The effects of production practices, storage conditions and sprouting on number of stems per seed tuber and the grading of potato crops

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D M Firman E J Allen & V J Shearman

Cambridge University Farm

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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 2001-2004. Experiments with these seed stocks have examined the effects of seed size, sprouting, planting density, planting date and controlled atmosphere treatment on the number of stems produced and other aspects of crop growth. Details of seed crops produced in 2004 are reported together with experiments using 2002 and 2003 produced seed. Details of seed crops produced as part of this project since 2000 and experiments on growth of this seed have been reported previously.

For seed of Estima replanted from cold-storage the number of stems produced per seed tuber increased until *c*. 600 days after emergence of the seed crop. For seed planted after storage for very long periods (> 600 days after seed emergence) the number of stems produced decreased and emergence was increasingly slow and incomplete. For other varieties examined a similar pattern occurred but deterioration of seed during storage reduced the period over which stem numbers increased and this occurred frequently with Charlotte. In all varieties examined to date (Charlotte, Estima, Hermes, Maris Peer, Maris Piper, Saturna, Shepody) more stems were produced from the earliest seed than the latest planted seed but in some cases there was little difference between stocks from intermediate plantings. For Estima planted following a short period of storage (young seed), the increase in number of stems with increase in seed weight was much less than for old seed so that the absolute difference between stocks in number of stems per seed tuber was greatest with large seed. In most other varieties a similar but less marked effect was found however in Charlotte, differences between seed stocks were often least in large seed.

In most cases, increase in sprout development tended to increase the number of stems produced in both chronologically young and old seed with more effect from significant sprouting than where limited bud growth was induced. There were however marked differences between varieties, with no effect in Maris Peer and a large effect in Saturna. Sprouting of very old seed resulted in increased emergence than from unsprouted seed and in some cases crops with high yields and very high numbers of tubers were produced but in some cases emergence was poor.

Where young and old seed were planted at a range of plant spacings, highest stem and tuber populations were achieved by planting old seed at narrow spacings and the yield of small tubers was greater for old seed than young seed. Young seed planted at wide spacings

produced the greatest mean tuber size and although total yield was reduced at very low stem populations, yield of large tubers was generally greatest with young seed.

Use of controlled atmosphere (CA) treatment increased numbers of stems more than a limited degree of sprouting in both young and older seed of Charlotte and Maris Peer but not in Shepody where sprouting resulted in most stems. Where CA increased numbers of stems, numbers of tubers were also greater and mean tuber size reduced.

These data demonstrate that differences in seed age can affect stem populations and tuber size distributions substantially. Some of the variation in stem populations between crops can be explained by differences in seed age and appreciation of this should now enable the effect of other factors to be better examined. Limitations to the use of seed younger and older than in normal use can be evaluated from the data reported but it is clear that opportunities for more effective use of seed exist.

Introduction

This project which began in 2000 was undertaken to quantify effects of different seed production practices, storage regimes and sprouting following earlier experiments which showed that the timing of production and replanting of seed could substantially change the number of stems produced by seed tubers. In order to provide a comprehensive dataset, seed from a broad range of production cycles was produced at a range of sites and was replanted at intervals over a long period. The project has developed to include a wider range of varieties than initially studied and to determine the use and value of seed stocks with contrasting potential for stem production. In addition to the wide range of experiments reported here and in previous years, demonstration crops have been grown at sites throughout the UK to bring these findings to the attention of growers. Since the beginning of this project the concept of manipulating stem populations by use of seed produced at different times has become widely accepted and adopted by an increasing number of growers.

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 additional varieties, Maris Peer, Shepody and Saturna, were produced, along with Estima and Charlotte, at four UK sites (three for Shepody) and Estima was again produced in Jerez, Spain. In 2004, Charlotte was also omitted, and Lady Rosetta was added, and the six varieties were produced at three UK sites (two for Shepody), and Maris Peer was produced in Jerez, Spain. Crops in the UK were all grown from a common source of seed and were planted and harvested mechanically. Counts of plant emergence were made to establish the date of 50 % emergence of the seed crops. Details of the 2004 seed crops are given in Table 1 (2000-2003 seed crops have been reported previously in the 2001-2003 BPC Project Reports).

Seed from all sites was graded in 5 or 10 mm increments 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 (Table 2).

Table 1. Timing of key events in the seed crops in 2004

Variety	Site	Date of Planting	Emergence	Defoliation	Harvest
Estima	Welsh P1	14 Apr	16 May	16 Jul	17 May
	Wiltshire	17 May	8 Jun	22 Jul	30 Aug
	Welsh P2	30 Jun	18 Jul	10 Sep	4 Oct
Maris Piper	Welsh P1	14 Apr	16 May	16 Jul	18 Aug
	Wiltshire	17 May	8 Jun	22 Jul	30 Aug
	Welsh P2	30 Jun	18 Jul	10 Sep	4 Oct
Maris Peer	Spanish	3 Feb	20 Mar	26 Apr	17 May
	Welsh P1	14 Apr	16 May	20 Jul	16 Aug
	Wiltshire	17 May	8 Jun	27 Jul	30 Aug
	Welsh P2	30 Jun	18 Jul	10 Sep	4 Oct
Saturna	Welsh P1	14 Apr	16 May	16 Jul	18 Aug
	Wiltshire	17 May	8 Jun	31 Jul	30 Aug
	Welsh P2	30 Jun	18 Jul	10 Sep	4 Oct
Shepody	Wiltshire	17 May	8 Jun	27 Jul	29 Aug
	Welsh P2	30 Jun	18 Jul	10 Sep	4 Oct
Lady Rosetta	Welsh P1	14 Apr	16 May	16 Jul	18 Aug
	Wiltshire	17 May	8 Jun	27 Jul	30 Aug
	Welsh P2	30 Jun	18 Jul	10 Sep	4 Oct

Table 2. Mean seed weights (g per tuber) prior to cold storage of 2003-produced seed

Variety	Stock	Spanish	Welsh P1	Wiltshire	Welsh P2	Northumberland
Estima						
	35-45 mm	64.7	41.6	47.2	46.3	49.1
	45-55 mm	103.2	94.2	83.3	81.6	97.1
Maris Peer						
	35-45 mm	-	48.2	38.8	44.2	44.5
	45-55 mm	-	84.5	67.2	83.1	74.2
Maris Piper						
	35-45 mm	-	44.8	41.8	63.2	45.9
	45-55 mm	-	82.0	75.0	80.3	90.1
Charlotte						
	35-45 mm	-	51.7	48.7	56.4	55.7
	45-55 mm	-	77.5	70.9	95.7	80.4
Saturna						
	35-45 mm	-	41.6	40.7	40.3	45.8
	45-55 mm	-	67.7	67.8	63.9	81.5
Shepody						
	35-45 mm	-	56.9	57.0	54.7	-
	45-55 mm	-	95.4	105.2	103.4	-

Assessment of dormancy

Samples of 35-45 mm Estima produced in Jerez in 2003 were held at *c.* 2 °C after grading and then *c*. 100 tubers placed in a 15 °C controlled temperature cabinet at approximately monthly intervals from July to October 2003, and in April, August and October in 2004. Weekly observations were made and the mean date of dormancy break was estimated as the first date when ≥ 50 % of tubers had sprouts ≥ 3 mm.

Field experiments in 2004

Using seed from the 2002 and 2003 seed crops, a series of experiments (Table 3) was conducted at Cambridge and at Hilborough, Norfolk. Treatments in each experiment consisted of all combinations of the factors listed in Table 3 except Expts 16-21 (see below). In Expts 7-9, where planting date was a treatment, a split-plot design with three replicates was used with planting dates as main plots and other treatment combinations as sub-plots, but in Expts 16-21 the two planting dates were treated and analysed as separate experiments. Pre-emergence herbicide was applied to the appropriate main plots following each planting. Experiments in which planting date was not a treatment were arranged in randomized blocks with three replicates, except Expts 10-15 where four replicates were used. All seed was initially held at *c*. 3 °C in a commercial cold store but transferred to an experimental store at *c*. 2 °C prior to early plantings, and unsprouted seed for Expts 7, 8, and 10-21, was then held at *c.* 2 °C up to planting. Seed for which sprouting was a treatment was placed in 15 °C cabinets prior to planting (details given for individual experiments below).

All experiments at Cambridge were planted by hand into 76 cm rows, but in Expt 27, at Hilborough, Norfolk three rows were planted by hand into 1.81 m beds. Most experiments were planted at a within-row spacing of 30 cm, but for the density experiments (Expts 22-27), plant spacing was a treatment (as detailed in Table 3). At Cambridge no fertilizer P or K was used and fertilizer N was applied at a rate of 200 kg N/ha as liquid pre-planting. In Hilborough the Expt was treated as for the surrounding commercial crop. Plots consisted of single rows of 20 plants in Expts 1-8 and 10-15, four rows of 10 plants in Expt 9, 16-21 and 28. In Expts 22-27, the number of plants differed between densities (see Table 3) with three 12 m rows in Expts 22-24, five 3 m rows in Expt 25, four 6 m rows in Expt 26, and six 4 m rows in 2 beds in Expt 27. 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 22-27 and graded yield determined for Expts 9, 16-28. Emergence of stems was recorded regularly for Expts 7-9. Only fully guarded plants were harvested from each experiment, with the target of 12 plants per plot from Expts 9, 16-21 and 28. In Expts 22-27, the number of plants harvested differed between densities (see Table 3) with 4 m harvested in Expts 22-24 and 26, 3 m in Expts 25 and 27 at each of 2 harvests. Where planting date was a treatment, sequential harvests were made of individual plantings, and experiments were harvested as follows (Expt nos in parentheses following date): 19 Aug, 30 Sep (9); 13 Aug, 23 Sep (16); 12 Aug, 23 Sep (17); 18 Aug, 27 Sep (18); 17 Sep, 29 Sep (19); 3 Sep, 1 Oct (20); 9 Sep, 1 Oct (21); 15 Jul, 15 Sep (22); 19 Jul, 24 Sep (23); 21 Jul, 20 Sep (24); 2 Jul, 22 Jul (25); 16 Jul, 8 Sep (26); 9 Aug, 23 Aug (27); 6 Sep (28). Plants in experiments with single-row plots (Expts 1-8 and 10-15) were pulled for accurate recording of numbers of mainstems and secondary stems for all plants in Expts 7 and 8 (missing plants noted), and for guarded plants only in Expts 1-6 and 10-15 (target of 16 plants per plot) as follows (Expt nos in parentheses following date): 9 Jul (1,2); 8 Jul (3,4); 7 Jul (5); 6 Jul (6); 16 Aug, 13 Sep, 29 Sep, 3 Nov (7); 16 Aug, 26 Aug, 21 Sep, 3 Nov (8); 14 Jul (10, 11, 12); 15 Jul (13, 14, 15).

Table 3. List of field experiments in 2004

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, Northumberland, Spanish	16 Apr	
2	Charlotte	As Expt 1	Welsh (P1 & P2), Wiltshire, Northumberland	7 Apr	
3	Maris Peer	As Expt 1	As Expt 2	15 Apr	
4	Maris Piper	As Expt 1	As Expt 2	15 Apr	
5	Saturna	As Expt 1	As Expt 2	8 Apr	
6	Shepody	As Expt 1	Welsh (P1 & P2), Wiltshire	15 Apr	
7	Estima	30-35, 45-50	2002 seed: Spanish, Welsh (P1 & P2), Wiltshire, Cambridge, Northumberland	23 Mar, 12 May, 28 Jun, 17 Aug	
8	Charlotte, Hermes	30-35, 45-50	Northumberland 2002 seed	As Expt 7	
9	Estima, Charlotte, Hermes	30-35	2002 seed: Northumberland, Cambridge. 2003 Estima, Charlotte: Northumberland. 2003 Hermes: Wiltshire	26 Apr, 2 Aug	
10	Estima	45-55	Welsh (P1 and P2)	26 Apr	3 sprouting treatments: cold stored, 'eyes open', sprouted
11	Charlotte	45-55	Welsh (P1 and P2)	26 Apr	As Expt 10
12	Maris Piper	45-55	Welsh (P1 and P2)	26 Apr	As Expt 10
13	Maris Peer	45-55	Welsh (P1 and P2)	26 Apr	As Expt 10
14	Saturna	45-55	Welsh (P1 and P2)	26 Apr	As Expt 10
15	Shepody	45-55	Welsh (P1 and P2)	26 Apr	As Expt 10
16	Estima	45-55	Welsh (P1 and P2)	13 Apr, 14 Jul	2 sprouting treatments: sprouted, not sprouted
17	Charlotte	45-55	Welsh (P1 and P2)	13 Apr, 14 Jul	As Expt 16
18	Maris Peer	45-55	Welsh (P1 and P2)	13 Apr, 14 Jul	As Expt 16
19	Maris Piper	45-55	Welsh (P1 and P2)	13 Apr, 14 Jul	As Expt 16
20	Saturna	45-55	Welsh (P1 and P2)	13 Apr, 14 Jul	As Expt 16
21	Shepody	45-55	Welsh (P1 and P2)	13 Apr, 14 Jul	As Expt 16
22	Estima	35-45	Welsh (P1 and P2), Spanish	20 Apr	5 within-row spacings: 19, 24, 31, 44, 80 cm
23	Maris Piper	35-45	Welsh (P1 and P2)	20 Apr	As Expt 22
24	Saturna	35-45	Welsh (P1 and P2)	20 Apr	As Expt 22
25	Charlotte	35-45	Welsh (P1 and P2)	16 Apr	5 within-row spacings: 12, 16, 20, 24, 28 cm
26	Shepody	35-45	Welsh (P1 and P2)	16 Apr	5 within-row spacings: 15, 18, 22, 29, 40 cm
27	Maris Peer	35-45	Welsh (P1 and P2)	26 May	5 within-row spacings:14, 17, 20, 25, 33 cm
28	Charlotte, Maris Peer, Shepody	35-45	Welsh (P1 and P2)	14 Apr	3 treatments: cold stored, sprouted and controlled atmosphere treated

Experiments 1-8, 22-27

For these experiments, boxes or nets of seed were removed from cold storage immediately prior to planting, weighed (Expts 1-8) and planted. Separate individual plastic boxes were allocated to sequential plantings in Expts 7 and 8 so that this seed could be held undisturbed at 2 °C.

