delay in planting found in previous years was shown more clearly in the late-produced Cambridge and Welsh P2 stocks (Figure 9). The larger seed (45-50 mm) produced more stems than the smaller seed (30-35 mm) and the increase in number of stems with delay in planting for the late-produced stocks was more marked for this larger seed. Goodwin (1963) stated that apical dominance developed less rapidly with large than with smaller tubers, allowing more stems to develop.

The relationships between the interval from emergence to replanting (of seed) and number of stems were less clear than in previous years. The first two plantings produced more stems than expected from earlier-produced seed and this was associated with cold soil (mean for 2 weeks following first planting 7 ºC, second planting 14 ºC, other plantings ≥ 21 ºC). A similar result occurred for the first two plantings into cold soil in 2002 (11 ºC, 15 ºC) particularly for earlier-produced seed). The early planting of unsprouted Estima seed in the physiological age experiment in 2002 also resulted in more stems when planted into cold soil (12 ºC) than at subsequent plantings into warmer soil (≥ 16 ºC), and the effect was larger for the earlier-produced Scottish seed than the later-produced Cambridge seed. This effect was not seen in the 2001 experiments, in which the first planting was into warmer soil (16 ºC). In a study of the variety Arran Pilot, Goodwin (1963), found that at temperatures over 15 ºC a single sprout was dominant, whereas at 10 ºC, several sprouts developed. These temperatures were similar to the soil temperatures that had an effect in the current study. It is possible that planting into cold soil has a similar effect to physiological ageing at low temperatures pre-planting, as it has been reported that slow growth at low temperatures is associated with the initiation of a large number of sprouts and consequently a larger number of stems than from seed stored at warmer temperatures (Krijthe, 1948). In this way, the cool soil temperatures at planting could have caused an increase in number of stems by slowing early growth, compared to seed planted straight from cold storage (2 ºC) into warmer soil. This effect was greater for earlier produced stocks than late produced stocks planted shortly following dormancy break. Results of the Estima physiological age experiment reported here (Expt 9) and in 2002 also support this, as seed stored at 4 ºC produced more stems than seed stored at 2 ºC immediately prior to planting in warm soil, particularly with the earlier-produced Northumberland seed stock.

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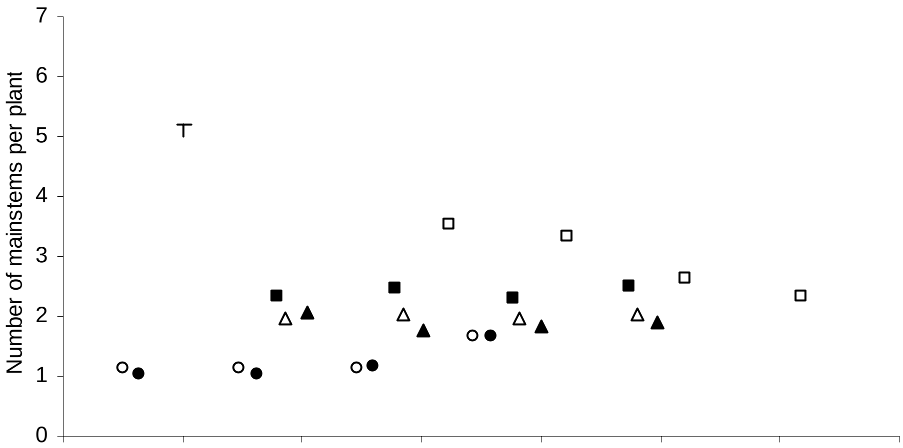
Figure 9. Effect of time from emergence of seed crop on number of mainstems per plant from seven seed stocks of 2002 produced Estima replanted in 2003 in Expt 5 a) 30-35 mm b) 45-50 mm. Seed stocks: ○, Cambridge; □, Spanish; Δ, Scottish; ▲, Welsh P1; ●, Welsh P2; ■, Wiltshire.

(a)



(b)

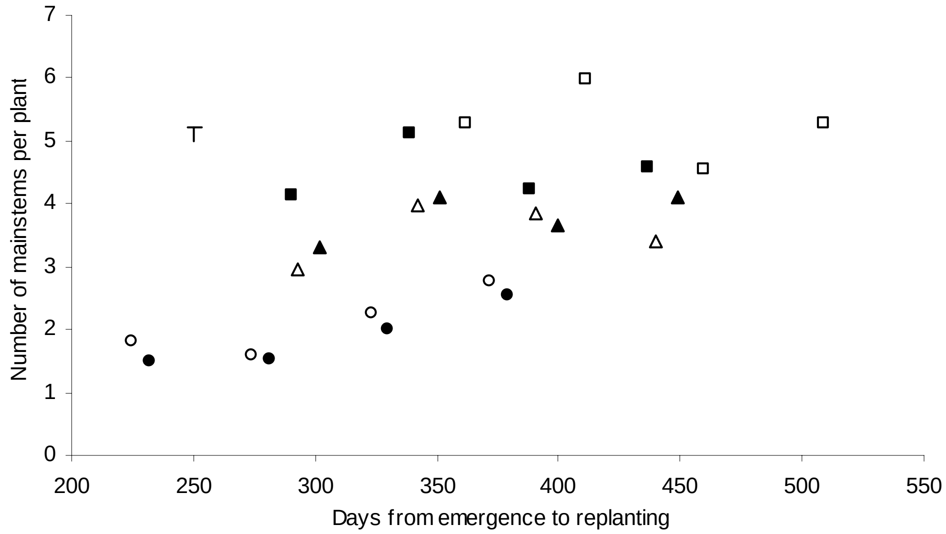


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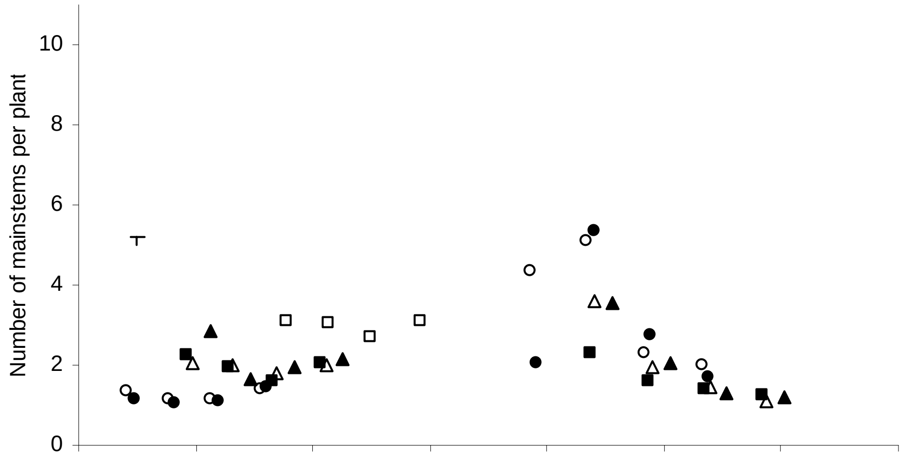
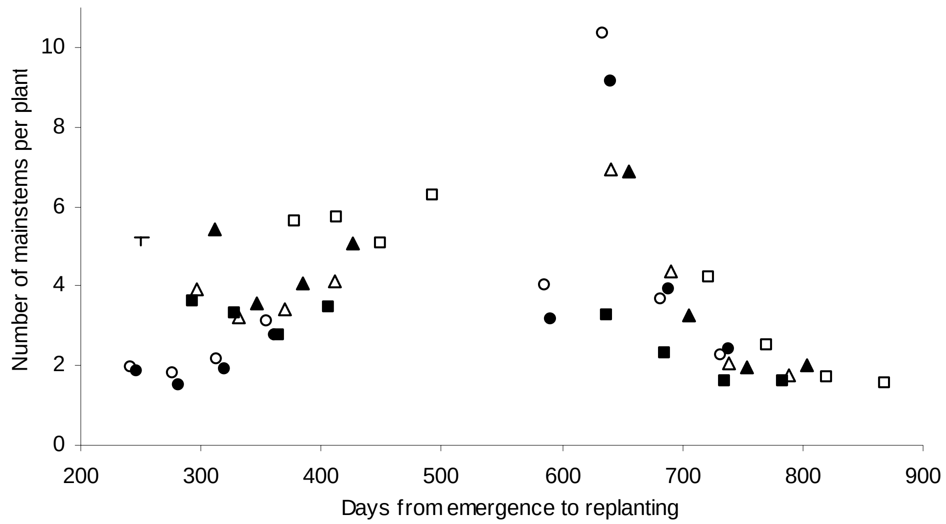
Figure 10. Effect of time from emergence of seed crop on number of mainstems per plant from seven seed stocks of 2001 produced Estima replanted in 2002 (Expt 3 in 2002 report) and 2003 in Expt 5 a) 30-35 mm b) 45-50 mm. Seed stocks: ○, Cambridge; □, Spanish; Δ, Scottish; ▲, Welsh P1; ●, Welsh P2; ■, Wiltshire.

(a)



(b)



The 2001 produced seed, replanted in 2002, was discussed in the 2002 Annual Report but generally the number of mainstems was greater for early-produced seed than late-produced seed and following the second planting of early-produced seed, the number of stems tended to increase with delay in planting (Figure 10). For 2001 produced seed replanted in 2003, the number of mainstems was low for the first planting of the late-produced large Cambridge and Welsh P2 seed but rose markedly by the second planting (> 9 stems per plant on average for the 45-50 mm seed) before decreasing for later plantings (Figure 10). A similar effect was found for 2000 late-produced seed replanted in 2002 (2003 Project Report). It is possible that the cold soil temperatures experienced at the first planting which favoured increased stem production for younger seed may have had the reverse effect for very old seed, and this is associated with poorer emergence in these stocks (Figure 7). The less extreme cold soil temperature for the second planting may have favoured stem production, as it appears to have done for the 2002

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produced seed. The smaller seed showed a similar but less marked effect for the Welsh P2 seed, though the Cambridge seed produced a large number of stems at the first planting. For all other stocks, the number of mainstems decreased for seed planted more than *c*. 600 days after emergence (2003 planting) with the early-produced Scottish and Welsh P1 seed producing a relatively high number of stems at the first planting.

