Effects of date of planting, date of harvesting and seed rate on yield of seed potato crops

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SUMMARY

Fourteen experiments which studied effects of date of planting in July, date of harvesting and seed rate on seed tuber yields (10–51 mm) of several potato varieties were carried out in four seasons in East Anglia. Seed tuber yields of *c.* 30 t/ha in Estima, Wilja and Maris Piper and 20 t/ha in Record were produced from the early planting and in all varieties *c.* 20 t/ha were produced from planting in late July. For maximum seed yield in all varieties, seed rates of 1·5–2 t/ha were sufficient for most harvests from both dates of planting but for the earliest harvest of the late-July planting, seed rates of only 1–1·5 t/ha were required. The value of seed crops was assessed as the number of ware hectares that could be replanted from the seed yield of one hectare graded 10–51 mm. In all varieties, the number of seed-size tubers and replantable hectares increased with increasing seed rate over most of the range, but numbers were close to the maximum at the early harvests. With delay in harvesting, the number of seed tubers and replantable hectares decreased in many experiments, especially from low seed rates, as more tubers exceeded the upper seed size limit. Maximum numbers of replantable hectares of 15, 15, 20 and 25 were found in Record, Estima, Wilja and Maris Piper, respectively.

The monetary value of seed crops of Record and Maris Piper was calculated using (i) a fixed price per tonne of seed and (ii) cost of seed per replantable ware hectare. Sale values from the latter were substantially higher than from the former at early harvests in Record and at all harvests in Maris Piper. In Record, differences in sale value between the two pricing methods decreased with delay in harvesting as yields increased while number of replantable hectares varied little. The results showed that high multiplication rates and monetary returns can be obtained from short-season seed potato crops which may follow crops harvested earlier in the same season. The implications for potato production in the UK are discussed.

INTRODUCTION

Recent reports (Allen & O'Brien 1987; Allen *et al.* 1992) have shown that seed tubers from the lower end of the legally saleable range (25–60 mm or 20–150 g) in the UK, and even smaller, can produce tuber yields in both seed and ware crops similar to those from seed from the higher end of the range, when each seed weight is planted at its optimum seed rate. Economic optimum seed rates are lower for small than for larger seed tubers (Jarvis 1977; Allen & O'Brien 1987; Allen *et al.* 1992) and, therefore, there are economies in all aspects of handling, transport, storage and planting, to be gained by using small rather than large seed tubers. The production of small seed tubers requires only a short growing season and this offers scope for integration of seed-potato crops with other crops within a single growing season. As several crops in the UK are harvested in July or earlier (e.g. onions, carrots, brassicas, winter barley), production of economic seed-potato crops following such early-harvested crops should be possible. Ware potatoes are double-cropped within a growing season in some areas of the UK, e.g. Suffolk, and in several other countries, but the economics and appropriate management of such crops for once-grown seed production are unknown. This paper reports, to a varying extent, the results of a number of experiments which investigated the effects of date of planting in July, date of harvesting and seed rate on seed tuber yields in short-season crops of several varieties in Suffolk and Cambridgeshire. Progeny tubers from these experiments were assessed in subsequent ware experiments (P. J. O'Brien & E. J. Allen, unpublished).

THE EXPERIMENTS

Fourteen similar experiments were carried out from 1984 to 1987 using different varieties at sites in Suffolk and Cambridgeshire. In all experiments, treatments

Table 1. *Details of experiments*

Year	Expt	Variety	Date of planting	Date of harvesting
1984	1	Wilja	9 July	7 September; 26 September; 15 October
			30 July	26 September; 15 October
	2	Record	9 July	7 September; 26 September; 15 October
			30 July	26 September; 15 October
1985	3	Wilja	10 July	8 October*
			31 July	8 October*
	4	Record	10 July	8 October
			31 July	8 October
	5	Saturna	10 July	8 October*
			31 July	8 October*
	6	Maris Piper	10 July	8 October*
			31 July	8 October*
1986	7	Record	7 July	10 September; 25 September
			28 July	25 September; 2 October
	8	Saturna	7 July	2 October*
			28 July	2 October*
	9	Wilja	8 July	9 September; 23 September; 9 October
			29 July	23 September; 3 October; 9 October
	10	Maris Piper	8 July	9 September; 23 September; 9 October
			29 July	23 September; 3 October; 9 October
1987	11	Estima	8 July	3 September; 14 September
			31 July	14 September; 22 September
	12	Wilja	8 July	3 September; 14 September
			31 July	14 September; 22 September
	13	Record	7 July	1 September; 15 September
			30 July	15 September; 23 September
	14	Maris Piper	7 July	2 September; 16 September
			30 July	16 September

* Tubers harvested for assessment in ware experiments only.