Experiment 9

Following planting of P1 and P3 of Expts 7 and 8, 30-35 mm seed of selected stocks (2002 produced Northumberland and Cambridge Estima, Charlotte and Hermes; 2003 produced Northumberland Estima and Charlotte and Wiltshire Hermes) was placed at 15 °C. Weekly observations of sprout development were made and the seed planted after *c*. 1 month at 15 °C.

Experiments 10-15

Trays of 45-55 mm seed were allocated to one of three sprouting treatments. Unsprouted seed was held at 2 °C until planting. The seed for the '> 230 °Cd' treatment seed was placed at 15 °C in the light on 13 Mar to accumulate at least 200 degree days before planting. 'Open eyes' treated seed was placed at 15 °C in the light on 19 Apr before planting on 26 Apr. At planting the length of all sprouts on 20 tubers was recorded.

Experiments 16-21

All seed was sprouted for *c.* two weeks prior to planting. Trays of 45-55 mm seed were placed at 15 °C in the light on 31 Mar for planting on 13 Apr, and on 28 Jun for planting on 14 Jul. 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 28

The controlled atmosphere treatment was performed by Greenvale AP (GVAP), on seed detailed in Table 3 and supplied to GVAP in November. The experiment was planted shortly after this seed was returned on 14 Apr following treatment. Nets of unsprouted seed were held in cold storage until immediately prior to planting, and 'sprouted' seed was placed at 15 °C in the light 6 days before planting so that most stocks had ≥ 50 % of tubers with sprouts ≥ 1 mm (although for late-produced Shepody only 30 % sprouts were ≥ 1 mm at planting).

Results and Discussion

Dormancy

Analysis of the sprouting of Estima samples placed sequentially at 15 °C showed that other than the earliest sample date, the apparent dormancy period (weeks from emergence to onset of sprouting) increased linearly (Figure 1). The linear increase in the apparent dormancy period (i.e. enforced due to cold storage) demonstrated that once the seed was chronologically older than needed for natural dormancy break, it remained viable and the interval from entering the 15 °C cabinet to ≥ 50 % of tubers with sprouts ≥ 3 mm was relatively constant (*c*. 2 weeks) for seed tested ≤ 510 days after emergence. For seed > 580 d after emergence the interval to end of dormancy increased to nearly 4 weeks, and sprouting was not complete (Figure 2) demonstrating a reduction in seed viability.

Figure 1. Interval from emergence to apparent dormancy break for 2003-produced Jerez Estima seed placed in a test chamber at different times in 2003 and 2004.

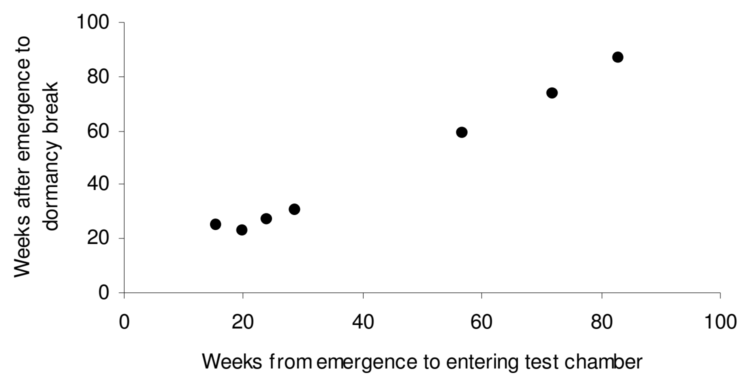
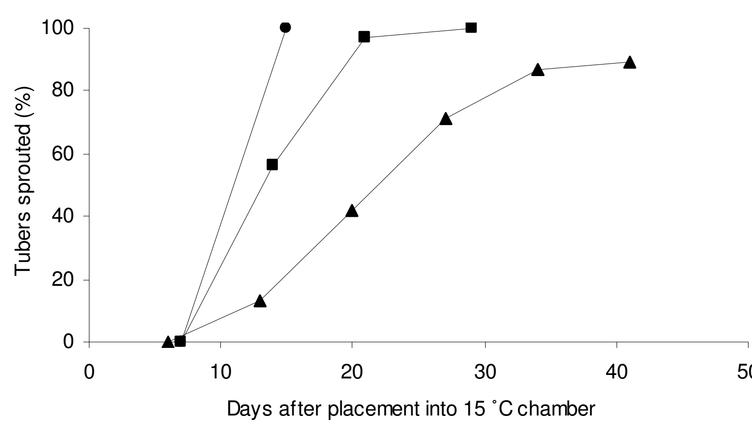


Figure 2. Sprout growth of 2003-produced Jerez Estima placed into the chamber at different times in 2004. Placed in chamber: 398 d, ●; 503 d, ■; 581 d, ▲ after emergence of the mother crop.



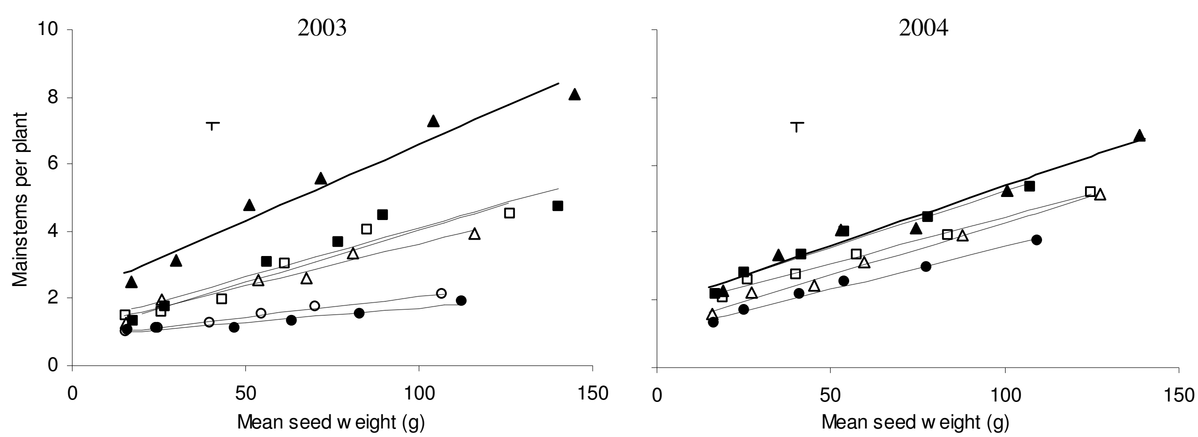
Expt 1. Seed size and stock (Estima)

Differences between stocks in the number of days from planting to 50 % emergence were small (mean for all seed sizes < 3 days), though the Wiltshire and Northumberland seed tended to emerge most quickly, and the Spanish seed the slowest (Table 4). Very few secondary stems were produced (< 0.01 per plant). The number of mainstems was least for the late-produced Welsh seed stock and most for the earlier Wiltshire and earliest-produced Spanish seed for which large seed produced nearly seven stems per plant. The relationship between number of mainstems and seed weight was analysed using linear regression with stock as a factor. For each of the stocks, the number of mainstems increased progressively with increase in seed size, although the differences in the rate of this increase between stocks were less apparent than in previous years (Figure 3). These smaller differences are partly explained by production dates in 2003, as late seed was planted earlier than previously and thus contrasted less with other stocks, but numbers of stems for Spanish seed were lower than might be expected.

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

	Stock				
Seed size (mm)	Welsh P1	Wilts	Northumberland	Welsh P2	Spanish
25-30	32.6	30.9	33.2	33.3	32.6
30-35	33.0	30.4	32.5	33.6	33.4
35-40	32.5	32.0	31.2	33.0	33.0
40-45	31.8	31.4	31.9	33.1	33.5
45-50	33.2	31.1	31.9	33.5	34.3
50-55	33.3	31.2	30.8	32.8	35.1
S.E.			0.53		

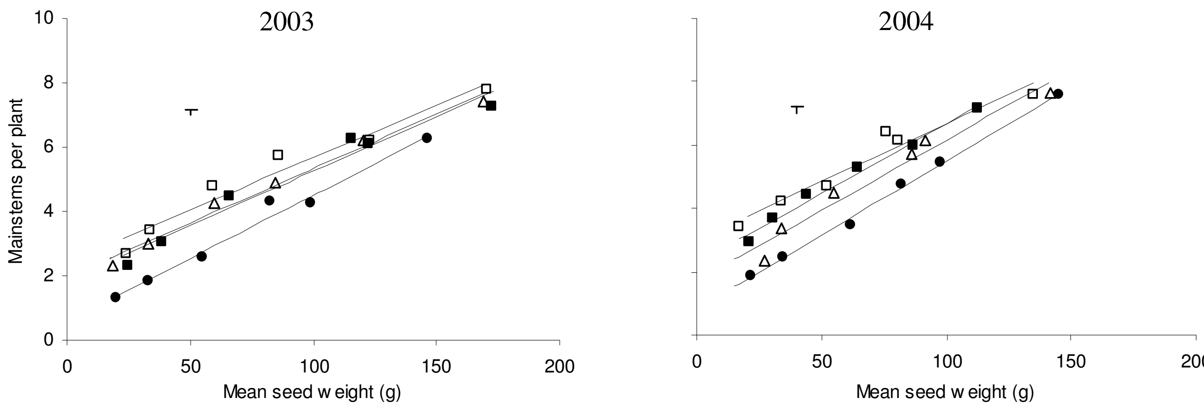
Figure 3. Linear relationships between number of mainstems per plant and seed weight for Estima in Expt 1 in 2004 and for the similar experiment in 2003. Seed stocks: Cambridge, ○; Welsh P1, □; Northumberland, △; Spanish, ▲; Welsh P2, ●; Wiltshire, ■. Bar indicates S.E.



Expt 2. Seed size and stock (Charlotte)

Emergence was, on average, later for the later produced stocks than the earlier produced stocks (mean of all seed sizes *c*. 3 days earlier for early-produced than for late-produced Welsh seed), but there was little difference (< 1 day) between seed sizes, and all plots reached near complete emergence. There were few secondary stems in any treatment (< 0.05 per plant). 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 the late-produced Welsh seed, and generally similar to results in 2003 (Figure 4).

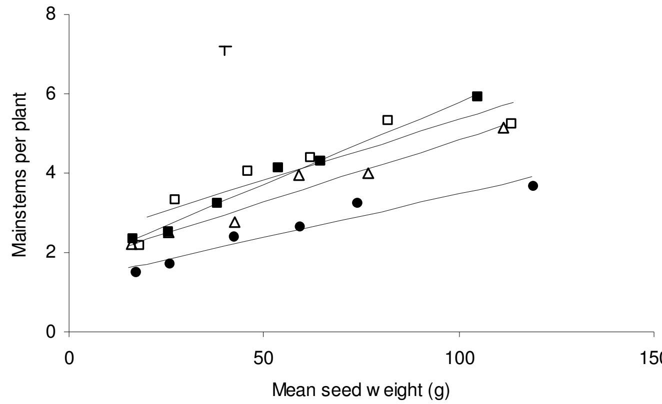
Figure 4. Linear relationships between the number of mainstems per plant and seed weight for Charlotte in Expt 2 in 2004 and for the similar experiment in 2003. Seed stocks: Cambridge, ○; Welsh P1, □; Northumberland, △; Welsh P2, ●; Wiltshire, ■. Bar indicates S.E.



Expt 3. Seed size and stock (Maris Peer)

Emergence was on average 1.3 days later for the late-produced Welsh stock than the other stocks and there was no difference in the rate of emergence between seed sizes. There were few secondary stems (average 0.09 per plant) in any treatment. The number of mainstems was greatest for early-produced Welsh P1 seed and least for late-produced Welsh P2 seed. The number of mainstems increased with increase in seed size in all stocks, but large early-produced Welsh seed produced fewer stems than expected, and the rate of increase was greater for Wiltshire seed than other stocks (Figure 5).

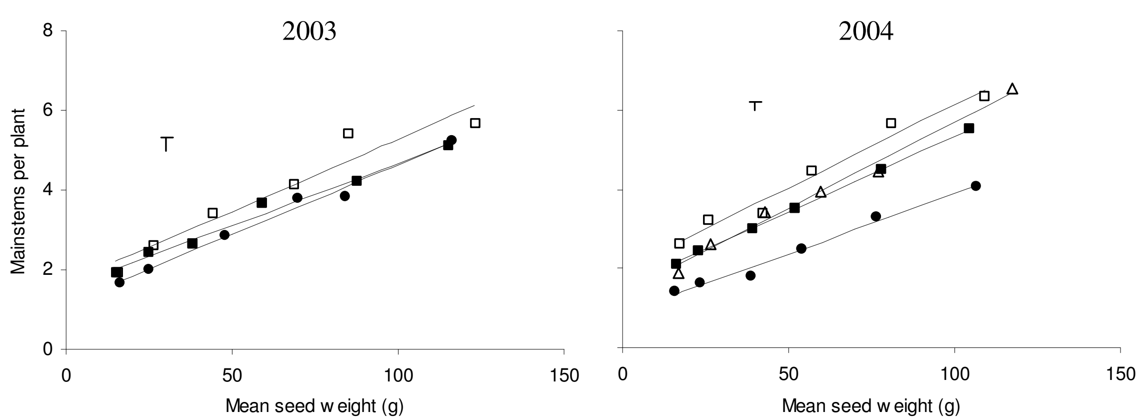
Figure 5. **Linear relationships between the number of mainstems per plant and seed weight for Maris Peer in Expt 3. Seed stocks: Welsh P1, □; Northumberland, △; Welsh P2, ●; Wiltshire, ■. Bar indicates S.E.**



Expt 4. Seed size and stock (Maris Piper)

The interval from planting to 50 % emergence was longest for the late-produced Welsh stock and shortest for the early-produced Welsh stock, but the difference was < 2 days on average, and there was no consistent effect of seed size on emergence. Most stocks reached complete, or near complete emergence, although only 87 % of the late-produced Welsh stock actually emerged. As in the previous year, smaller seed produced more secondary stems than larger seed and both Welsh stocks produced more secondary stems than the other stocks with small seed although the number of secondary stems was low (no more than 0.6 stems per plant in any treatment). The number of mainstems was greatest for the early-produced Welsh P1 seed and least for the later-produced Welsh P2 stock, and increased with seed size, although in 2004, this increase was less rapid for the late-produced Welsh stock than the other stocks (Figure 6).