As these data indicate both seed weight and the interval to replanting are important in determining the number of stems, improved prediction of stem production requires the combined effect of these factors to be quantified. The change in number of mainstems with increase in seed weight for each stock and planting date was calculated by dividing the difference in the number of stems produced by each of the two seed sizes by the difference in individual seed weight.

Thus in each case:
number of stems = seed weight x slope + constant

The constant differed between stock and replanting date, within a range of 0.56 to 2.76 and tended to increase with increase in the interval to replanting up to *c*. 500 days from emergence. For each of the stocks replanted in 2002, the number of mainstems increased with seed size, giving positive values for the slopes, but the effect of seed size was less for the late-produced stocks from Cambridge and Wales P2 than for the early-produced stocks, such as Wales P1 and Spanish seed. The relationship between these slopes and days from emergence to replanting (Figure 11) confirmed that as the period between emergence and replanting extended to *c*. 500 days, the number of mainstems increased more rapidly with increase in seed size. This is similar to the results shown in Expt 1, in that earlier produced stocks showed a greater response of number of stems to seed size than later produced stocks. However, as the time from emergence to planting was further delayed to over 550 days by replanting in 2003, the rate of increase in number of mainstems with seed size decreased, although it remained positive for the majority of stocks (Figure 11). The relationships established from these data allow estimates of the number of stems per plant to be made from seed weight and interval to replanting and allow the achievement of optimum stem densities with any size of seed and provenance.

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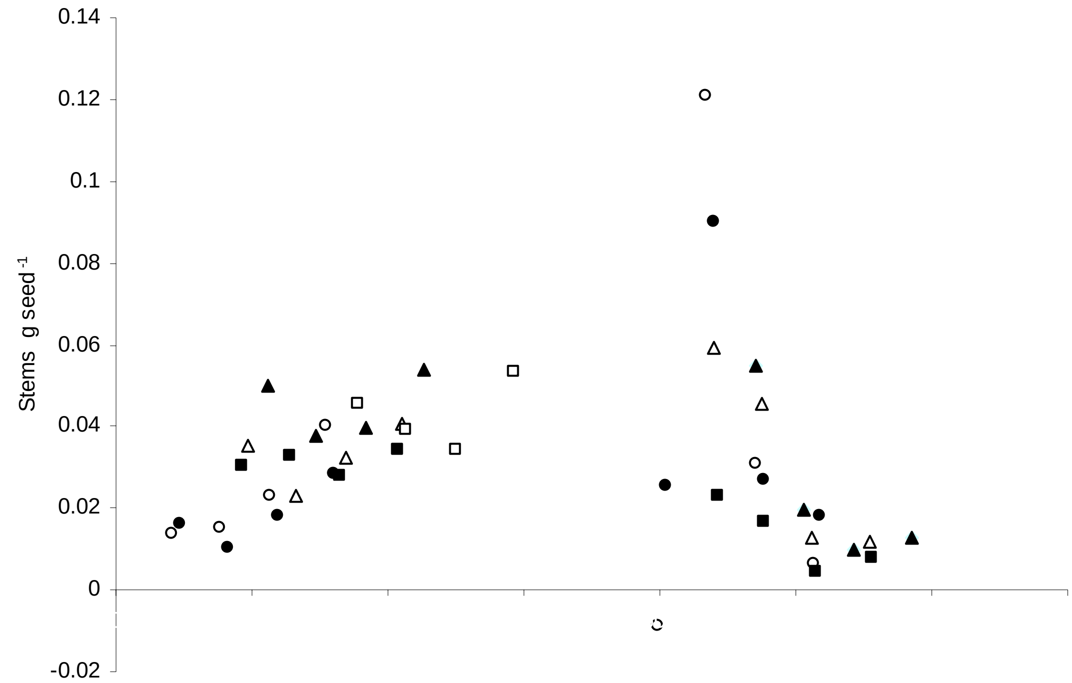
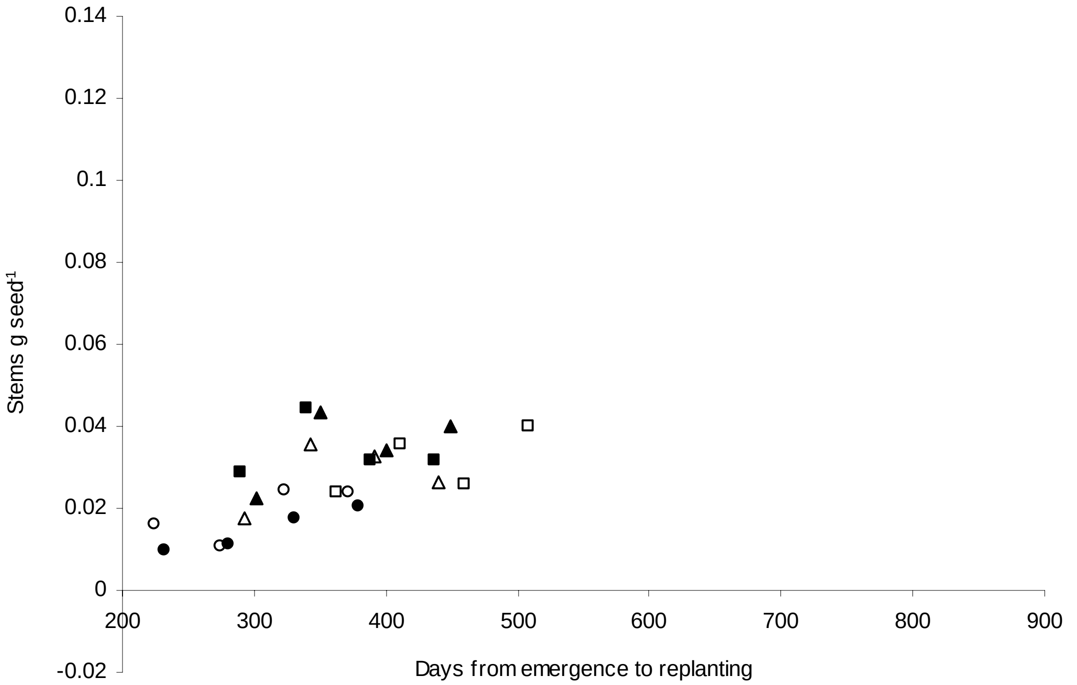
Figure 11. The relationship between the increase in number of mainstems with seed weight and time until replanting for (a) 2001 produced seed replanted in 2002 and 2003 and (b) 2002 produced seed replanted in 2003. Seed stocks: ○, Cambridge; □, Spanish; Δ, Scottish; ▲, Welsh P1; ●, Welsh P2; ■, Wiltshire.

(a)



(b)



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Expt 6. Stock and planting date (Charlotte)

Weight loss between loading seed into boxes and the first planting was relatively low for 2002 produced seed (< 2.5 % from grading before storage until planting) and remained low for later plantings (< 5 %). Weight loss between loading seed into boxes and the first planting was much greater for 2001 seed than for 2002 seed. Weight loss of 2001 seed was greatest in the larger (40-45 mm) seed and was 26 % at the first planting (12 % for smaller seed). By the final planting, weight loss of 45-50 mm seed had reached 45 %, associated with 85 % of these tubers having rotted by planting. The pattern of weight loss for small seed was similar (27 % weight loss initially, 47 % rots by the final planting).

All plantings of 2002 produced seed reached near full emergence (96 % on average), whereas 2001 seed emerged less completely, particularly the larger seed of which 60 % of plants emerged from the first planting but none emerged from the final planting (emergence for 30-35 mm seed was 85 % following early planting and 50 % following the final planting

(Table 6). The mean interval from planting to 50 % emergence decreased progressively with delay in planting from the first (86 days) to the final planting (25 days), with the first planting resulting in particularly protracted emergence due to planting into cold and dry soil.

More stems were produced from larger seed than smaller seed and there were few secondary stems in any treatment. For 2001 produced seed, replanted in 2002 and 2003, the number of mainstems generally increased with delay in planting in 2002 then decreased progressively with delay in planting for seed planted more than *c.* 600 days after emergence (2003 planting), associated with the deterioration of the health of the seed over time (Figure 12).

For 2002 produced seed replanted in 2003, the larger seed produced more stems than the smaller seed (Figure 13). The number of mainstems increased from the first planting to the subsequent plantings, which produced a similar number of stems (Table 6). Protracted emergence over the first three plantings may have affected these results as seed was planted into dry soil. Delayed emergence may have resulted in more stems than would otherwise have been expected, reducing any effect of planting date.

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Figure 12. Effect of time from emergence of seed crop on number of mainstems per plant from two seed sizes of 2001 produced Charlotte replanted in 2002 and 2003 in Expt 6. □, 45-50 mm; ○, 30-35 mm. Closed symbols 2002 planting; open symbols 2003 planting. Bars indicate S.E.