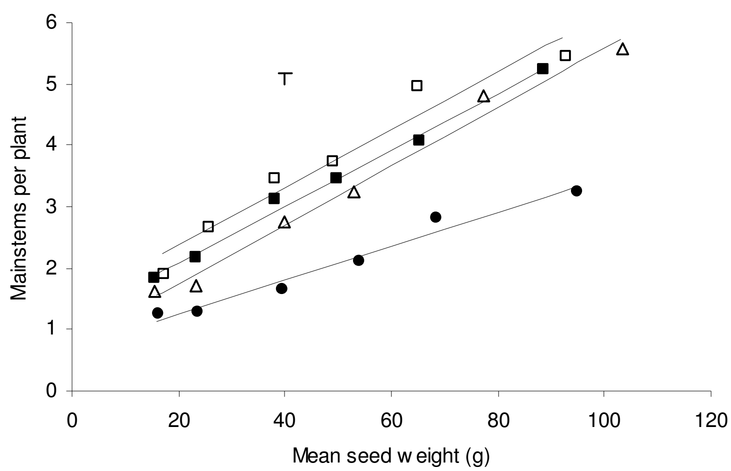
Figure 6. **Linear relationships between the number of mainstems per plant and seed weight for Maris Piper in Expt 4 in 2004 and for the similar experiment in 2003. Seed stocks: Welsh P1, □; Northumberland, △; Welsh P2, ●; Wiltshire, ■. Bar indicates S.E.**



Expt 5. Seed size and stock (Saturna)

Emergence was on average 3.5 days later for the late-produced Welsh stock than the other stocks and smaller seed emerged slightly more rapidly than larger seed (*c*. 1 day earlier for the smallest seed than the largest seed on average). Complete emergence was achieved by all treatments. There were few secondary stems (average 0.25 per plant) in any treatment, although smaller seed tended to produce more secondary stems than larger seed (an average across stocks of 0.64 secondary stems for 25-30 mm seed *cf.* 0.06 for 50-55 mm seed). The number of mainstems tended to be greatest for early-produced Welsh P1 seed and was least for late-produced Welsh P2 seed and the increase in number of stems with seed weight was markedly less rapid for the late-produced Welsh stock than the other stocks (Figure 7).

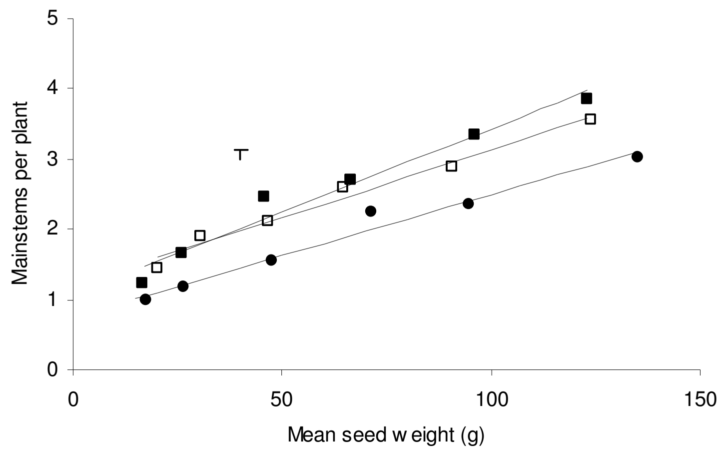
Figure 7. Linear relationships between the number of mainstems per plant and seed weight for Saturna in Expt 5. Seed stocks: Welsh P1, □; Northumberland, △; Welsh P2, ●; Wiltshire, ■. Bar indicates S.E.



Expt 6. Seed size and stock (Shepody)

The interval from planting to 50 % emergence was similar for all treatments. Most stocks achieved complete, or near complete emergence, however the late-produced Welsh stock emerged less well (92 % on average but no less than 87 % for any seed size). There were few secondary stems (< 0.05 per plant) in any treatment. The number of mainstems, and the increase in mainstems with seed size was less for late-produced Welsh seed than the other stocks (Figure 8).

Figure 8. **Linear relationships between the number of mainstems per plant and seed weight for Shepody in Expt 6. Seed stocks: Welsh P1, □; Northumberland, △; Welsh P2, ●; Wiltshire, ■. Bar indicates S.E.**



Expt 7. Stock and planting date (Estima)

Weight loss between loading 2002-produced seed into boxes and the first planting in 2004 was similar to that for old seed in previous years (3-8 % across all stocks). Further weight loss up to the final planting was no more than an additional 4 % for any stock and there was little difference in weight loss between seed sizes. Soft rotting was evident in all stocks, with up to *c*. 9 % of tubers having rotted by the final planting. Tubers with symptoms of decay were not planted but tubers with latent infection may not have been excluded.

At the first planting, near complete emergence was achieved in most stocks (> 93 %) but emergence was poorer for Welsh P2 (68 %) and Spanish (85 %) stocks. 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 9), although emergence for the Welsh P2 stock was generally poorer than expected.

The Cambridge-produced seed had the most rapid emergence, being on average over 10 days before the other stocks, of which the Spanish seed emerged most slowly (Table 5). The mean interval from planting to emergence increased with delay in planting from the second to fourth plantings, possibly due to deterioration in seed health. The first planting was into cold soil (mean soil temperature for 2 weeks following first planting 8 °C), which would have delayed emergence.

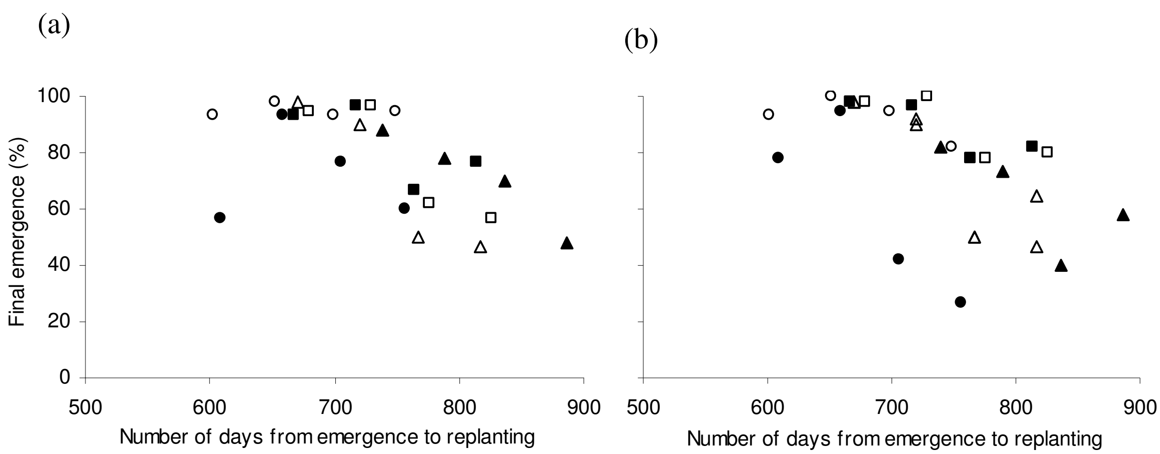
Table 5. **Effect of seed stock and planting date on days from planting to 50 % emergence for two seed sizes of Estima in Expt 7**

	Stock					
Planting date	Spanish	Welsh P1	Wiltshire	Northumberland	Welsh P2	Cambridge
			30-35 mm seed			
23-Mar	63.7	64.7	56.4	51.7	64.7	56.6
12-May	43.7	36.1	36.8	35.5	31.3	25.1
28-Jun	*56.7*	62.0	55.6	*61.1*	*47.0*	32.5
17-Aug	-	66.1	59.0	-	*61.8*	45.1
			45-50 mm seed			
23-Mar	68.7	67.5	63.1	61.3	58.0	53.0
12-May	43.0	35.9	37.3	44.3	30.5	29.2
28-Jun	-	39.1	41.8	*55.7*	-	29.3
17-Aug	*68.0*	52.2	58.4	*63.6*	-	45.9
S.E.†			(a) 1.95 (1.52*); (b) 3.72 (4.06*)			

† Analysis of variance conducted with restrictions due to not all treatments reaching 50 % emergence. (a) S.E. for all stocks and both seed sizes at the first two plantings; (b) S.E. for Welsh P1, Wiltshire and Cambridge stocks of both seed sizes at all plantings. Data in italics excluded from analysis.

* S.E. for comparisons at the same planting date

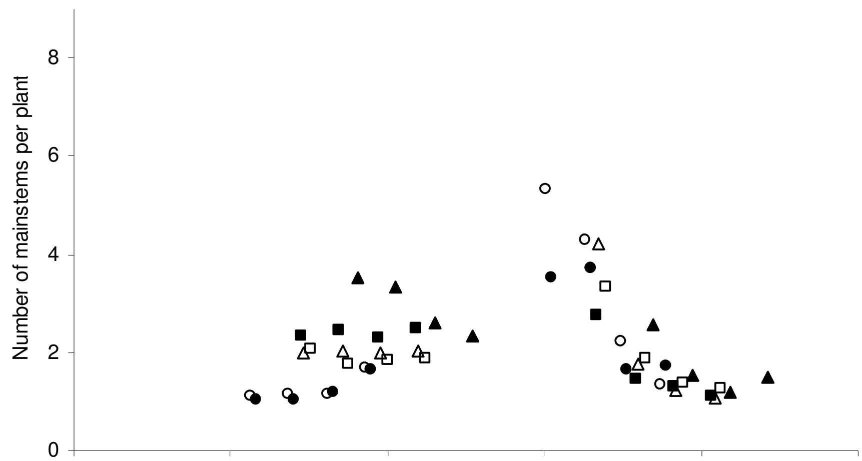
Figure 9. **Effect of time from emergence of seed crop on the final % emergence for six seed stocks of 2002 produced Estima replanted in 2004, in Expt 7. a) 30-35 mm b) 45-50 mm. Seed stocks: Cambridge, ○; Welsh P1, □; Scottish, △; Spanish, ▲; Welsh P2, ●; Wiltshire, ■.**



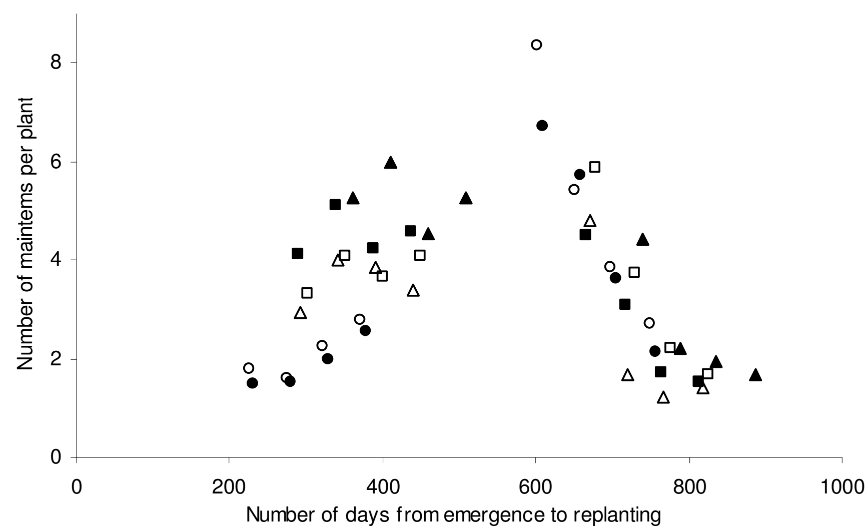
There were many mainstems produced at the first planting (> 5.7 stems per plant on average for the 45-50 mm seed) but numbers generally decreased rapidly with delay in replanting, except for the late-produced small Welsh P2 seed for which an increase from the first to second planting, was followed by a decrease for later plantings (Figure 10). A similar effect was found for late-produced seed replanted in 2002 and 2003 (2003 Annual Report).

Figure 10. Effect of time from emergence of seed crop on number of mainstems per plant from six seed stocks of 2002 produced Estima replanted in 2003 and 2004 Expt 7 a) 30-35 mm b) 45-50 mm. Seed stocks: Cambridge, ○; Welsh P1, □; Scottish, △; Spanish, ▲; Welsh P2, ●; Wiltshire, ■.

(a)



(b)



Expt 8. Stock and planting date (Charlotte and Hermes)

Weight loss between loading seed into boxes and planting was generally greater for Charlotte than for Hermes, but was similar across seed sizes and not as great as that experienced by old seed in 2003 (an average of 9.95 % compared to 58.5 % in 2003).

Emergence was not complete, and deteriorated with delay in planting, particularly for the large Charlotte seed of which 88 % of plants emerged from the first planting but none emerged from the final planting (emergence for 30-35 mm Charlotte seed was 92 % following early planting and 8.3 % following the final planting). Emergence also deteriorated for Hermes, from 97 % to 48 % for the first to final plantings (Table 6). Hermes emerged more rapidly than Charlotte across all plantings and where 50 % emergence was achieved, the mean interval from planting to 50 % emergence increased progressively with delay in planting from the second (44 days for large Hermes seed) to the final planting (66 days for large Hermes seed). The first planting resulted in delayed emergence due to planting into cold soil (55 days from planting for large Hermes seed). Charlotte seed did not reach 50 % emergence at either the third or fourth planting, and the interval from planting to 50 % emergence decreased from 80 to 60 days from the first to second plantings.

More stems were produced from larger seed than smaller seed and there were few secondary stems in any treatment. Charlotte produced more stems than Hermes for the smaller seed, as shown in previous years' experiments, but fewer than Hermes for the larger seed. The number of mainstems generally decreased progressively with delay in planting for both varieties, associated with the deterioration of the health of the seed over time but following the early planting many stems were produced in Hermes, considerably more than from any plantings of this stock in 2003 (Figure 11).

Figure 11. Effect of time from emergence of seed crop on number of mainstems per plant from two seed sizes of 2002 produced Charlotte and Hermes replanted in 2003 and 2004 in Expt 8. 30-35 mm, ○; 45-50 mm, □. Closed symbols, Charlotte; open symbols, Hermes. Bars indicate S.E.

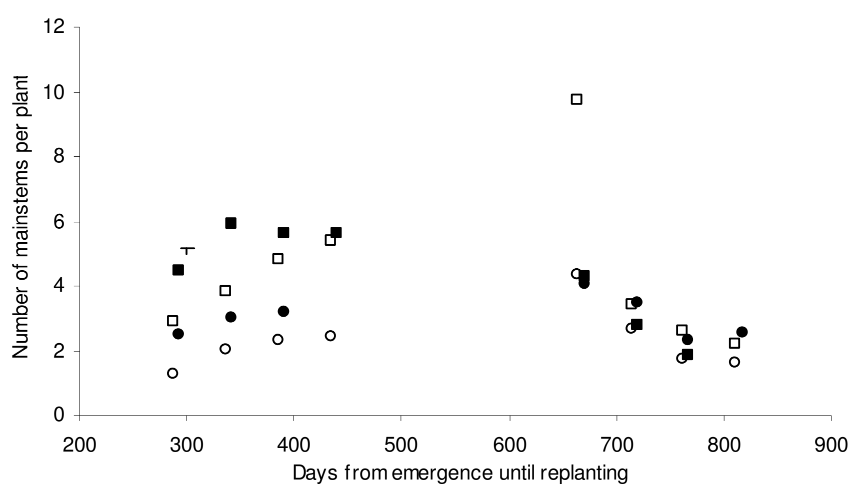


Table 6. Effect of planting date of 2002 produced Charlotte and Hermes seed on final % emergence and number of mainstems per plant in Expt 8

Planting date	Charlotte		Hermes	
Seed size	30-35	45-50	30-35	45-50
Final % emergence				
23 Mar	91.7	95.0	88.3	98.3
12 May	75.0	93.3	58.3	95.0
28 Jun	36.7	73.3	23.3	71.7
17 Aug	8.3	35.0	0.0	60.0
S.E.	4.98 (4.76*)			
Number of mainstems				
23 Mar	4.04	4.51	4.34	9.72
12 May	3.50	2.78	2.64	3.43
28 Jun	2.33	1.87	1.74	2.62
17 Aug	2.56	-	1.64	2.18
S.E.	0.450 (0.436*)			

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

Expt 9. Sprouting, stock and planting date (Estima, Charlotte and Hermes)

Prior to each planting, rotting tubers were removed and the number recorded. No rotting was observed in the 2003 seed but at the first planting, the incidence of rotting in 2002 seed was 37 % in the younger Cambridge Charlotte, 10 % in the Cambridge Hermes, 20 % in the older Northumberland Estima, 16 % in the Northumberland Hermes and none in the Cambridge Estima. At the first planting, all stocks had > 65 % of tubers with sprouts > 3mm, although the 2002 Northumberland produced Charlotte was the least well sprouted. At the second planting, 45 % of 2002 Northumberland produced Charlotte tubers had sprouts > 3 mm (longest sprout per tuber 6 mm) whereas the other stocks were all > 75 % (longest sprout per tuber > 11mm). Owing to failure of the lighting in the 15 °C cabinet holding the seed for the second planting, etiolation occurred, particularly in Estima stocks and the 2003 Northumberland Charlotte, for which the longest sprouts per tuber were > 21 mm, on average, at planting.

Younger seed stocks tended to emerge more rapidly than older seed at both plantings, and at the later planting very rapid emergence was associated with the etiolation of sprouts (Table 7). The 2002 produced seed tended to emerge less completely than the 2003 seed, particularly in Charlotte (Table 7). At the first planting emergence of 2002 Cambridge Estima was particularly poor, despite all seed having > 3 mm sprouts at planting, but following the second planting when the soil was warmer complete emergence was achieved. A similar effect was noted for late-produced sprouted Estima seed from 2001 planted in 2003 (2003 Annual Report).

Table 7. Effect of planting date, stock (2002 and 2003) and variety on the interval from planting to 50 % emergence, final % emergence, number of mainstems per plant, number of tubers and yield in Expt 9

Stock	2002 Cambridge		2002 Northumberland		2003	
Planting date	26 Apr	2 Aug	26 Apr	2 Aug	26 Apr	2 Aug
Interval from planting to 50 % emergence (days)						
Estima	21.9	6.2	23.6	14.8	20.5	5.3
Hermes	19.5	8.1	20.0	13.8	20.4	4.4
Charlotte	21.5	15.4	44.8	23.1	22.7	5.7
S.E.			0.57 (0.33*)			
Final % emergence						
Estima	73.3	100.0	95.0	91.7	100.0	100.0
Hermes	98.3	100.0	96.7	95.0	100.0	100.0
Charlotte	86.7	95.0	86.7	83.3	100.0	100.0
S.E.			4.33 (3.65*)			
Number of mainstems per plant						
Estima	4.15	4.56	2.81	1.76	2.78	3.81
Hermes	3.87	4.47	4.92	3.73	2.64	3.11
Charlotte	6.42	4.97	3.66	2.50	3.94	4.86
S.E.			0.325 (0.327*)			
Number of tubers > 10 mm (000/ha)						
Estima	296	646	442	240	323	687
Hermes	674	574	779	360	480	569
Charlotte	941	548	440	126	648	667
S.E.			43.6 (46.1*)			
Tuber yield (t/ha)						
Estima	24.6	16.2	47.4	8.0	45.8	17.3
Hermes	52.7	12.0	53.0	7.3	57.8	15.3
Charlotte	50.3	8.7	18.6	1.2	57.7	18.3
S.E.			2.59 (2.56*)			

* S.E. for comparisons at the same planting date or stock

The earlier-produced Cambridge 2002 seed tended to produce more mainstems than other stocks (Table 7), particularly in Charlotte. The later-produced Northumberland 2002 stock produced fewer stems than the other stocks, and this may be due to it being replanted more than 698 days after emergence of the mother crop (2002 Cambridge stock was planted less than 638 days after emergence), similar to the results shown in Expts 5-7. Later planting generally resulted in more mainstems than early planting for the Cambridge produced 2002 and the 2003 stocks, but not with the 2002 Charlotte. The 2002 Cambridge Charlotte and all varieties of the old Northumberland seed produced fewer stems at the second planting than the early planting, probably due to deterioration in seed health. No secondary stems were produced by any stock.

The 2003-produced stock produced more tubers at the second planting than at the first planting. Consistent with the large number of mainstems, the 2002 Cambridge produced Charlotte seed produced the most tubers at the first planting (Table 7). Within the 2002-produced stocks, the first planting tended to produce more tubers than the second planting, the exception being the Cambridge produced Estima, which produced few tubers at the first planting following poor emergence. The second planting produced low tuber yields due to the short interval from planting to harvest, but large yields were produced by most stocks following the first planting, except 2002 Northumberland produced Charlotte (which had a protracted emergence and produced fewer tubers than the other Charlotte stocks) and the Cambridge 2002 Estima.

The results of this experiment confirmed those of the experiment in 2003 that sprouting prior to planting may extend the period over which seed remains viable. In Expts 5-7, plantings of unsprouted seed from 2002 resulted in protracted and poor emergence, and although the emergence was protracted for the first planting of Northumberland 2002 Charlotte, and poorer for the Cambridge 2002 Estima, numbers of tubers and tuber yields were comparable to the 2003 produced seed for most stocks. These data exclude seed that rotted prior to planting but nevertheless results from the early planting of Cambridge produced Charlotte in particular demonstrate that production of very high yields of small tubers is possible using old seed, although this may not be reliable.

Expt 10-15. Sprouting x Stock (Estima, Charlotte, Maris Peer, Maris Piper, Saturna and Shepody)

These experiments had the same sprouting treatments for all varieties and the results are presented together below (Table 8). The physiological age at planting for the well-sprouted seed was *c*. 310 °Cd for all stocks other than the early-produced Shepody, and the late-produced Saturna, for which it was *c*. 230 °Cd.

Cold storage resulted in negligible sprout development (< 0.1 sprouts > 3 mm, longest sprout per tuber < 1.2 mm), whereas the 'eyes open' treatment resulted in sprouts ranging from 0.8 mm (late-produced Saturna) to 3.6 mm (early-produced Charlotte), and both more and longer sprouts developed in the early-produced stocks than the late-produced stocks in Charlotte, Maris Peer and Saturna. This effect of stock was more clearly expressed in the well-sprouted seed, for which the degree of sprouting was greater for the early-produced stock than the late-produced stock in all varieties (Table 8). Saturna tended to be the least sprouted and Maris Peer the most sprouted across all treatments at planting (Table 8).

Table 8. The effect of sprouting on the numbers of sprouts and sprout length at planting for early and late produced stocks of Estima, Charlotte, Maris Peer, Maris Piper, Saturna and Shepody in Expts 10-15

Storage Stock	Variety					
	Charlotte	Estima	Maris Peer	Maris Piper	Saturna	Shepody
Number of sprouts >3 mm per tuber						
Early-produced						
'Eyes open'	1.4	0.3	1.8	0.4	1.3	0.2
S.E.	0.25	0.12	0.32	0.15	0.35	0.16
Sprouted	9.6	6.7	10.1	9.9	8.3	8.0
S.E.	0.68	0.36	0.66	0.51	0.42	0.53
Late-produced						
'Eyes open'	1.0	1.1	1.0	1.3	0.0	1.0
S.E.	0.28	0.28	0.26	0.43	0.00	0.35
Sprouted	7.8	5.6	7.8	5.3	3.1	7.7
S.E.	0.45	0.36	0.30	0.33	0.33	0.30
Longest sprout per tuber (mm)						
Early-produced						
'Eyes open'	3.6	2.2	3.3	1.8	2.9	1.7
S.E	0.54	0.19	0.26	0.28	0.34	0.15
Sprouted	12.2	11.5	11.9	20.6	12.7	22.4
S.E	0.44	0.42	0.36	0.53	0.43	0.51
Late-produced						
'Eyes open'	2.6	2.7	2.5	2.4	0.8	2.1
S.E	0.14	0.18	0.17	0.23	0.11	0.21
Sprouted	10.3	10.2	14.8	9.2	9.4	19.2
S.E	0.33	0.42	0.54	0.39	0.27	0.41

The interval from planting to 50 % emergence was generally up to *c*. 1 week less for seed planted with 'eyes open' than unsprouted seed and up to *c*. 2 weeks less for well-sprouted seed

(Table 9). The early-produced stock emerged slightly more rapidly than the late-produced stock in Charlotte, Maris Peer and Saturna. All treatments achieved complete or near-complete emergence. Consistent with other findings in this report where the interval from emergence to replanting had an effect on the number of stems, the early-produced stock tended to produce more stems than the later-produced stock; although the difference between stocks for Shepody and Charlotte was only apparent for the well-sprouted seed (Table 9). The number of stems increased progressively with the extent of sprouting for the early-produced stock of Estima, Maris Piper, Saturna and Shepody, and the well-sprouted early-produced stock produced the most stems, except in Maris Peer (Table 9).

Table 9. The effect of sprouting on the interval from planting to 50 % emergence and the number of mainstems per plant for early and late-produced stocks of Estima, Charlotte, Maris Peer, Maris Piper, Saturna and Shepody in Expts 10-15

Sprouting treatment		Unsprouted		'Open eyes'		Sprouted		
Variety	Stock	Early	Late	Early	Late	Early	Late	S.E.
Days from planting to emergence								
Estima		30.6	33.0	25.8	26.3	22.2	20.5	0.74
Charlotte		30.6	32.2	24.8	27.3	19.9	21.9	0.24
Maris Peer		29.5	31.3	24.3	25.4	17.9	20.3	0.28
Maris Piper		32.5	33.2	26.1	25.8	19.8	20.4	0.25
Saturna		28.6	34.3	23.5	27.9	21.0	24.3	0.21
Shepody		33.7	33.3	26.9	25.9	16.9	17.2	0.24
Number of mainstems per plant								
Estima		4.1	2.9	4.2	3.6	4.5	3.4	0.16
Charlotte		6.8	6.8	6.4	6.5	7.2	4.9	0.45
Maris Peer		5.6	3.9	5.3	4.2	4.9	3.8	0.19
Maris Piper		5.0	3.4	6.0	3.5	6.5	4.7	0.23
Saturna		4.6	2.8	5.0	3.2	8.0	4.7	0.13
Shepody		2.6	2.6	2.8	3.1	3.8	3.0	0.12

Expt 16-21. Sprouting x Stock x Planting date (Estima, Charlotte, Maris Peer, Maris Piper, Saturna and Shepody)

These experiments had the same sprouting treatments for all varieties and the results are presented together (Table 10). At the first planting, all of the sprouted stocks had visible sprouts on all tubers at planting, and more than 90 % of tubers had sprouts greater than 3 mm in all stocks except the early-produced Shepody and late produced Saturna (45 and 70 % of tubers with sprouts > 3 mm, respectively). The length of the longest sprout per tuber at the first planting ranged from 5 mm for the early-produced Shepody and late-produced Saturna, to

13 mm for the early-produced Maris Peer at the first planting. Sprouting was less advanced at the second planting, with the percentage of tubers with sprouts > 3 mm ranging from 0 for the late-produced Saturna to 85 for the early-produced Maris Peer; the ranking of stocks being similar to those recorded for the first planting. No sprouting had occurred in the 'unsprouted' treatments at either planting.

The sprouting treatment shortened the interval from planting to 50 % emergence for all plantings and varieties (Table 10). The early-produced stock tended to emerge earlier than the late-produced stock and for both plantings of Maris Peer and Saturna, and the first planting of Charlotte, the effect was statistically significant (Table 10). All treatments achieved complete or near-complete emergence. Consistent with other findings in this report, where statistically significant differences were found, the early-produced seed stock tended to produce more stems than the later-produced stock, although for the second planting of Charlotte the results were reversed (Table 10). More stems tended to be produced at the second planting than at the first (consistent with the number of stems increasing with a longer period between emergence and replanting) across all varieties. Sprouting increased the numbers of mainstems at both plantings of Maris Piper, the second planting of Saturna, and the first planting of Shepody, but at the first planting of Charlotte, the unsprouted seed produced more stems than sprouted seed (Table 10).

Differences in the number of tubers produced were generally consistent with the number of stems for the first planting across all varieties, but this relationship was less apparent for the second planting (Table 10). At the second planting, more tubers were produced by the sprouted than the unsprouted treatment for Estima and Charlotte, and the early-produced stock of Saturna produced more tubers than the late-produced stock (Table 10).

Sprouting increased the total yield of Shepody by an average of 23 t/ha compared to unsprouted seed at the first planting, but had no effect on yield of other varieties (Table 10). Sprouting also increased the mean tuber size at both plantings of Charlotte, and at the second planting of Maris Peer and Saturna, generally consistent with comparatively fewer tubers, whereas at the first planting of Estima, sprouting decreased the mean tuber size (Table 10). At both plantings of Estima, the early plantings of Saturna and Shepody, and the late planting of Maris Piper, a larger mean tuber size was produced by the late, compared to the early-produced stock, but for the late plantings of Shepody and Maris Peer, this was reversed.