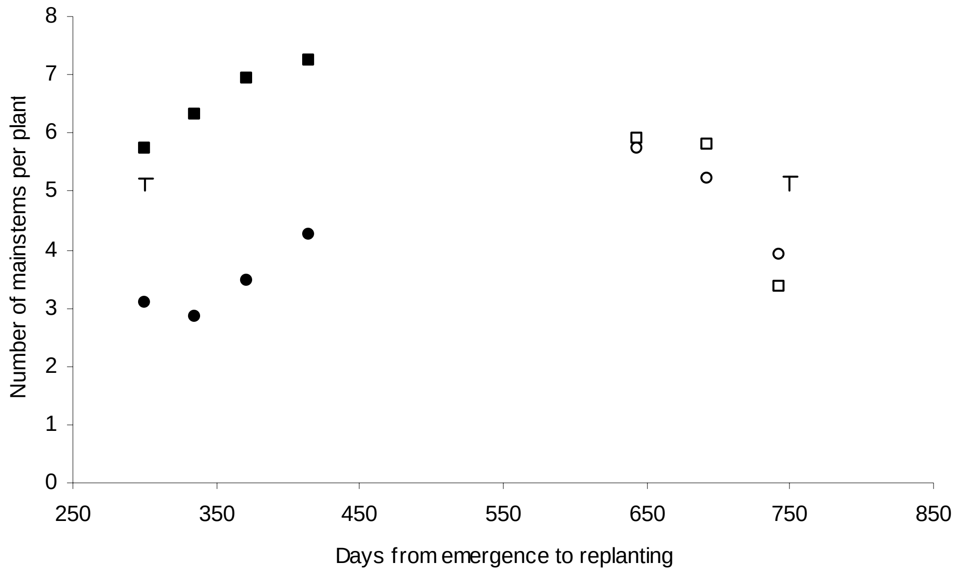

Figure 13. Effect of time from emergence of seed crop on number of mainstems per plant from 2002 produced Charlotte replanted in 2003 in Expt 6. ■, 45-50 mm; ●, 30-35 mm. Bar indicates S.E.

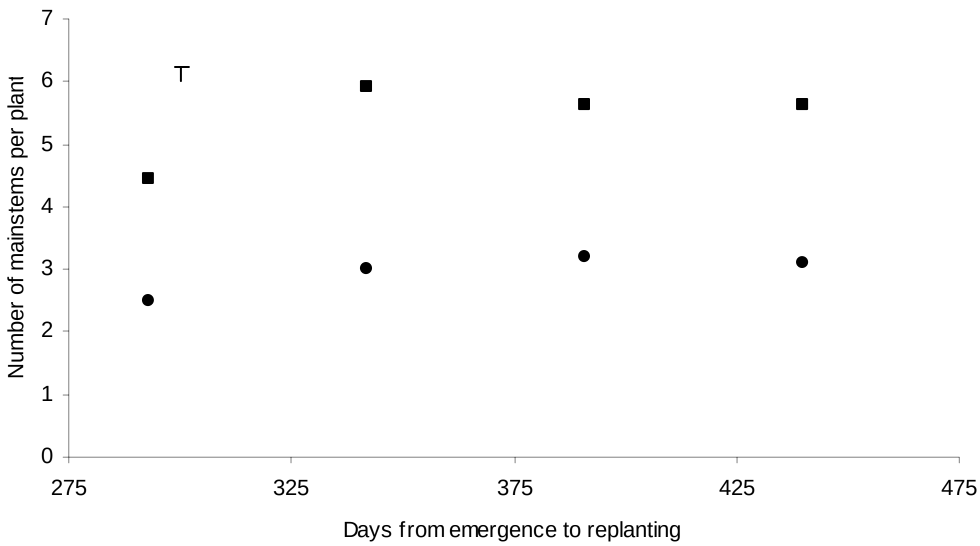

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Table 6. Effect of planting date of 2001 and 2002 produced Charlotte seed on final % emergence and number of mainstems per plant in Expt 6

Planting date	2001 seed		2002 seed	
Seed size	30-35	45-50	30-35	45-50
Final % emergence				
12 Mar	85.0	60.0	100.0	93.3
30 Apr	86.7	61.7	100.0	98.3
18 Jun	76.7	36.7	98.3	98.3
6 Aug	50.0	0.0	78.3	95.0
Number of mainstems				
12 Mar	5.74	5.89	2.48	4.44
30 Apr	5.22	5.81	3.00	5.92
18 Jun	3.91	3.38	3.21	5.62
6 Aug†	-	-	*3.11*	*5.61*
S.E.	(a) 0.396 (0.438*) (b) 0.264 (0.219*)			

† Data for P4 are for 2002 seed only (these data excluded from the analysis of variance). (a) for comparisons within the first three plantings (b) for comparisons within the 2002 seed
*S.E. for comparing same planting or seed size

Expt 7. Stock and planting date (Hermes)

Weight loss between loading seed into boxes and the first planting was low for 2002 produced seed (< 2 %), and remained low for later plantings (< 4 % total weight loss). Weight loss between loading seed into boxes and the first planting was much greater for 2001 seed than for 2002 seed (12-15 %). By the final planting, weight loss of seed was *c*. 22 % for both seed sizes, associated with 46 % rotting for the larger seed and 29 % rotting for the smaller seed.

All plantings of 2002 produced seed reached near full emergence, whereas 2001 produced seed emerged less completely, particularly the larger seed, and emergence of this 2001 seed decreased with later planting (Table 7). For the 2002 seed, the mean interval from planting to 50% emergence decreased progressively with delay in planting from the first (51 days) to the final planting (17 days). This decrease was also seen in the first three plantings of 2001 produced seed (62 days for the first planting and 41 days for the third planting) although the emergence was more protracted at the final planting (51 days), probably due to deterioration in seed health.

More stems were produced from larger seed than smaller seed (Table 7) and there were few secondary stems in any treatment. For 2001 produced seed, the number of mainstems increased rapidly with delay in planting in 2002, particularly in the larger seed. When replanted in 2003, the number of mainstems showed a progressive decrease with delay in planting for seed planted more than *c*. 550 days after emergence, associated with deterioration in the health of the seed over time (Figure 14). For 2002 produced seed replanted in 2003, the number of mainstems increased with delay in planting, particularly for the larger (45-50 mm) seed (Figure 15), though the increase was less than had been observed in previous years for the smaller (30-35 mm) seed.

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Table 7. Effect of planting date of 2001 and 2002 produced Hermes seed on final % emergence and number of mainstems per plant in Expt 7

Planting date	2001 seed		2002 seed	
Seed size (mm)	30-35	45-50	30-35	45-50
Final % emergence				
12 Mar	91.7	78.3	100.0	100.0
30 Apr	83.3	53.3	100.0	100.0
18 Jun	81.7	48.3	100.0	100.0
6 Aug	48.3	26.7	98.3	98.3
Number of mainstems				
12 Mar	3.20	4.97	1.28	2.90
30 Apr	3.48	3.97	2.00	3.83
18 Jun	2.75	3.41	2.34	4.83
6 Aug	2.11	2.72	2.42	5.39
S.E.	0.169 (0.183*)			

*S.E. for comparing same planting and seed size

Figure 14. Effect of time from emergence of seed crop on number of mainstems from two seed sizes of 2001 produced Hermes replanted in 2002 and 2003 in Expt 7. ■, 45-50 mm; ●, 30-35 mm. Closed symbols 2002 planting; open symbols 2003 planting. Bar indicates S.E.

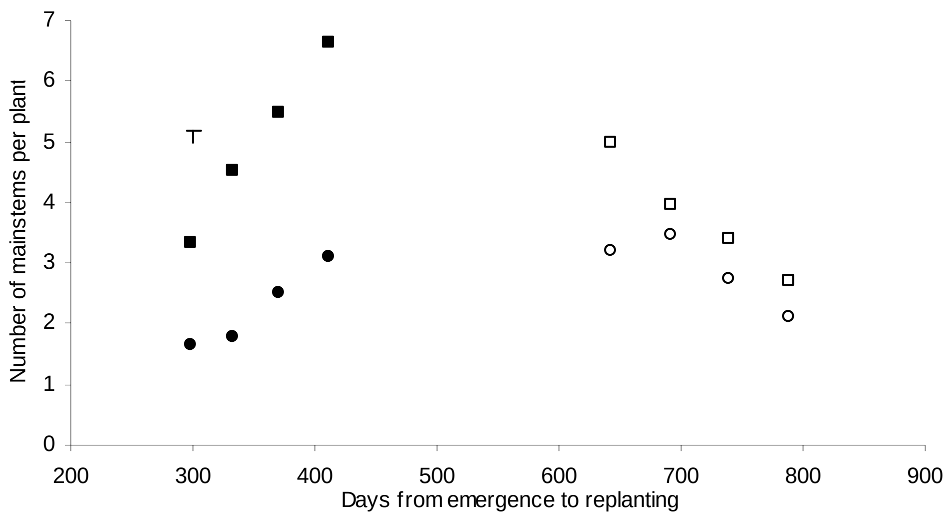

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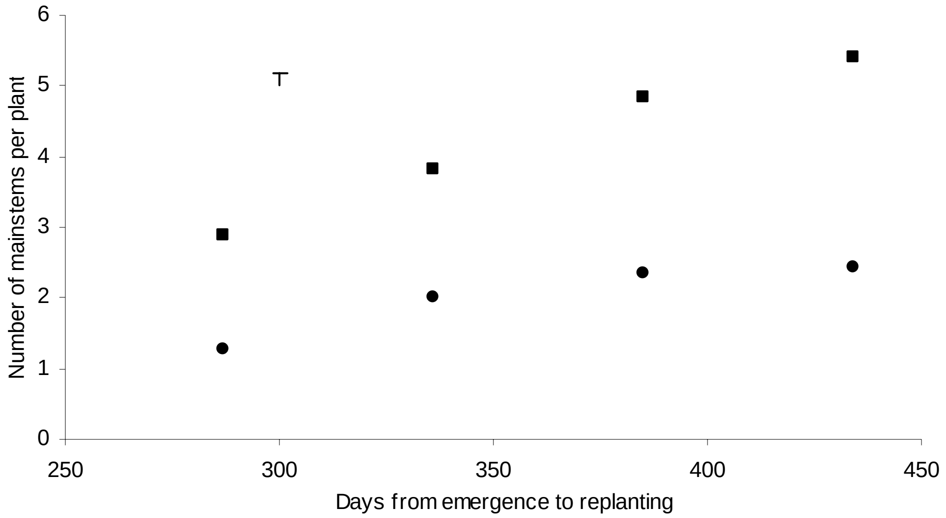
Figure 15. Effect of time from emergence of seed crop on number of mainstems from field-grown plants of 2002 produced Hermes replanted in 2003 in Expt 7. ■, 45-50 mm; ●, 30-35 mm. Bar indicates S.E.