Table 10. The effect of sprouting, stock and planting date on the interval from planting to 50 % emergence, numbers of mainstems, numbers of tubers > 10 mm, tuber yield and mean tuber size for Estima, Charlotte, Maris Peer, Maris Piper, Saturna and Shepody in Expts 16-21

	Planted 13 April					Planted 14 July				
	Sprouted		Unsprouted		S.E.	Sprouted		Unsprouted		S.E.
Variety Stock	Early	Late	Early	Late		Early	Late	Early	Late	
Days from planting to emergence										
Estima	27.0	28.6	34.7	35.4	0.68	15.7	15.4	18.5	18.5	0.40
Charlotte	27.7	32.5	33.7	36.5	0.35	14.6	14.7	18.2	18.3	0.09
Maris Peer	24.4	27.4	33.2	35.8	0.54	14.6	15.2	18.1	18.7	0.20
Maris Piper	26.5	26.7	34.6	36.1	0.86	15.6	18.0	25.8	21.9	0.36
Saturna	27.0	35.5	33.6	40.0	0.32	14.6	16.5	18.0	18.3	0.34
Shepody	27.2	28.5	37.2	37.0	0.45	15.6	15.9	20.2	19.0	0.32
Number of mainstems (000/ha)										
Estima	194	153	192	131	5.9	216	177	193	157	12.3
Charlotte	246	213	294	259	13.7	278	294	260	317	12.6
Maris Peer	196	174	203	163	16.5	372	306	346	289	17.1
Maris Piper	220	117	204	115	11.8	374	270	260	216	32.1
Saturna	230	117	176	175	19.1	248	187	210	179	8.9
Shepody	170	131	121	124	8.7	165	180	174	190	7.3
Number of tubers > 10 mm (000/ha)										
Estima	628	535	634	523	17.5	474	501	447	424	18.0
Charlotte	718	593	787	769	38.4	651	629	608	508	25.0
Maris Peer	577	576	666	526	54.6	802	745	889	788	75.2
Maris Piper	673	540	695	486	33.0	711	667	630	672	67.3
Saturna	752	469	620	548	27.6	733	603	674	610	24.9
Shepody	420	395	338	278	19.0	486	448	436	450	25.9
Tuber yield (t/ha)										
Estima	65.7	68.0	65.6	64.0	1.90	23.1	26.8	21.3	22.1	1.26
Charlotte	60.4	55.0	57.8	58.0	1.42	24.3	21.8	20.1	17.7	0.39
Maris Peer	59.2	64.4	65.6	68.2	5.19	21.8	20.5	19.2	16.9	0.53
Maris Piper	64.4	65.6	65.1	67.6	2.33	22.2	21.5	18.7	22.7	1.53
Saturna	54.3	44.0	45.8	49.9	2.13	24.4	22.7	20.0	19.7	0.83
Shepody	63.8	65.3	51.4	54.4	2.25	28.3	23.2	22.4	21.5	0.79
Mean tuber size (μ, mm)										
Estima	56.8	60.7	58.5	61.5	0.46	43.1	46.3	43.1	45.5	0.85
Charlotte	48.5	52.3	48.6	52.1	0.67	35.0	34.9	33.6	33.5	0.36
Maris Peer	56.2	57.6	55.5	60.0	1.00	35.7	33.8	33.3	32.6	0.39
Maris Piper	56.2	59.3	55.5	57.9	1.90	39.9	40.9	36.9	41.5	0.84
Saturna	48.3	52.3	48.6	52.1	0.92	39.1	39.8	37.3	38.2	0.55
Shepody	61.3	63.1	61.1	66.0	1.16	48.3	44.9	46.0	43.6	1.06

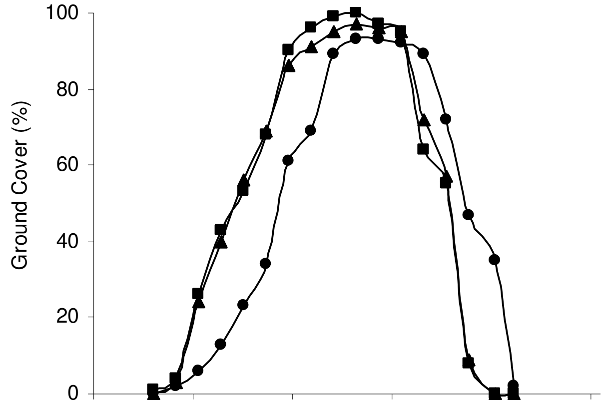
Expt 22. Density (Estima)

There were no differences between stocks in the rate of emergence and whilst ground cover increased more slowly at the widest plant spacings than at closer spacings, all treatments reached full ground cover (Figure 12). Canopies of the wide spaced early-produced Welsh and Spanish stocks persisted slightly longer than closer spacings (Figure 12).

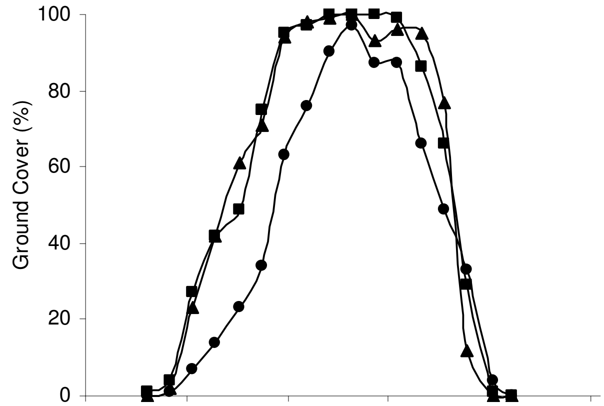
At the final harvest the early-produced Spanish seed produced the most stems (5.48 ± 0.132), and the late-produced Welsh seed the least (2.00). Although the number of mainstems per plant for the early-produced Welsh seed (2.90) was very similar to the number produced in 2003 (2.81 ± 0.06), the late-produced Welsh seed produced more stems in 2004 than previously (1.22 in 2003). There were similar differences in numbers of mainstems between the stocks at the earlier harvest. Few secondary stems were recorded in any treatment at the final harvest (< 0.07 per plant), or at the early harvest (< 0.40 per plant). Stem populations at final harvest ranged from 33 900/ha for the late Welsh stock planted at 80 cm spacing to 374 000/ha for the Spanish stock planted at 19 cm spacing. The number of tubers increased in relation to increasing stem density at both harvests, (Figure 13a). Total yield also tended to increase with increase in stem density but mainly for densities below *c*. 100 000/ha (Figure 13b). At higher densities tuber yield remained relatively stable. Mean tuber size decreased progressively with increase in stem density at the final harvest from 66.3 mm to 54.5 mm (Figure 13c), and a similar trend was shown at the earlier harvest. Late-produced seed produced a greater yield of tubers > 60 mm than earlier-produced seed, and this was related to differences in the number of stems (Figure 13d), as yield > 60 mm decreased with increasing stem populations, achieved either through closer planting densities, or through the planting of older seed.

Figure 12. The effect of plant density on ground cover for (a) early Welsh P1 (b) late Welsh P2 and (c) Spanish produced stocks of Estima in Expt 22. Plant spacings (cm): 80, ●; 31, ▲; 19, ■ (intermediate densities not shown).

(a)



(b)



(c)

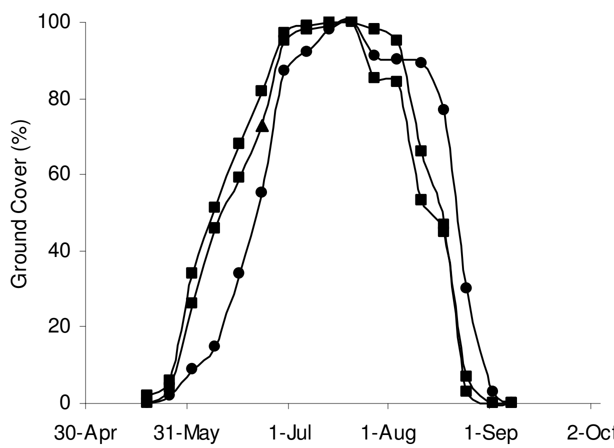
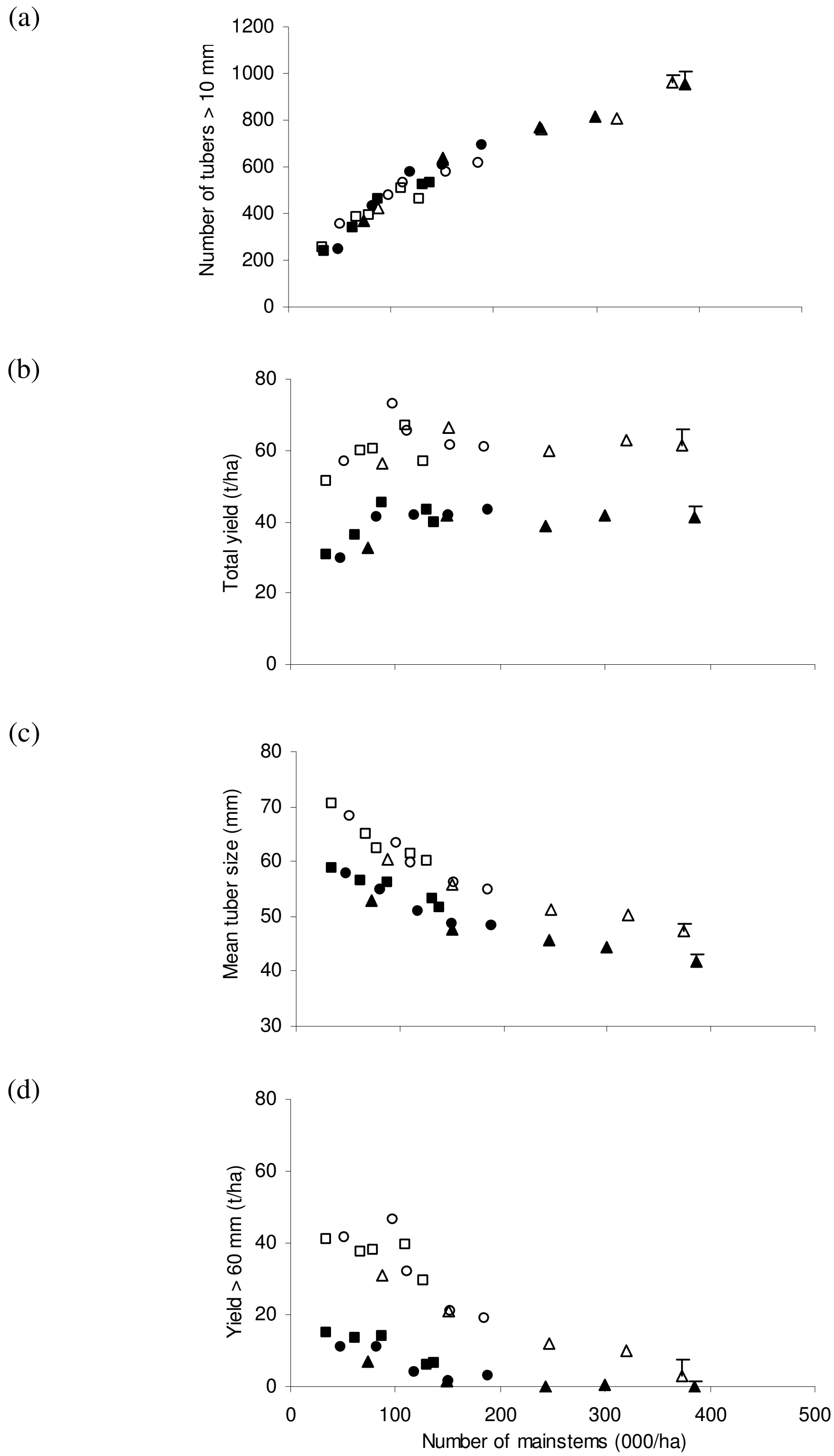


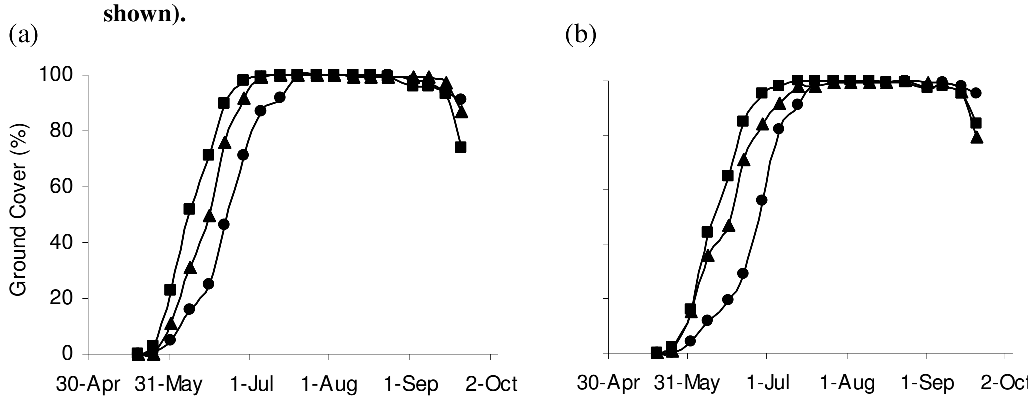
Figure 13. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size, and (d) yield of tubers > 60 mm and number of mainstems/ha at two harvest dates of Estima in Expt 22. Stocks: Welsh P1 first harvest, ●; Welsh P2 first harvest, ■; Spanish first harvest, ▲; Welsh P1 second harvest, ○; Welsh P2 second harvest, □; Spanish second harvest, △.



Expt 23. Density (Maris Piper)

The early-produced stock emerged slightly earlier (< 1 day) than the late produced stock. Ground cover increased more slowly at the wider plant spacings than at closer spacings, with the 80 cm spacing attaining full ground cover *c*. 2 weeks later than the 19 cm spacing but all treatments achieved full ground cover (Figure 14). Senescence began in late September (Figure 14) and the final harvest was taken prior to complete senescence.