Expt 8. Sprouting, stock and planting date (Estima)

Prior to planting of Expts 9-12, rots were removed and recorded and further rots were removed after sprouting at 15 ºC, prior to each planting of Expt 8. Little rotting was observed in the 2002 seed but prior to sprouting at the first planting, the incidence of rotting in 2001 seed was 5 % in Cambridge Estima and 11-14 % in all other stocks. At the later planting, rotting remained relatively low in Cambridge Estima but high in all other stocks particularly Charlotte, for which 42 % of tubers had rotted prior to sprouting and only 19 % remained viable after sprouting.

2001 produced seed tended to take longer to emerge when planted later, probably reflecting deterioration in seed health, whereas delayed planting of 2002 seed resulted in a more rapid emergence, due to planting in warmer soil (Table 8). The 2001 seed tended to emerge less completely than the 2002 seed (Table 8) and following the first planting of CUF Estima 2001 seed emergence was particularly poor, although this improved after the second planting when soil temperature was warmer.

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Table 8. Effect of planting date of 2001 and 2002 produced sprouted seed on the interval from planting to 50 % emergence, final % emergence, number of mainstems per plant, number of tubers and yield in Expt 8

	2001 seed		2002 seed	
Stock	P1	P2	P1	P2
Interval from planting to 50 % emergence				
Cambridge Estima	13.8	11.6	15.5	10.6
Northern† Estima	13.3	14.4	13.3	9.4
Northern† Hermes	13.1	14.0	15.2	12.1
Northern† Charlotte	12.7	17.1	17.5	10.1
S.E.		0.87		
Final % emergence				
Cambridge Estima	54.3	100.0	100.0	100.0
Northern† Estima	96.7	97.2	100.0	100.0
Northern† Hermes	90.0	100.0	100.0	95.0
Northern† Charlotte	93.3	95.8	100.0	100.0
Number of mainstems per plant				
Cambridge Estima	3.10	3.42	1.86	2.28
Northern† Estima	3.25	2.81	1.75	2.53
Northern† Hermes	2.38	3.33	1.58	2.47
Northern† Charlotte	5.33	4.42	2.50	4.42
S.E.		0.315 (0.328*)		
Number of tubers (000/ha)				
Cambridge Estima	1013	461	381	340
Northern† Estima	729	379	408	383
Northern† Hermes	883	445	591	339
Northern† Charlotte	1725	512	594	468
S.E.		124.6 (118.7*)		
Tuber yield (t/ha)				
Cambridge Estima	78.6	21.2	69.2	25.2
Northern† Estima	63.4	20.4	69.7	25.0
Northern† Hermes	75.4	18.9	67.7	20.5
Northern† Charlotte	87.7	12.3	64.1	24.5
S.E.		5.33 (4.01*)		

† Northern seed from Scotland in 2001 and Northumberland in 2002
* S.E. for comparisons at the same planting date, stock or year of seed production

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Seed from 2001 produced more mainstems than seed from 2002 and the first planting of 2002 seed produced the least mainstems (Table 8). Later planting resulted in more mainstems than early planting for both Estima stocks of the 2002 seed and for the earlier-produced Cambridge 2001 seed but a decrease in the number of mainstems was found at the second planting date of the very old Scottish seed. Few secondary stems were produced but the Cambridge Estima produced more secondary stems than other stocks at the second planting date (average of 2001 and 2002 Cambridge stocks 0.46 ± 0.030 per plant, all other stocks ≤ 0.20 per plant).

Consistent with the increase in number of mainstems, the older 2001 seed tended to produce more tubers and a greater yield than the 2002 seed (Table 8). This difference was particularly evident for the first planting of the Cambridge Estima and Northern Charlotte, which produced very high numbers of tubers (1 013 000/ha and 1 725 000/ha respectively); it should be noted that the results of Cambridge Estima are from a small sample area following poor emergence of this treatment. The first planting produced a greater tuber yield than the second (Table 8) but the interval from planting to harvest was considerably shorter for the second planting. The difference in yield between planting dates was greater for the slower emerging 2001 seed than the 2002 produced seed.

The results of this experiment confirmed those of the pilot experiment in 2002 that sprouting prior to planting may extend the period over which seed remains viable. In Expts 5-7, plantings of unsprouted seed from 2001 resulted in protracted and poor emergence, but this was not found with the sprouted seed in this experiment and very high numbers of stems and tubers were produced. These data exclude seed that rotted prior to planting but nevertheless results from the early planting of Charlotte demonstrate that production of very high yields of small tubers is possible using old seed.

Expts 9-12. Seed storage (Estima, Charlotte, Hermes and Maris Piper)

These experiments had the same storage treatments for all varieties and results are reported together.

Weight loss during storage ranged from *c.* 1-5 % for most treatments, although the late 300 ºC d treatment experienced 6-8 %, and the 15 ºC treatment 12-15 % weight loss, which was not associated with rotting. Storage at 2 ºC resulted in negligible sprout development whereas at 4 ºC, sprouts > 3 mm were present on most tubers of the Northumberland Estima, Charlotte and Maris Piper, though in Hermes sprouts were mainly < 3 mm (Table 9). This is important as previous studies of physiological age reported in the literature have used 4 ºC as a base temperature (e.g. Allen and O'Brien, 1986; O'Brien *et al.* 1983; Hay and Hampson, 1991). This study shows that sprouting does occur at this temperature, and 0-2 ºC has been reported as the temperature below which visible development does not occur (Firman *et al.* 1992). The ‘non-aged’ treatments in the experiments reported in the literature may have accumulated different amounts of temperature over a base of 2 ºC, as different stocks may break dormancy at different times.

The length of the longest sprout was greater for the earlier-produced Northumberland Estima than Cambridge Estima seed in most cases, and the longest sprouts were produced by the 15 ºC treatment (Table 9) for which the physiological age at planting was *c.* 850 ºC d for the Cambridge Estima and > 1300 ºC d for the other stocks. The late 300 ºC d treatment resulted in

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more sprouts > 3 mm than the early treatment in all varieties, similar to the previous years' experiments, and the results reported by Wurr (1979).

Few secondary stems were produced in any treatment but ageing resulted in substantial differences in numbers of mainstems. Treatments with protracted emergence suffered from rook damage with some plants removed as they emerged and damage caused to others. This mainly affected the 2 ºC and 4 ºC treatments but also the early ageing treatment in Maris Piper, so results from these treatments need to be interpreted with care as limited areas were harvested. Although only guarded plants were harvested, plants that had been damaged and subsequently recovered may have been sampled, and damage may have influenced both number of stems and yield of remaining plants. Charlotte (Expt 10) was not affected by damage from rooks, as this experiment was located at a different site.

The Cambridge produced Estima and particularly the Maris Piper produced more mainstems from aged seed; the 15 ºC treated Maris Piper produced more than twice as many stems as seed stored at 2 ºC (Table 10). A similar effect of age on number of stems for Maris Piper was shown by O'Brien *et al.* (1986). By contrast, in Charlotte the number of stems was greater from storage at 2 ºC than the other treatments, a similar effect to that shown for the equivalent planting date in 2002, demonstrating that the effects of ageing on the number of stems are variety specific (Allen and Scott, 1980). The number of stems in Charlotte did not reflect the number of sprouts produced, this being consistent with the conclusion that the effect of ageing on sprout number is not well related to the number of stems produced in the field (Wurr 1979, Hay and Hampson, 1991). Consistent with previous years' experiments, the late 300 ºC d treatment produced more sprouts than the early 300 ºC d treatment, as previously discussed, although it only produced significantly more stems in Hermes and Maris Piper in 2003.

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Table 9. Effects of seed storage and seed stock on the numbers of sprouts and sprout length at planting in Expts 9-12

Storage	Stock				
	Estima Cambridge	Estima Northumberland	Charlotte	Hermes	Maris Piper
Number of sprouts > 3 mm per tuber					
2 ºC	0.0	0.0	0.0	0.0	0.0
4 ºC	0.1	1.6	1.9	0.3	4.2
S.E.	0.07	0.17	0.25	0.10	0.30
Late 300 ºC d	4.2	4.5	4.4	6.3	6.2
S.E.	0.25	0.32	0.36	0.30	0.24
Early 300 ºC d	2.7	2.1	1.2	1.3	1.6
S.E.	0.25	0.27	0.18	0.13	0.15
15 ºC	2.4	1.5	1.6	1.0	1.7
S.E.	0.29	0.14	0.11	0.07	0.16
Longest sprout per tuber (mm)					
2 ºC	0.1	0.1	0.1	0.1	0.1
4 ºC	1.5	4.5	10.5	1.9	14.0
S.E.	0.15	0.34	1.02	0.24	0.72
Late 300 ºC d	8.3	9.8	10.0	8.7	9.0
S.E.	0.39	0.42	0.47	0.26	0.27
Early 300 ºC d	6.9	11.1	9.7	7.2	7.5
S.E.	0.38	0.44	0.41	0.36	0.47
15 ºC	16.0	32.1	36.2	32.3	19.5
S.E.	0.46	0.99	1.85	2.28	0.92

The number of mainstems was greater for the Northumberland Estima than the Cambridge Estima from storage at 2 ºC and 4 ºC where limited sprout development occurred (Table 10). With the 15 ºC treatment, the larger number of sprouts in the Cambridge Estima produced more mainstems than the Northumberland stock but there was little difference between Estima stocks for seed with 300 ºC d whether acquired early or late (Table 10).

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Table 10. Effect of seed storage temperature regime and seed stock on the interval from planting to 50 % emergence and the number of mainstems in Expt 9-12

Stock	Seed storage temperature regime					
	2 ºC†	4 ºC†	Early 300 ºC d	Late 300 ºC d	15 ºC	S.E.
Days from planting to emergence						
Estima Northumberland	38.7	22.2	18.5	15.6	12.4	1.50
Estima Cambridge	29.6	27.9	17.4	17.1	16.3	
Charlotte	35.2	27.7	29.4	26.8	22.2	0.87
Hermes	32.6	26.4	20.6	15.5	13.1	1.80
Maris Piper	27.7	17.3	21.9	15.8	12.3	0.55
Number of mainstems per plant						
Estima Northumberland	1.89	2.02	2.19	2.27	2.31	0.178
Estima Cambridge	1.26	1.53	2.15	2.08	3.04	
Charlotte	3.63	2.35	2.50	2.40	2.92	0.276
Hermes	2.49	1.98	1.98	3.19	2.47	0.201
Maris Piper	2.22	2.83	2.43	3.02	4.67	0.220

† These treatments subject to rook damage, see text (except Charlotte)

The 15 ºC treatment emerged most rapidly and the 2 ºC treatment had the most protracted emergence in all stocks (Table 10) as found in the previous years' experiments. Within the Estima stocks, differences were most marked in the Northumberland stock in which the 2 ºC treatment took 26 days longer to emerge than the 15 ºC treatment whereas for the Cambridge stock, the difference was only 13 days (Table 10). The difference observed between Estima stocks was at least in part due to the 15 ºC treatment not producing a consistent physiological age, as the later-produced Cambridge stock broke dormancy later and so was physiologically younger than the earlier-produced Northumberland stock. The late aged treatment (held at 15 ºC prior to planting) consistently emerged more quickly than the early aged treatment (held at 2 ºC prior to planting), and this was similar to the results of Jenkins *et al.* (1993), in which the timing of the ageing treatment had a large influence on crop growth.

Northumberland Estima seed produced more tubers than the later produced Cambridge Estima seed except for the late 300 ºC d and 15 ºC treatment (Table 11). Early ageing consistently produced more tubers than late ageing of Estima as found in previous experiments (Table 11). Tuber yield tended to be greater for Northumberland Estima seed than Cambridge Estima seed, except for the 15 ºC treatment, and this was associated with a greater stem density and earlier emergence. However, with both Hermes and Maris Piper late ageing produced both the most tubers > 10 mm and the greatest yield (Table 11). This was associated with the relatively high number of stems and rapid canopy expansion for the late 300 ºC d seed.

Yield was also greater from the 15 ºC treated Hermes than for seed held at 2 ºC and 4 ºC (Table 11); the rate of canopy expansion having a larger effect on yield than the rate of senescence, although low yields for the 2 ºC and 4 ºC may be also be associated with rook damage. Similarly in Maris Piper, the 2 ºC treatment produced the fewest tubers > 10 mm and the lowest yield, and although this was associated with fewer stems and more protracted emergence, these differences may be exaggerated by the rook damage experienced in these plots.

There was no effect of seed age on either the number of tubers or yield of Charlotte (average 295 000/ha and 21.0 t/ha respectively).

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Table 11. Effect of seed storage temperature regime on number tubers and yield in Expts 9, 11 and 12

	Seed storage					
Stock	2 ºC†	4 ºC†	Early 300 ºC d	Late 300 ºC d	15 ºC	S.E.
Tubers > 10 mm (000/ha)						
Estima Northumberland	491	515	514	400	396	36.2
Estima Cambridge	282	357	457	397	443	
Hermes	487	447	540	692	514	41.3
Maris Piper	421	680	709	721	643	66.6
Tuber yield (t/ha)						
Estima Northumberland	70.1	59.4	63.2	68.3	59.6	5.83
Estima Cambridge	40.3	49.1	61.5	63.5	62.9	
Hermes	46.1	46.6	54.8	73.5	60.3	4.00
Maris Piper	49.0	63.4	60.4	69.7	62.9	3.34

† These treatments subject to rook damage, see text

Expt 13. Density (Estima)

The early-produced stock (Welsh P1) reached 50 % emergence *c.* 4 days earlier (43.4 ± 0.19 DAP) than the late-produced (Welsh P2) stock (47.8 DAP). Ground cover increased more slowly at the widest plant spacings than at closer spacings but all treatments reached full ground cover, despite the very low plant density at 80 cm spacing, and there was little difference in senescence (Figure 16).

At the final harvest there were more than twice as many mainstems per plant from early-produced seed (2.81 ± 0.074) than for late seed (1.22). There were similar differences in numbers of mainstems between the two stocks at the earlier harvest. Few secondary stems (< 0.2 per plant) were recorded in any treatment at the final harvest, whereas at the early harvest, plants at the widest spacing produced more secondary stems than those at narrower spacing (average of both stocks 1.0 ± 0.17 per plant at widest spacing). The apparent loss of secondary stems from the first to final harvest may have been due to senesced stems no longer being detectable. Stem populations at final harvest ranged from just 21 900/ha for the late stock planted at 80 cm spacing to 173 900/ha for the early stock planted at 19 cm spacing and whilst the number of tubers increased in relation to increasing stem density at both harvests, at comparable mainstem populations the number of tubers was generally greater from the late-produced seed (Figure 17a). This finding is consistent with less clumping of stems in the late-produced seed for which the number of stems per seed tuber was lower. Total yield also tended to increase with increase in stem density but mainly for densities below *c.* 50 000/ha (Figure 17b). Mean tuber size decreased progressively with increase in stem density at the final harvest from 72.0 mm to 59.5 mm (Figure 17c) and whilst there was no significant difference in yield of tubers > 60 mm between treatments (Figure 17d), late seed planted at 24 and 31 cm spacing produced very high yields in this size fraction (48.1 and 49.1 t/ha respectively).

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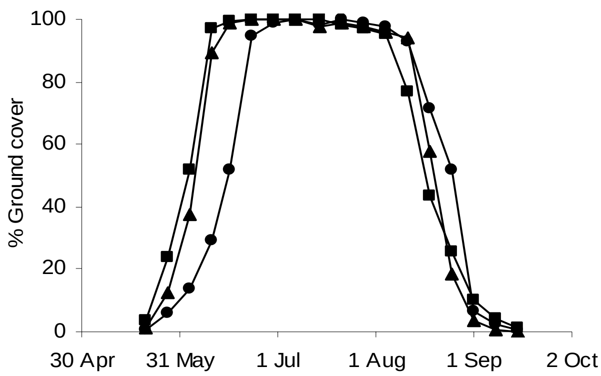
Figure 16. The effect of plant density on ground cover for (a) early Welsh P1 and (b) late Welsh P2 produced stocks of Estima in Expt 13. Plant spacings (cm): ●, 80; ▲, 31; ■, 19 (intermediate densities not shown).

(a)



(b)