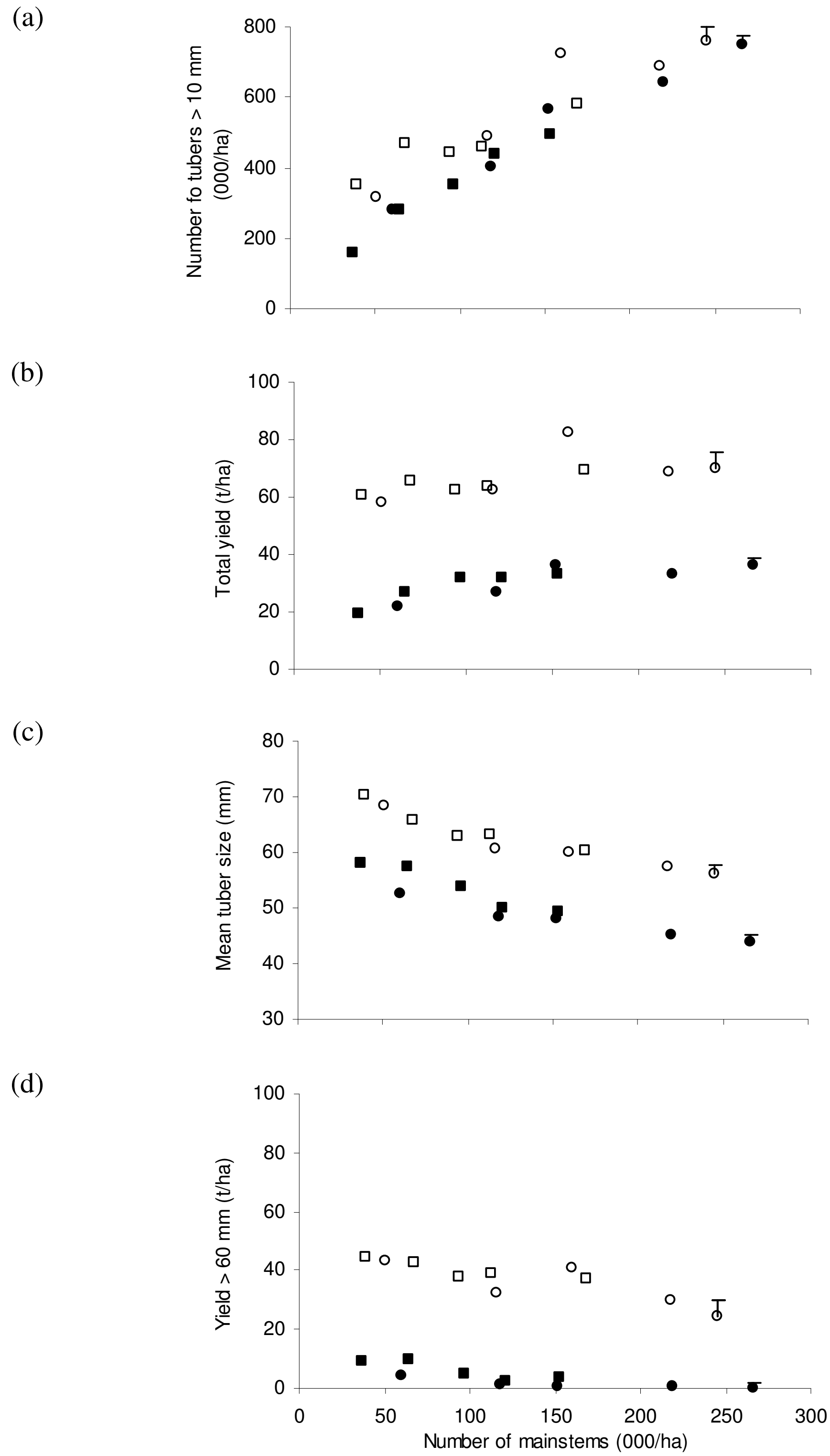
Figure 14. The effect of plant density on ground cover for (a) Welsh P1 and (b) Welsh P2 produced stocks of Maris Piper in Expt 23. Plant spacing (cm): 80, ●; 31, ▲; 19, ■ (intermediate densities not shown).



The number of mainstems per plant was greater from early-produced seed (3.65 ± 0.088 at the final harvest) than for late seed (2.27). The number of secondary stems was greater for the late-produced stock (0.14 ± 0.02 at the final harvest) than the early-produced stock (< 0.01) at both harvests, and at the final harvest the number of secondary stems increased with increase in plant spacing in the late-produced stock (none at the closest spacing and 0.5 ± 0.02 per plant at the widest spacing).

Stem populations at final harvest ranged from 50 900/ha for the later (Welsh P2) stock planted at 80 cm spacing to 266 700/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 (Figure 15a). Total yield tended to increase only very slightly with increase in stem density over the wide range in stem density, (Figure 15b) whilst both mean tuber size (Figure 15c) and yield of tubers > 60 mm decreased (Figure 15d). These results demonstrate that although the planting densities used in this experiment had little effect on total yield, and only a slight effect on the rate of canopy closure, the differences in stem population changed the size distribution of the yield. The relatively low number of stems produced by late produced, widely spaced seed resulted in fewer tubers than earlier seed planted at close-spacing, allowing for more reliable production of large tubers early in the season.

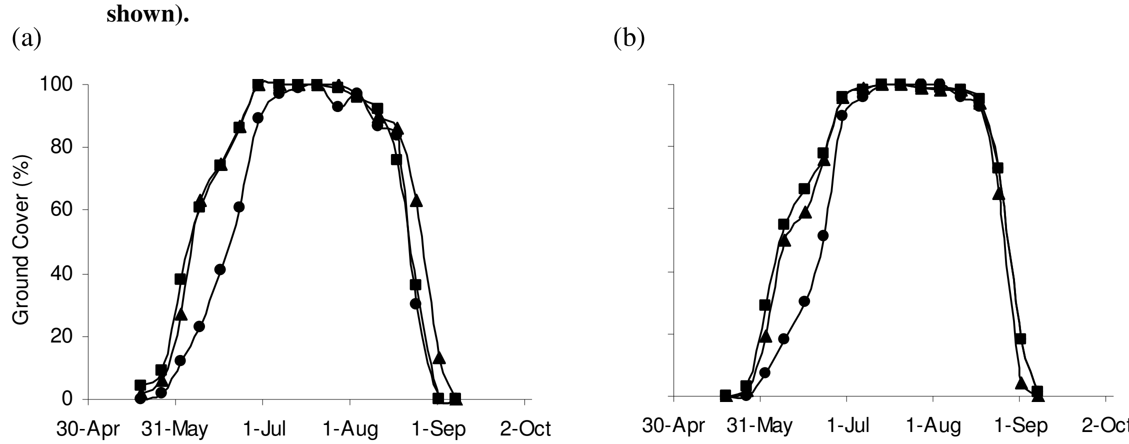
Figure 15. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size (µ), and (d) yield of tubers > 60 mm and number of mainstems/ha at two harvest dates of Maris Piper in Expt 23. Stocks: Welsh P1 first harvest, ●; Welsh P2 first harvest, ■; Welsh P1 second harvest, ○; Welsh P2 second harvest, □.



Expt 24. Density (Saturna)

The early-produced stock emerged slightly earlier (50 % emergence 29.6 ± 0.16 DAP) than the late-produced stock (32.5 DAP). Ground cover increased more slowly at the wider plant spacings than at closer spacings but all treatments achieved full ground cover (Figure 16) and senescence began in late August.

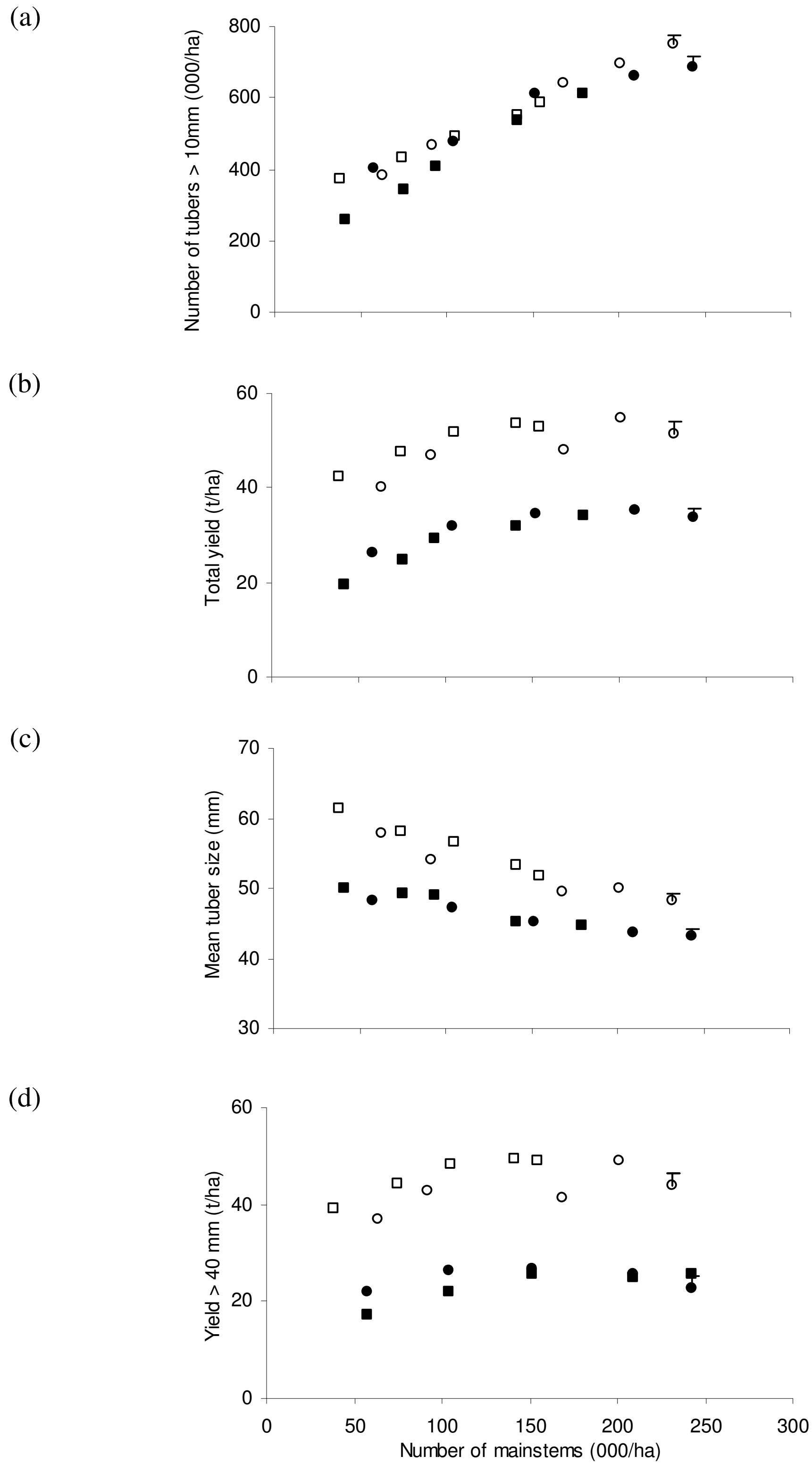
Figure 16. The effect of plant density on ground cover for (a) Welsh P1 and (b) Welsh P2 produced stocks of Saturna in Expt 24. Plant spacing (cm): 80, ●; 31, ▲; 19, ■ (intermediate densities not shown).



The number of mainstems per plant was greater from early-produced seed (3.58 ± 0.162 at the final harvest) than for late seed (2.42). At the early harvest, the number of secondary stems increased with wider planting density across both stocks, (ranging from 0.1 ± 0.14 secondary stems per plant at 19 cm spacing, to 1.3 stems per plant at 80 cm spacing), but few (< 0.01) secondary stems were recovered at the final harvest, probably due to senescence.

Stem populations at final harvest ranged from 38 300/ha for the later (Welsh P2) stock planted at 80 cm spacing to 231 800/ha for the early (Welsh P1) stock planted at 19 cm spacing. The number of tubers increased with increasing stem density at both harvests (Figure 17a). At equivalent stem populations < 100 000 /ha at the first harvest, the late-produced seed set fewer tubers than the early-produced seed, but this was not repeated at the final harvest (Figure 17a). As with Estima, total yield increased with increase in stem density up to stem populations of *c.* 100 000/ha; but further increases in stem population did not increase yield (Figure 17b). The mean tuber size (Figure 17c) and yield of tubers > 60 mm decreased with increasing stem density but the yield of tubers > 40 mm was similar to the total yield, and increased with stem density up to stem populations of *c.* 100 000/ha (Figure 17d). A small yield (1.5 t/ha) of very large tubers (> 80 mm) was only found in the late-produced stock planted at 80 cm spacing

Figure 17. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size, and (d) yield of tubers > 40 mm and number of mainstems/ha at two harvest dates of Saturna in Expt 24. Stocks: Welsh P1 first harvest, ●; Welsh P2 first harvest, ■; Welsh P1 second harvest, ○; Welsh P2 second harvest, □.



Expt 25. Density (Charlotte)

Seed weights at grading differed between stocks, as the early-produced seed was *c*. 52 g *cf.* 56 g per tuber for the late-produced stock. The early-produced stock emerged *c*. 1 day earlier than the late-produced stock (± 0.06 days). There were few secondary stems produced (< 0.01 per plant), and slightly more mainstems per plant were produced from early-produced seed (7.42 ± 0.240) than for late seed (6.85) at the final harvest (not statistically significant). This may be related to the differences in seed size, as although the early-produced stock would be expected to produce more stems than the late-produced stock, the seed was, on average, slightly smaller. There were larger differences in the numbers of stems between stocks in Expt 2, although the differences were less apparent for the larger seed sizes, for which the difference in seed weight between stocks was greater. Full ground cover was achieved in all treatments, and there was little difference in the rate of attainment of full cover between planting densities, although this was slightly later at low planting densities (Figure 18). The number of tubers generally increased with increase in stem density and the most tubers were produced from early-produced seed planted at high density. However, for late-produced seed at the first harvest there were similar numbers of tubers at all densities (Figure 19a). At the first harvest there was little effect of stem density on yield, though yields were generally greater for early produced seed than late-produced seed at comparable stem populations. Total yield tended to increase slightly with increase in number of mainstems at the final harvest. A similar effect of stock was shown on the yield of small (20-40 mm) tubers at both harvests. Mean tuber size also varied little between stem densities, although at the later harvest the mean tuber size tended to be greater for the late than for the early-produced seed.

Figure 18. The effect of plant density on ground cover for (a) Early Welsh P1 and (b) Late Welsh P2 produced stocks of Charlotte in Expt 25. Plant spacing (cm): 20, ●; 14, ▲; 11, ■ (intermediate densities not shown).