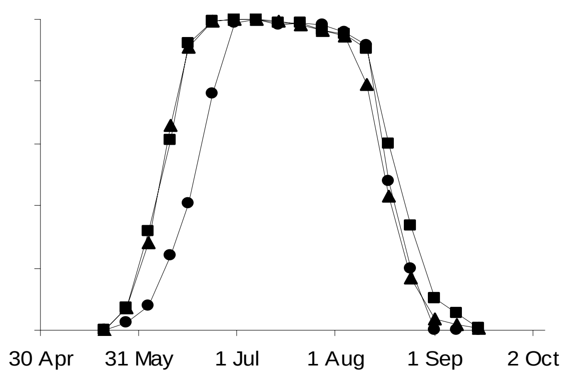


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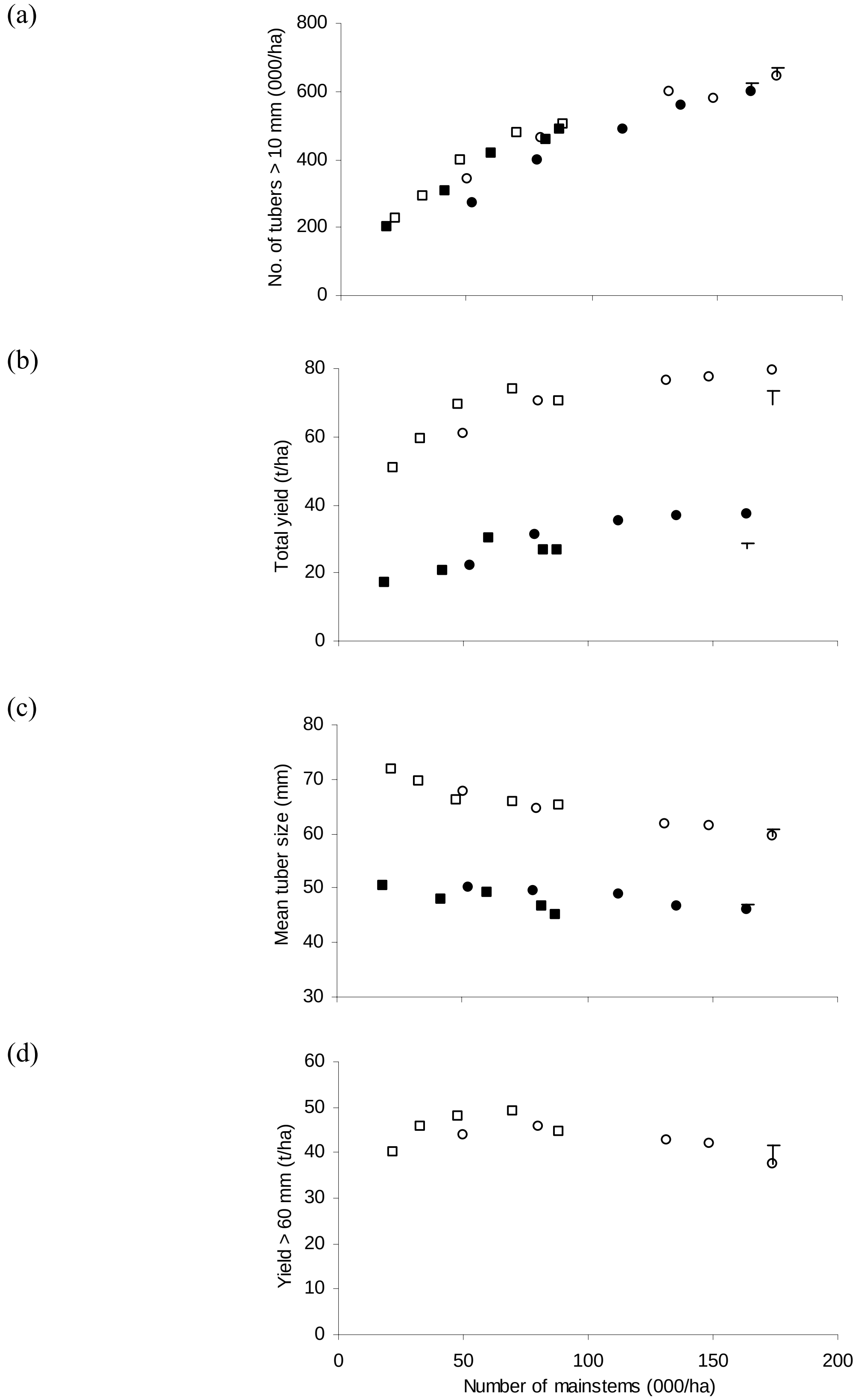
Figure 17. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size, and (d) number of tubers > 60 mm and number of mainstems/ha at two harvest dates of Estima in Expt 13. Stocks: ●, Welsh P1 first harvest; ■, Welsh P2 first harvest; ○, Welsh P1 second harvest; □, Welsh P2 second harvest.



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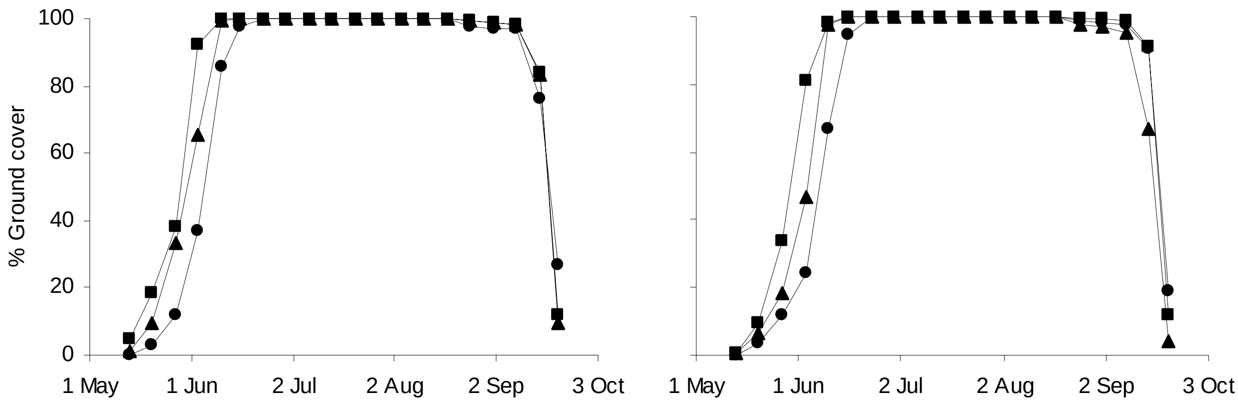
Expt 14. Density (Maris Piper)

The early-produced stock emerged slightly earlier (50 % emergence 36.9 ± 0.13 DAP) than the late-produced stock (38.2 DAP). Ground cover increased more slowly at the wider plant spacings than at closer spacings but all treatments achieved full ground cover; the 80 cm spacing attaining full ground cover *c*. 1 week later than the 19 cm spacing (Figure 18). Senescence occurred in late September in all treatments (Figure 18).

Figure 18. The effect of plant density on ground cover for (a) Welsh P1 and (b) Welsh P2 produced stocks of Maris Piper in Expt 14. Plant spacing (cm): ●, 80; ▲, 31; ■, 19 (intermediate densities not shown).



The number of mainstems per plant was greater from early-produced seed (3.22 ± 0.088 at the final harvest) than for late seed (2.43). At the first harvest, numbers of secondary stems increased with increase in plant spacing in both stocks but more in the late-produced stock (0.4 ± 0.27 per plant at the closest spacing and 2.1 per plant at the widest spacing) than the early stock (0.1 and 0.7 per plant). There were few secondary stems detected at the final harvest (0.38 per plant for widely spaced plants and < 0.1 per plant for other treatments), probably due to senescence.

Stem populations at final harvest ranged from 42 100/ha for the later (Welsh P2) stock planted at 80 cm spacing to 236 200/ha for the early (Welsh P1) stock planted at 19 cm spacing. As for Estima, the number of tubers increased in relation to increasing stem density at both harvests and at comparable mainstem populations at the final harvest, the number of tubers was generally greater from the late- produced seed (Figure 19a). Total yield tended to increase slightly with increase in stem density, (Figure 19b) and mean tuber size decreased (Figure 19c) but there was no significant difference in yield of tubers > 60 mm between treatments (Figure 19d).

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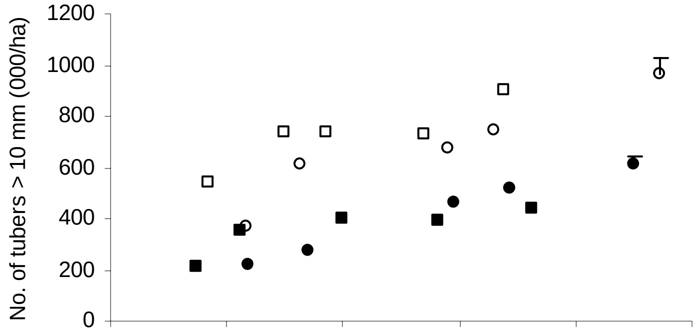
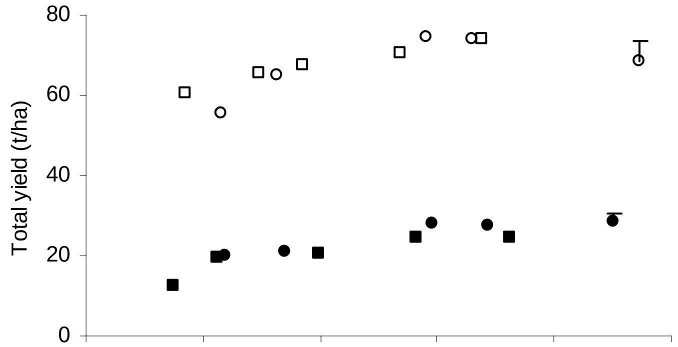
Figure 19. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size, and (d) number of tubers > 60 mm and number of mainstems/ha at two harvest dates of Maris Piper in Expt 14. Stocks: ●, Welsh P1 first harvest; ■, Welsh P2 first harvest; ○, Welsh P1 second harvest; □, Welsh P2 second harvest.

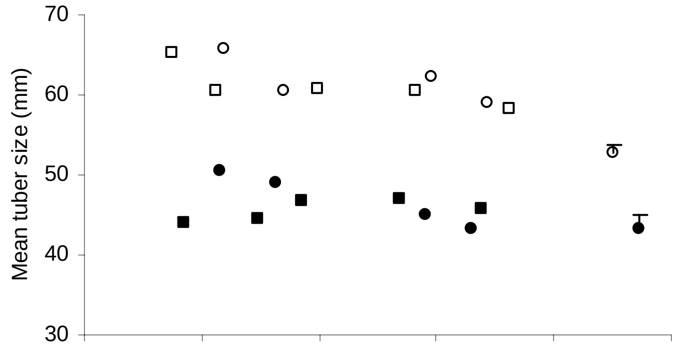
(a)



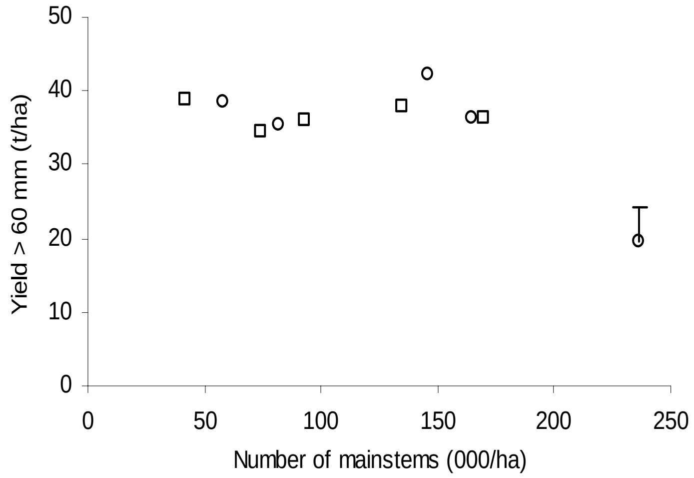
(b)



(c)



(d)



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Expt 15. Density (Charlotte)

As in the density experiments with Estima and Maris Piper, the early-produced stock emerged earlier than the late-produced stock but the difference was greater for Charlotte with 50 % emergence 41.9 ± 0.32 DAP for the early Welsh P1 stock and 49.2 DAP for the Cambridge stock. The larger effect for Charlotte compared to the other varieties was probably accentuated by the dry seedbed at the site of this experiment. There were few secondary stems produced (< 0.1 per plant), but as with other varieties, more mainstems per plant were produced from early-produced seed (4.56 ± 0.179 at the final harvest) than for late seed (3.04). Full ground cover was achieved in most treatments but later at low planting densities than high densities and later for the late seed than early-produced seed (Figure 20). The number of tubers increased with increase in stem density (Figure 21a) so that the most tubers were produced from early-produced seed planted at high density. Numbers of tubers per stem were low so that even at high stem populations, the total number of tubers was relatively low and this was probably associated with the soil conditions at this site where the initially dry seedbed slumped and consolidated. Total yield increased with increase in number of mainstems and mean tuber size decreased so that yield of small (20-40mm) tubers was much greater at the higher stem densities than at low density (Figure 21b-d), and generally greater for early produced seed.

Figure 20. The effect of plant density on ground cover for (a) Early Welsh P1 and (b) Cambridge produced stocks of Charlotte in Expt 15. Plant spacing (cm): ●, 33; ▲, 20; ■, 14 (intermediate densities not shown).

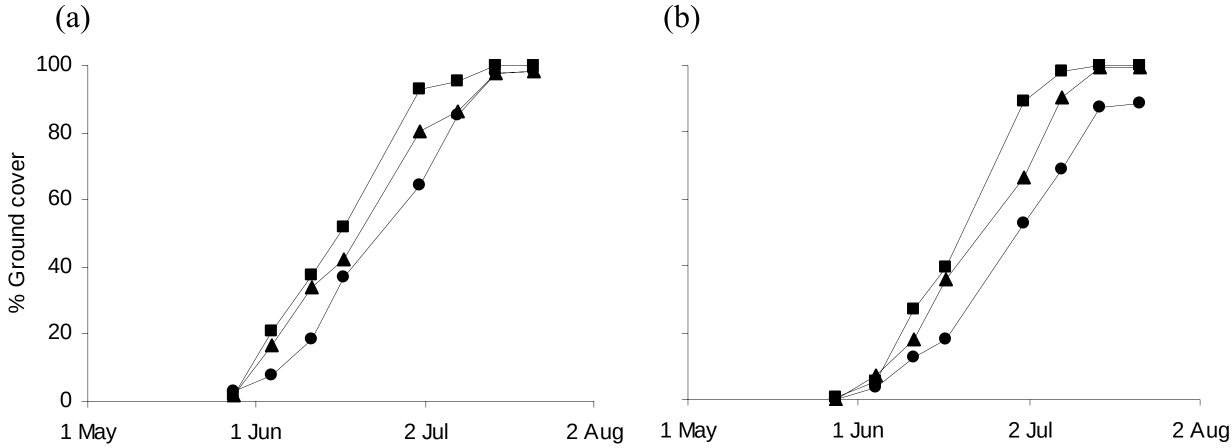

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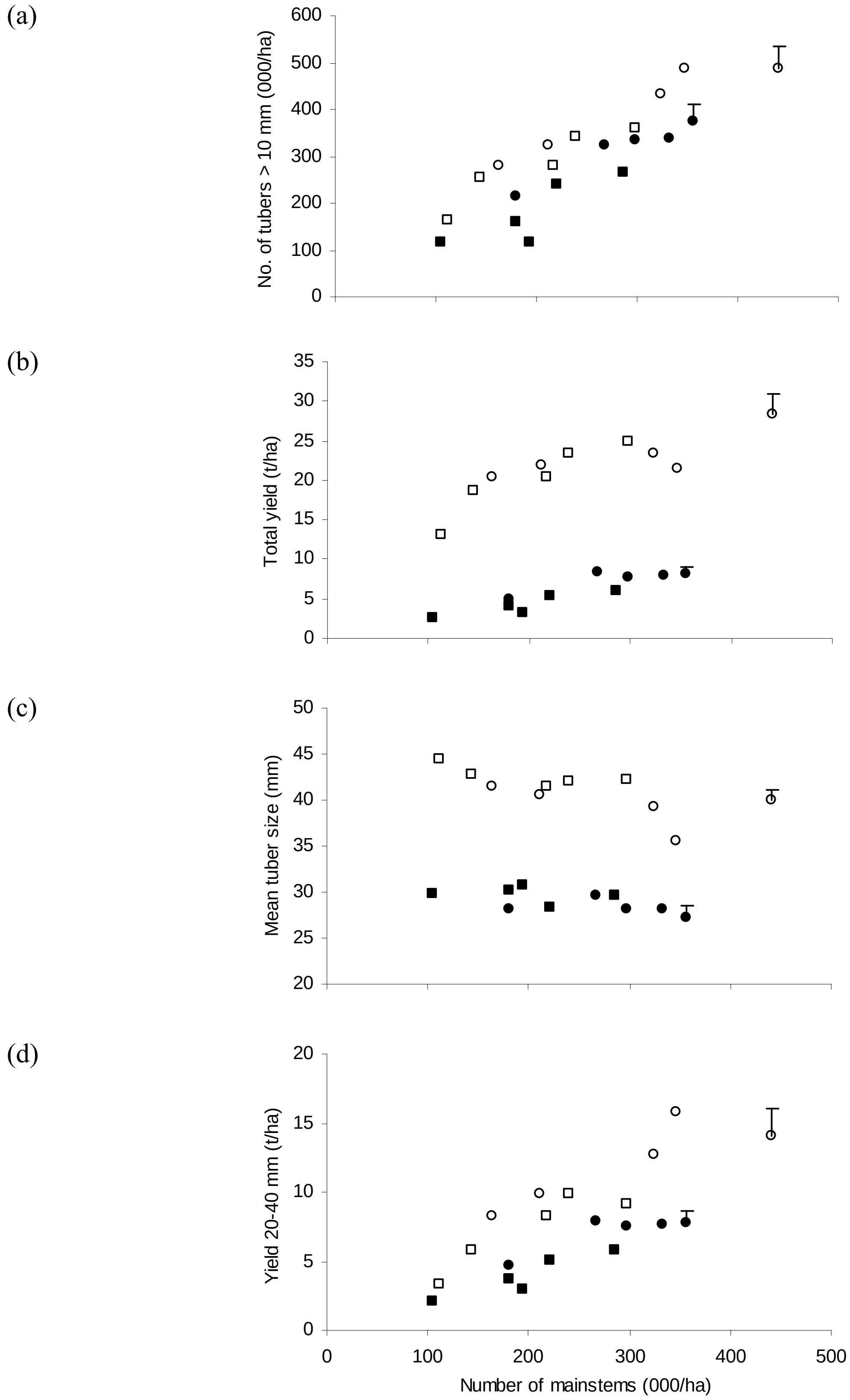
Figure 21. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size, and (d) number of tubers 20-40 mm and number of mainstems/ha at two harvest dates of Charlotte in Expt 15. Stocks: ●, Welsh P1 first harvest; ■, Cambridge first harvest; ○, Welsh P1 second harvest; □, Cambridge second harvest.



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Expt 16. Seed emergence date and number of stems (Estima)

The late-emerged seed produced fewer mainstems per plant (1.40 ± 0.066) than the early-emerged seed or the control (1.58 and 1.57 respectively), confirming that some of the within-crop variation can be accounted for by differences in emergence of individual plants. The earlier-emerged seed produced more plants with two stems than the later-emerged plants which were mainly single stemmed. There was, however, no significant effect of emergence date on number of tubers or yield. There was no effect of the number of stems on the mother plant on stem production of the daughter tubers.

Expt 17. Seed emergence date and tuber production zone (Estima)

Seed in this experiment was obtained from careful harvesting of individual plants and was limited in quantity so that mean seed weight differed between treatments, ranging from 41-70 g (Table 12). Owing to this potentially confounding effect, analysis of numbers of stems was done excluding plants from extreme seed sizes as well as for the complete data set. Similar effects were found in both cases and results are presented for all plants.

Table 12. Mean seed weight (g) for treatments in Expt 17

Emergence of mother plant		Early		Late	
Zone		2	3	2	3
Mean tuber size at planting	Sprouted	46.9	70.4	41.4	51.2
	Unsprouted	58.1	50.4	48.7	48.4

Sprouting reduced the interval from planting to 50 % emergence by *c*. 13 days on average (Table 13). Sprouted seed produced more mainstems and secondary stems than unsprouted seed and early emergence of the mother plant resulted in slightly more stems than from later emerging plants (Table 13), as found in Expt 16.

Seed tubers from zone 3 (tubers produced lowest on the below-ground stem) produced slightly more stems than tubers from zone 2 (tubers produced on the mid part of the below-ground stem) for early-emerged seed but this was not so with late-emerged seed (Table 13), and when extreme seed sizes were excluded the effect was not significant. Sprouting increased the number of tubers and tuber yield and this effect was more marked for the early-emerged than late-emerged seed (Table 13). There was no difference in the number of tubers or yield between plants grown from seed from different zones.