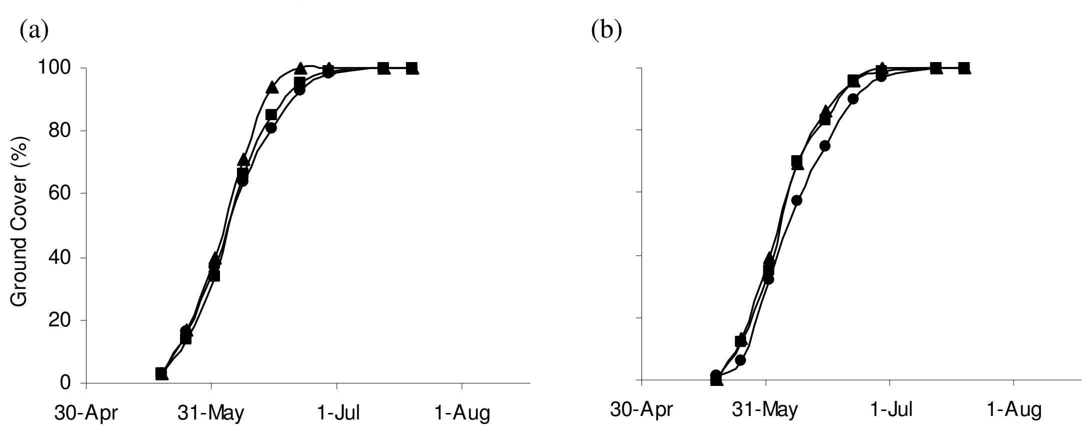
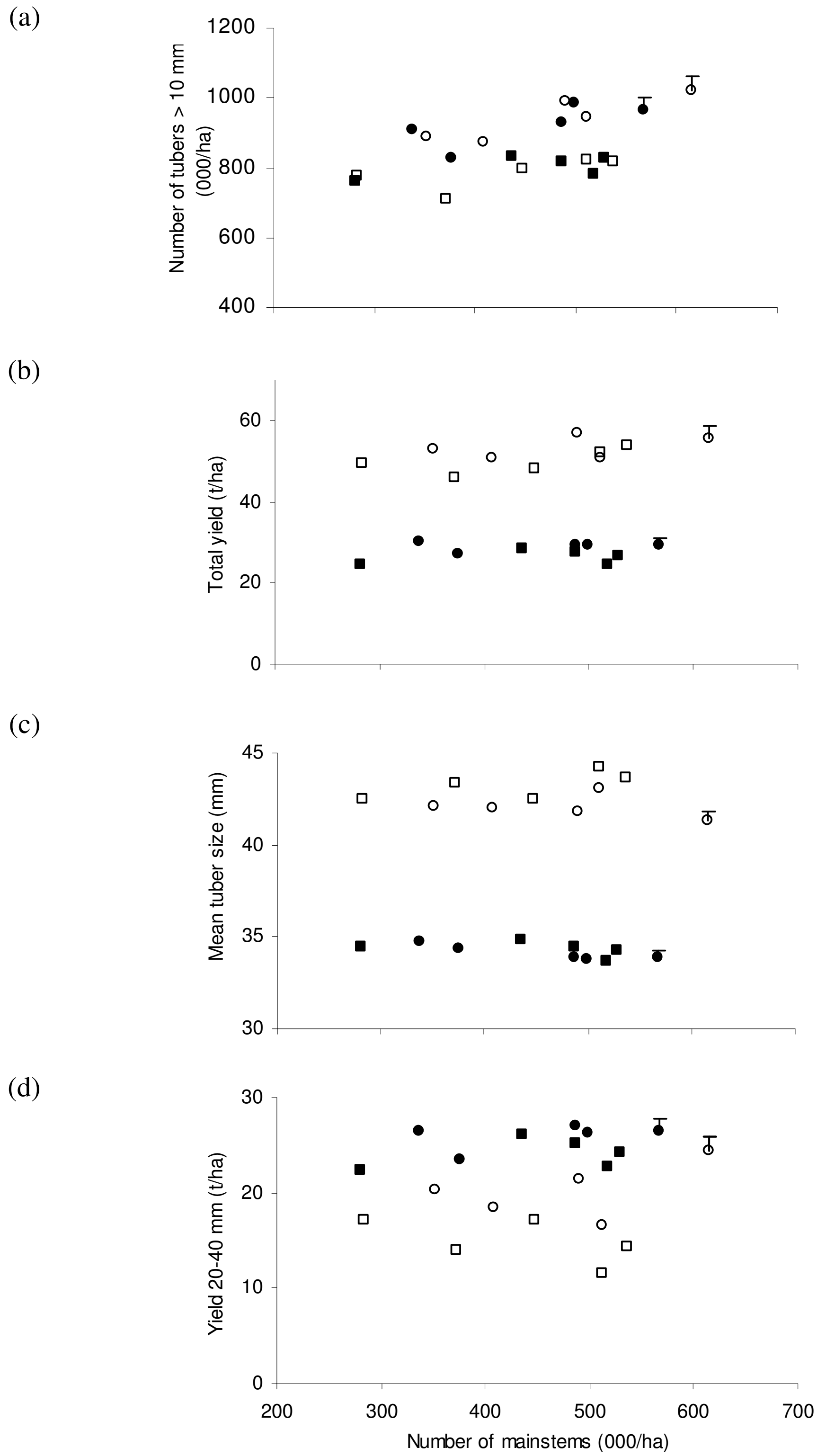


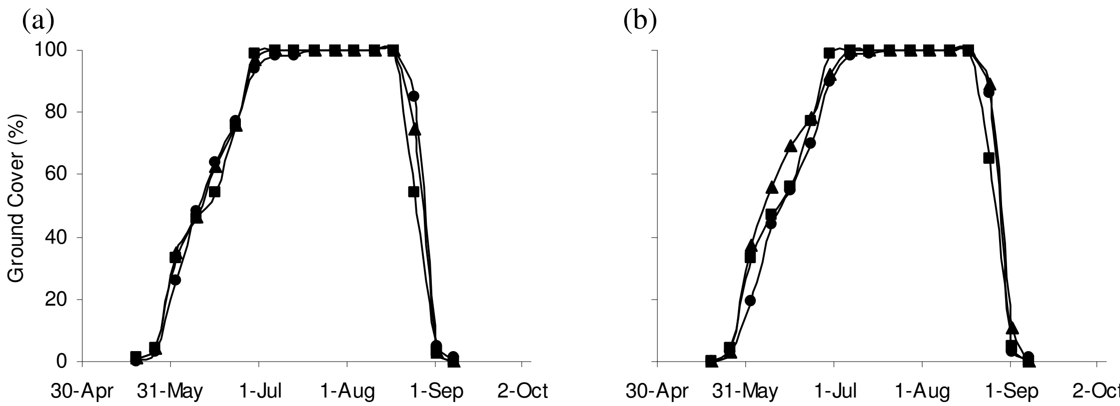
Figure 19. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size (μ), and (d) yield of tubers 20-40 mm and number of mainstems/ha at two harvest dates of Charlotte in Expt 25. Stocks: Welsh P1 first harvest, ●; Welsh P2 first harvest, ■; Welsh P1 second harvest; ○; Welsh P2 second harvest, □.



Expt 26. Density (Shepody)

There was no difference between stocks in the rate of emergence or attainment of complete ground cover (Figure 20). There was little difference in ground cover between plant spacings, and all treatments senesced rapidly in late August.

Figure 20. The effect of plant density on ground cover for (a) Welsh P1 and (b) Welsh P2 produced stocks of Shepody in Expt 26. Plant spacing (cm): 40, ●; 22, ▲; 15, ■ (intermediate densities not shown).



The number of mainstems per plant was slightly greater from early-produced seed (2.66 ± 0.052 at the final harvest) than for late seed (2.17). Few secondary stems were produced by any treatment (< 0.2 secondary stems per plant), but at the early harvest the late-produced stock had more secondary stems (0.09 ± 0.023 stems per plant averaged across densities) than the late-produced stock (0.004). Stem populations at final harvest ranged from 70 800/ha for the later (Welsh P2) stock planted at 40 cm spacing to 229 700/ha for the early (Welsh P1) stock planted at 15 cm spacing. As with other varieties, the number of tubers increased with increasing stem density at both harvests (Figure 21a). Total yield increased with increase in stem density up to stem populations of *c*. 100 000/ha, whereas further increases in stem population had no effect on yield (Figure 21b). Mean tuber size decreased with increasing stem density, but for comparable mainstem populations, the late-produced stock had a larger mean tuber size than the early-produced stock (Figure 21c). The yield of tubers > 40 mm was similar to the total yield, and increased with stem density up to stem populations of *c*. 100 000/ha (Figure 21d). The yield of tubers > 80 mm at the final harvest was generally low for early-produced seed except at the widest spacing (3.3 ± 0.99 t/ha) but greater for late-produced seed, particularly at the three widest spacings for which the yield of very large tubers accounted for between 12-19 % of the total yield (7.2 to 11.2 t/ha).

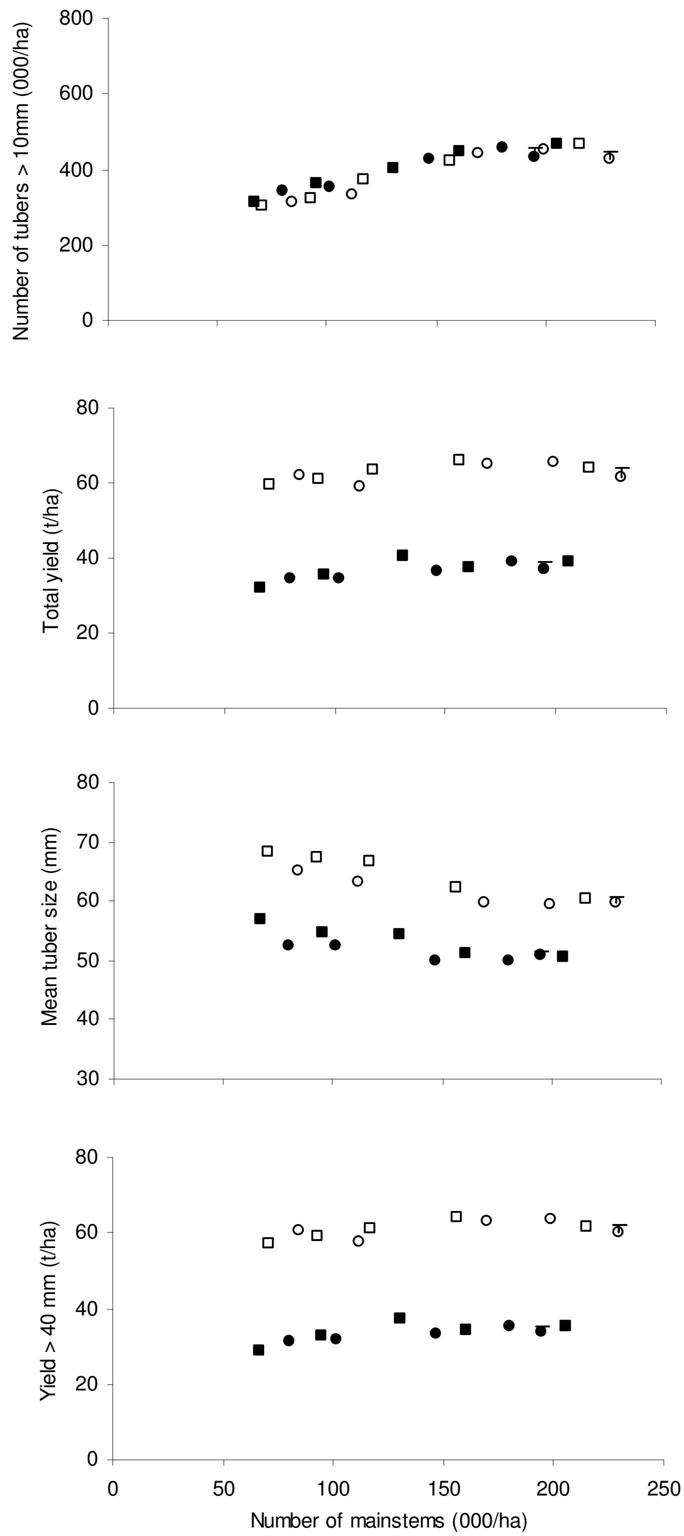
Figure 21. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size (μ), and (d) number of tubers > 40 mm and number of mainstems/ha at two harvest dates of Shepody in Expt 26. Stocks: Welsh P1 first harvest, ●; Welsh P2 first harvest, ■; Welsh P1 second harvest; ○; Welsh P2 second harvest, □.