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Table 13. The effect of sprouting, emergence date of seed crop and zone on the interval from planting to 50 % emergence, number of mainstems and secondary stems per plant, number of tubers > 10 mm and tuber yield in Expt 17

Emergence of mother plant		Early		Late		
Zone		2	3	2	3	S.E.
Days from planting	Sprouted	21.8	21.1	21.2	21.2	0.68
to emergence	Unsprouted	35.1	34.2	34.6	34.6	
Mainstems / plant	Sprouted	2.00	2.67	1.60	1.60	0.210
	Unsprouted	1.30	1.55	1.20	1.20	
Secondary stems / plant	Sprouted	0.67	0.97	0.53	0.53	0.237
	Unsprouted	0.07	0.07	0.33	0.33	
Tubers > 10 mm (000/ha)	Sprouted	531	612	477	477	30.6
	Unsprouted	436	462	424	424	
Tuber yield (t/ha)	Sprouted	83.5	83.5	70.4	70.4	2.86
	Unsprouted	55.6	57.0	61.8	61.8	

Expt 18. Cut seed (Hermes)

At planting, sprouted whole tubers had an average of 6.5 visible sprouts per tuber. Cut seed had an average of 5.4 sprouts on rose-end pieces and 1.3 sprouts on heel end pieces and the longest sprouts for all treatments were *c*. 2 mm. The commercially-produced Welsh stock took on average *c*. 4 days longer to emerge than the other stocks and in all cases sprouted seed emerged more quickly than unsprouted seed but the effect was greater for whole than cut seed. Cutting slightly reduced the final emergence from an average of 98 % in whole seed to 95 %.

The number of mainstems for whole unsprouted seed was least for the Northumberland stock and most for the early-produced Welsh stock (Table 14). Sprouting generally increased the number of stems, but the effect was greater for whole than cut seed and most marked in Cambridge and Northumberland seed (Table 14). Rose end pieces produced similar numbers of stems (1.32 stems ± 0.112) to heel end pieces (1.23 stems ± 0.126) and thus did not reflect differences in the number of sprouts. Within the cut seed, the commercially produced Welsh seed produced numerically fewer stems than the other stocks, from both rose and heel-end pieces. Cutting promoted stem production, in that a cut rose and heel-end piece together produced *c*. 0.2 to 1.0 more stems than a whole seed tuber of the same stock and sprouting regime, but there did not appear to be a consistent difference between stocks. There were few secondary stems in any treatment (< 0.1 per plant).

The number of tubers > 10 mm was, on average, greater for whole than cut seed but there was no significant effect of other treatments. Tuber yield was also, on average, greater for whole (41.6 ± 1.76 t/ha) than cut seed (36.2 t/ha) but this difference was relatively small considering cut seed was planted at the same spacing and thus half the seed rate.

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Table 14. The effect of cutting, sprouting and stock on the interval from planting to 50 % emergence, number of mainstems per plant, the number of tubers > 10 mm and tuber yield in Expt 18

		Cut seed		Whole seed		
	Stock	Unsprouted	Sprouted	Unsprouted	Sprouted	S.E
Days from planting to emergence	Welsh P1	32.3	29.4	31.8	28.6	0.46
	Northumberland	31.2	28.3	34.7	28.2	
	Cambridge	31.9	29.3	33.2	28.5	
	Welsh (commercial)	35.5	35.0	37.3	32.2	
Mainstems per plant	Welsh P1	1.24	1.44	1.89	1.97	0.068
	Northumberland	1.17	1.36	1.47	2.31	
	Cambridge	1.33	1.42	1.67	2.61	
	Welsh (commercial)	1.09	1.14	1.71	1.83	
Tubers > 10 mm (000/ha)	Welsh P1	369	415	450	438	51.2
	Northumberland	292	257	322	428	
	Cambridge	348	317	380	428	
	Welsh (commercial)	297	338	416	446	
Tuber yield (t/ha)	Welsh P1	38.7	42.4	38.9	46.3	4.97
	Northumberland	34.4	28.7	31.3	47.3	
	Cambridge	40.6	37.7	39.3	44.2	
	Welsh (commercial)	31.9	35.5	39.7	46.1	

Expt 19. Controlled Atmosphere (Estima, Maris Piper and Hermes)

The controlled atmosphere (CA) treatment advanced emergence, particularly for Hermes with a difference of over 8 days between treated and untreated seed (Table 15). This effect was probably associated with differences in sprout development at planting between CA treated seed and seed kept in cold store but sprout lengths were not recorded. For Maris Piper and Estima, the early-produced stocks emerged more rapidly than the later-produced stocks, and the CA treatment had a greater effect on emergence in the slower emerging late-produced stocks but this was not the case for Hermes. All treatments reached complete, or near complete emergence.

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Table 15. Effect of Controlled Atmosphere treatment, variety and stock on the interval from planting to emergence, number of mainstems per plant, number of tubers > 10 mm, and tuber yield in Expt 19

Variety		Maris Piper		Estima		Hermes		
CA treatment	Stock	Early	Late	Early	Late	Early	Late	S.E.
Days from planting to emergence								
Treated		25.2	26.0	24.2	26.5	23.6	22.9	0.323
Untreated		26.8	27.7	26.4	33.1	32.7	31.3	
No. of mainstems per plant								
Treated		4.11	3.11	3.83	2.39	3.19	3.75	0.251
Untreated		3.25	2.45	3.11	1.31	2.25	1.89	
No. of tubers > 10 mm (000/ha)								
Treated		661	510	606	461	570	673	47.2
Untreated		563	470	503	384	485	334	
Tuber yield (t/ha)								
Treated		49.1	52.6	71.1	72.6	47.5	57.6	3.35
Untreated		54.6	45.3	65.0	64.1	49.6	39.0	

Controlled Atmosphere treatment increased the number of mainstems per plant in all varieties and stocks (Table 15). Early-produced stocks produced more stems than later stocks in Maris Piper and particularly Estima but not in Hermes. Controlled Atmosphere treatment increased the number of tubers > 10 mm, consistent with the increase in number of stems and early-produced stocks tended to produce greater numbers of tubers than late-produced stocks (Table 15). Controlled Atmosphere treatment increased tuber yield in late-produced stocks but not early-produced stocks (Table 15) consistent with effects on emergence.

The effects of CA in this experiment cannot be separated from effects of storage temperature affecting sprout development and a further experiment is planned for 2004 where both unsprouted and sprouted seed can be compared with CA treated seed.

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Conclusions

The results of the three years of experiments were generally consistent, and confirmed that the effects of chronological age on stem production are repeatable and operate over a long period. Effects are influenced to a varying extent by storage conditions, post-planting environment and variety, but the re-growth of unsprouted, healthy seed tubers follows a predictable time course within a variety when planted into warm soil. The comprehensive set of information gathered on Estima over several experiments and seasons allows the re-growth to be modelled to give a prediction of number of stems for a given seed weight and interval to replanting. This should allow more soundly based recommendations for planting densities to be established.

The timing of dormancy break has also been shown to be relatively conservative although the interval to dormancy break may be over-estimated if tests are carried out beyond the period of natural dormancy. The establishment of accurate measurements of the dormant period post tuber initiation is clearly fundamental to a more efficient use of seed, but it also has implications in many other aspects of potato production, e.g. application of sprout suppressants or management of stored processing crops.

The experiments indicate an influence of low soil temperature on the pattern of re-growth, with early plantings into cold soil producing more stems than would otherwise be expected. This appears to be a similar effect to physiological ageing at low temperatures pre-planting, as slow growth at low temperatures is associated with the initiation of a large number of sprouts, and hence potential stems (Krijthe, 1948). Such factors may influence effects of chronological age in other varieties particularly if the rate or duration of change is less marked than in Estima or if only small differences in seed production are compared. The Estima model will be developed and used to compare information gathered for a range of varieties destined for all market uses.

The continuation of replanting of seed produced in 2001 during 2003, showed that the changes in number of stems continue over a very long period, >2 years. Towards the end of this period, number of stems clearly decreased from the peak values, but many tubers remained viable. Rotting was associated with physiological deterioration, and was caused by secondary pathogens. Tubers with symptoms of decay were not planted, but tubers with latent infection may not have been excluded and the deterioration in seed health will be important if tubers are to be stored for such long periods. The use of fungicides could provide an opportunity for storing seed for longer periods than previously considered which may be particularly useful for high value seed (e.g. mini-tubers), for breeders, and for out-of-season production.

The continued investigation of the effects of storage temperature produced relatively consistent results in terms of sprout production, but these did not always lead to the expected differences in the field, as the effect of both variety and of the field environment resulted in substantial differences in stem and tuber production. Hay and Hampson (1991) concluded that due to the considerable variation between varieties, seasons, and even batches of tubers in their response to physiological ageing, extrapolation from experimental results to predict number of stems in the field might not be justified, but it should be possible to improve the predictability of these effects. Within the Estima stocks, the early-produced stock tended to produce more stems and tubers than the later produced stock, though these differences were reduced by sprouting, and even reversed by the most extreme sprouting treatment. The implications of the resulting changes in number of stems for potato production in practice require further development to identify the causes of the environmentally induced variation within each variety.

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The experiments investigating the effect of planting density on tuber production in early and late-produced stocks confirmed that at the same plant density, late produced stocks can be used to produce more large tubers than early-produced stocks. These findings should assist in the efficient targeting of seed and planting densities for specific markets, and the greater number of varieties to be examined in 2004 will allow these effects to be further detailed.

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