(a)

(b)

(c)

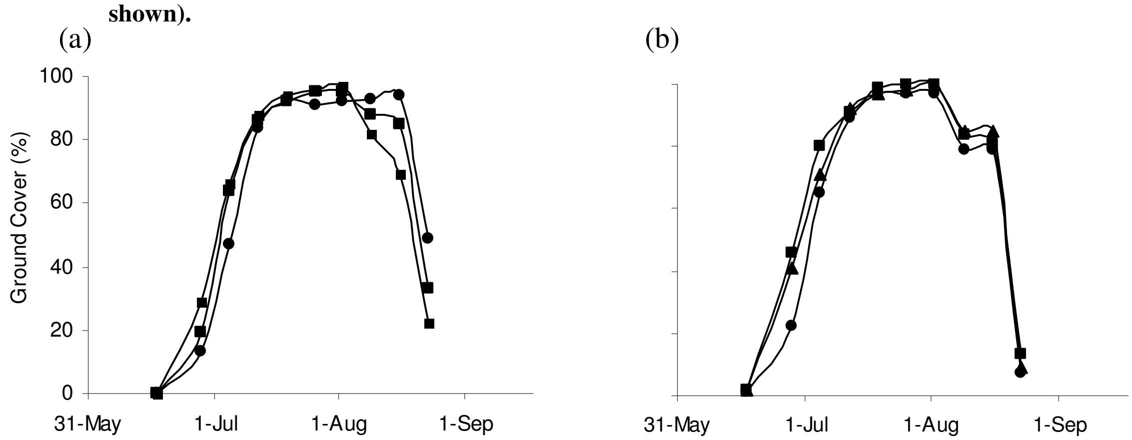
(d)



Expt 27. Density (Maris Peer)

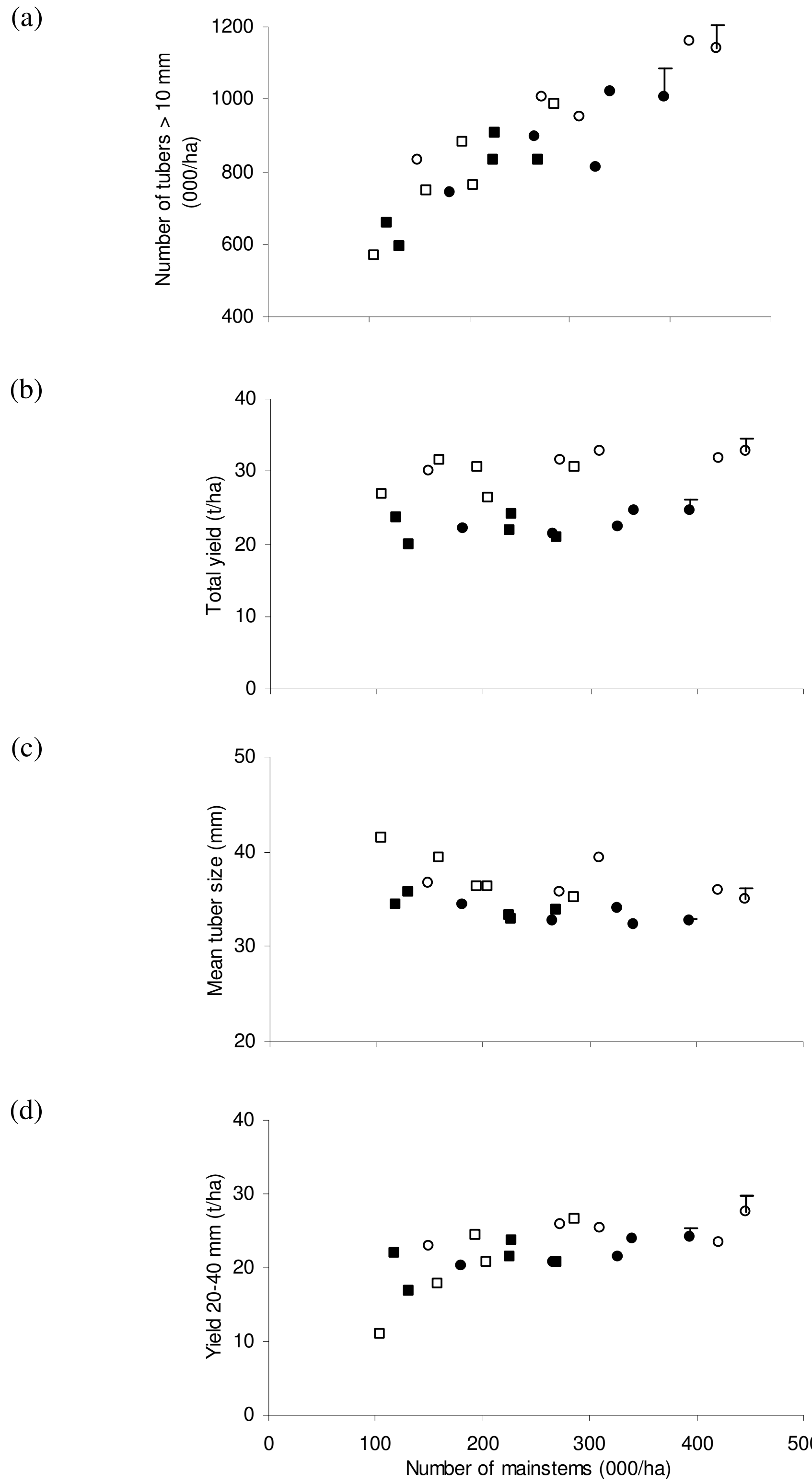
The early-produced stock emerged earlier (50 % emergence 22.6 ± 0.52 DAP) than the late-produced stock (25.2 DAP). Ground cover increased slightly more slowly at the wider plant spacings than at closer spacings but despite the wide furrows between the beds, all treatments achieved close to full ground cover (> 93 %) (Figure 22).

Figure 22. The effect of plant density on ground cover for (a) Welsh P1 and (b) Welsh P2 produced stocks of Maris Peer in Expt 27. Plant spacing (cm): 33, ●; 20, ▲; 14, ■ (intermediate densities not shown).



The number of mainstems per plant was greater from early-produced seed (3.78 ± 0.307 at the final harvest) than for late seed (2.27). Few secondary stems (< 0.07 at the first harvest) were found in any treatment. Stem populations at final harvest ranged from 105 000/ha for the later (Welsh P2) stock planted at 33 cm spacing to 445 900/ha for the early (Welsh P1) stock planted at 14 cm spacing. As for other varieties, the number of tubers increased with increasing stem density at both harvests (Figure 23a). There was little effect of stem density on total yield (Figure 23b), but the yield of small tubers (20-40 mm) increased with increasing stem density up to stem populations of *c*. 250 000/ha (Figure 23d). Mean tuber size (Figure 23c) slightly decreased with increasing stem density.

Figure 23. The relationship between (a) number of tubers > 10 mm, (b) tuber yield, (c) mean tuber size (µ), and (d) number of tubers 20-40 mm and number of mainstems/ha at two harvest dates of Maris Peer in Expt 27. Stocks: Welsh P1 first harvest, ●; Welsh P2 first harvest, ■; Welsh P1 second harvest, ○; Welsh P2 second harvest, □.



Expt 28. Controlled Atmosphere (Charlotte, Maris Peer and Shepody)

The controlled atmosphere (CA) treatment tended to advance emergence compared to cold stored seed, but emergence was earliest for sprouted seed (Table 11) consistent with differences in sprout development at planting. The CA treated seed tended to have slightly longer sprouts, a larger proportion of tubers with visible sprouts, and more visible sprouts per tuber at planting than cold stored seed, but sprout development of CA seed was less than for the sprouted treatment (Table 11). The early-produced stocks tended to emerge more rapidly than the later-produced stocks, and the Shepody was slightly slower emerging than the other varieties, broadly corresponding to differences in sprouting at planting. All treatments reached complete, or near complete emergence (Table 11).

CA treatment tended to increase the number of mainstems per plant compared to both the cold stored untreated stocks, and the sprouted stocks except for Shepody for which the sprouting treatment produced the most stems (Table 11). Early-produced stocks produced more stems than later stocks, except for the sprouted Charlotte stocks. CA treatment increased the number of tubers > 10 mm in line with the increase in number of stems so that CA treatment produced the most tubers in Charlotte and Maris Peer but not in Shepody, where sprouting produced the most stems and tubers (Table 11). Early-produced stocks produced greater numbers of tubers than late-produced stocks in all cases (Table 11). Yield was on average higher in Maris Peer than Charlotte or Shepody but was not affected by stock, CA or sprouting treatments (Table 11). There were relatively large effects of CA and stock on mean tuber size consistent with effects on numbers of tubers so the mean tuber size was generally lowest for CA treated early-produced seed (Table 11).

Table 11. Effect of Controlled Atmosphere (CA), sprouting, variety and stock on the interval from planting to emergence, number of mainstems per plant, number of tubers > 10 mm, tuber yield and mean tuber size in Expt 28

Variety		Charlotte		Maris Peer		Shepody		
CA and sprouting	Stock	Early	Late	Early	Late	Early	Late	S.E.
Days from planting to emergence								
CA Treated		32.8	32.3	29.3	31.7	34.5	36.0	0.45
Untreated		31.8	35.2	32.0	32.2	34.9	36.3	
Sprouted		30.0	32.2	29.1	30.8	33.1	32.0	
Longest sprout per tuber at planting (mm)								
CA Treated		1	1	2	1	0.5	0.5	
Untreated		0.5	0.1	2	0	0.5	0.1	
Sprouted		2	2	3	2	2	1	
% tubers with visible sprouts at planting								
CA Treated		100	100	100	100	50	35	
Untreated		80	90	15	0	15	0	
Sprouted		100	100	100	100	100	90	
No. visible sprouts per tuber at planting								
CA Treated		4.1	3.1	4.0	3.5	0.8	0.4	
Untreated		2.2	2.2	0.4	0.0	0.6	0.0	
Sprouted		5.5	3.2	5.2	5.5	3.5	3.2	
No. of mainstems per plant								
CA Treated		6.97	6.22	6.03	3.39	2.31	1.45	0.247
Untreated		5.14	4.19	3.67	2.11	2.01	1.56	
Sprouted		4.86	4.92	3.69	2.32	2.86	1.82	
No. of tubers > 10 mm (000/ha)								
CA Treated		1129	938	888	689	357	262	27.9
Untreated		809	718	705	465	282	263	
Sprouted		717	686	681	510	402	307	
Tuber yield (t/ha)								
CA Treated		59.5	59.7	62.4	69.3	57.9	58.8	4.11
Untreated		50.4	59.0	63.6	64.3	55.0	61.5	
Sprouted		58.8	59.3	65.2	62.1	60.7	61.0	
Mean tuber size (μ, mm)								
CA Treated		40.9	43.3	49.3	54.9	60.2	67.0	1.21
Untreated		46.4	46.6	53.4	59.7	63.3	66.9	
Sprouted		46.7	47.3	53.6	58.2	59.3	64.6	

Conclusions

Replanting of 2002 produced seed in 2004 completed the replanting sequence from three years of seed production and together with data collected from assessment of sprouting and other experiments the results allow the progressive effect of seed age on stem production to be evaluated fully. In Estima, a consistent pattern was repeated for replanting seed produced in all three years (2000-2002). Small seed planted after only a short period of cold storage produced almost exclusively single stem plants and even with large seed on average fewer than two stems per plant were produced. At any date of planting in the year following seed production, seed from early planted seed crops produced more stems than seed from later planted seed crops irrespective of the geographical site of production. For both early and late produced seed the number of stems produced also tended to increase with delay in date of replanting (i.e. increase in length of storage) and the number of stems generally increased linearly with the interval from emergence of the seed crop to the date of replanting between *c*. 250 and 500 days. Planting seed < *c*. 250 days from emergence of the seed crop generally resulted in similar (low) numbers of stems to plantings up to *c*. 250 days.

In some cases, early spring plantings tended to produce more stems for seed of similar chronological age than later plantings into warmer soil so that for some late planting dates of early produced seed an increase in number of stems with delay in planting was not observed. This result supports the hypothesis that relatively low soil temperatures after planting result in production of more stems than higher soil temperatures but importantly this effect does not negate differences in stem production between seed differing in age. Early plantings in the second year following seed production (i.e. following > 1 year of cold storage) generally resulted in production of many stems (up to 10 per plant for seed planted *c*. 600 days after emergence) but for replanting 600-800 days after seed emergence there was a progressive decrease in the number of stems per plant and emergence was generally slow and incomplete for such very old seed.

Sprouting of seed held at 15 ºC began at a similar interval from emergence of the seed crop irrespective of site or date of production so that the apparent duration of dormancy was conservative. Seed placed to sprout at 15 ºC after cold storage sprouted rapidly up to *c*. 400 days after emergence of the seed crop but after longer periods of storage, sprout growth slowed reflecting the delayed emergence observed in the field for old seed.

The less extensive dataset for Hermes and Charlotte showed a similar pattern of increase and decline in stem production and viability of seed to Estima but replantings early in the second year following seed production usually resulted in fewer stems than late plantings in the previous year. Emergence for plantings in Charlotte in the second year was generally very poor indicating that there are important differences in the period over which seed of different varieties remains productive and viable. Experiments where seed was sprouting prior to planting in the second year following production demonstrated complete emergence and high yields of crops with very high numbers of stems and tubers can be achieved with old seed. Nevertheless, whilst sprouting improved viability of very old seed, results were variable and decay of stored seed was often observed particularly in Charlotte so that use of such old seed (> 600 days after emergence) is unlikely to be adopted in practice. Autumn and winter plantings of slightly younger seed may be viable in Iberia and elsewhere and research to develop these opportunities is being undertaken.

Examination of the increase in numbers of stems with increase in seed size for Estima showed that the relationship differed according to seed age. Seed planted after a short period of storage (young seed) produced few stems for all seed weights so that there was relatively little difference between seed weights. With progressively longer periods of storage, more stems were produced for all seed sizes but the absolute increase with seed age was greater at larger sizes so that there may be one additional stem per seed tuber with small seed but two extra stems for large seed and thus the differences between stocks in stems per tuber was greatest for large seed. The data for other varieties indicates that the change in stem production with seed weight and age differs. In Charlotte, there was no clear difference in the increase in number of stems with seed weight between stocks so that the absolute differences between stocks may be similar for all sizes (e.g. one stem per tuber) but the relative difference was thus greatest for small seed for which few stems are produced. In Hermes the data indicate a similar relationship to Estima but that the magnitude of the effects was smaller. Further analysis of the combined datasets and collation of complementary data will now enable predictive equations to be developed and tested. Data for a wider range of varieties from ongoing work will widen the scope and strengthen these analyses.

The practical consequences of differences in stem productivity of contrasting seed stocks were evaluated in the series of density experiments. At very low densities, there was a tendency for (late produced) seed stocks that produced fewer stems per seed tuber to achieve slightly greater yields than (early produced) seed stocks with more stems per seed tuber consistent with less uniform 'clumped' distribution. In practice, however, the relationship between stem population, yield and size distribution was similar irrespective of seed stock in all varieties examined so that improved prediction of stem production accounting for seed provenance should enable more efficient use of seed and better achievement of tuber size distributions required in crops. For crops where high tuber populations are required, use of early produced seed is advantageous as higher stem populations can be achieved at a given seed rate than with later produced seed. Late produced seed may be advantageous for production of crops with a large mean tuber size particularly where early achievement of this is required as a low stem density can be achieved by planting at within row spacings that are not as extreme and impracticable (e.g. > 60 cm) as may be required using early produced seed.

Effects of sprouting and controlled atmosphere (CA) treatment on the differences in stem production of contrasting seed stocks of several varieties were also examined. Sprouting generally resulted in a slight increase in the number of stems irrespective of seed stock but effects did differ between varieties with for example quite a large increase in number of stems in Saturna and usually a decrease in Charlotte. Although often small, the effects of sprouting clearly can influence stem production and even limited sprout development may introduce further variation between seed stocks in practice. Effects of CA treatment were largely consistent resulting in an increase in stems for both early and late produced seed stocks in most cases demonstrating that there is potential for manipulating stem populations using a combination of seed provenance and CA treatment.

These experiments have indicated how variation in current practice of seed production and use can account for considerable differences in stem production between stocks. The data also indicate how manipulating practices can extend the normal range in stem production per seed tuber with advantage for specific crops. In field crops, variation in numbers of stems and tubers produced by stems is increased by disease and disruption to growth and improved understanding of these effects in ongoing work will result from studying effects of these factors on crops grown from seed from contrasting production cycles.