comprised all combinations of two planting dates (early and late July) and five within-row seed spacings replicated three times in a randomized-block design. The spacings were 20, 24, 30, 45 and 60 cm in 1984–86 (Expts 1–10) and 10, 15, 20, 24 and 30 cm in 1987 (Expts 11–14). The seed rates, therefore, ranged from 0·77 to 2·46 t/ha in Expts 1–10 and from 1·64 to 4·92 t/ha in Expts 11–14. Details of varieties and dates of planting and harvesting are shown in Table 1. In 1984 and 1985 (Expts 1–6), the experiments were on fine loamy soils of the Swaffham Prior Association (Soil Survey of England and Wales 1984) near Bury St Edmunds, Suffolk. In 1986, Record (Expt 7) and Saturna (Expt 8) crops were produced on fine flinty-loam soils of the Ludford Association (Soil Survey of England and Wales 1984) near Moulton, Suffolk. In 1986, Wilja (Expt 9) and Maris Piper (Expt 10) and all varieties in 1987 (Expts 11–14) were grown on light gravelly soils of the Milton Association at Cambridge University Farm, Cambridge. Experiments 1–6 followed overwintered onion crops harvested in the same season; the remaining experiments were planted in soils left fallow until early July. At the Suffolk sites, all cultivations and husbandry apart from herbicide application were carried out by the grower and the experimental area was left ridged by the passage of the planter with the planting mechanism disengaged.

In all experiments, the fertilizer dressing was applied to the entire experimental area prior to or at the time of the first planting. Fertilizer dressings of N (74 kg/ha), P (16 kg/ha) and K (31 kg/ha); N (125 kg/ha), P (26 kg/ha) and K (50 kg/ha); and N (164 kg/ha), P (86 kg/ha), K (150 kg/ha) and Mg (29 kg/ha) were applied to all experiments at the Suffolk sites in 1984, 1985 and 1986, respectively. Experiments 9–14 at Cambridge received N (75 kg/ha), P (32 kg/ha), K (94 kg/ha) and Mg (21 kg/ha). In all experiments, a pre-emergence herbicide was applied to appropriate plots at each planting date using a knapsack sprayer. At all sites, tubers were planted *c.* 10 cm deep (upper surface of tuber to soil surface) in ridges using dibbers. After each planting, the ridges were restored to their original shape using hand hoes. All experiments were irrigated to maintain soil moisture deficits < 25 mm. Selected certified Scottish (or Dutch Saturna) seed weighing 35 ± 5 g was used for all experiments. This seed was stored in hessian sacks in cabinets set at 3–4 °C from shortly after delivery in November–December to near the time of the first planting in 1984–86 and until mid-March in 1987. All seed was then placed in trays at ambient temperatures until sprouts *c.* 2 mm long were produced and was then returned to 3–4 °C until planting. As very little sprout elongation occurs at 3–4 °C, seed with similar sprout length was used in all the experiments for both planting dates. In 1985 and 1986, considerable damage to sprouts and in consequence poor plant stands (especially in the variety Saturna) resulted from infection by the skinspot fungus *Polyscytalum pustulans* in several varieties. The effects of this disease on sprout growth appeared to be most severe after prolonged, uninterrupted low temperature storage of dormant seed tubers. Therefore, some sprout growth was encouraged early in 1987 and there was minimal damage to sprouts in Expts 11–14 due to this disease even after prolonged cold storage.

In all experiments, plots were three rows wide and 13·2 m long, allowing for three harvests each from a 3·6 m length of row. Harvesting was carried out systematically within plots in order to avoid disturbing the foliage of later harvests and harvest date was, therefore, not included as a treatment. Data were analysed separately for each harvest date. Row widths were 76 and 71 cm at sites in Suffolk and Cambridgeshire, respectively. In all experiments, tubers were harvested from undefoliated crops and, where necessary, tubers were detached from stolons by hand. Plots were dug with a hand fork and, after allowing skins to harden (for *c.* 1 week) the tubers were graded into different size fractions, counted and weighed. A tuber was defined as a swelling whose width exceeded twice the diameter of its subtending stolon. Tubers were graded into Imperial size grades in 1984 and 1985 and into metric sizes in 1986 and 1987. For convenience all results are expressed in metric units. In view of the precise grading of tubers in the experiments, the upper size limit for seed tubers was taken as 50 or 51 mm (Imperial grade), which was considered to correspond most closely to that (55 mm) commonly used in practice. At many harvests, the number of mainstems and secondary stems per 3·6 m length of row was also recorded.

No visible symptoms of any virus disease were observed in any of the varieties in any year. Late blight infection, spread from adjacent infected ware crops, severely affected foliage growth in Wilja, Saturna and Maris Piper crops (Expts 3, 5 and 6) in Suffolk in 1985 and also curtailed growth in Maris Piper from the second date of planting in 1987 (Expt 14). Very limited foliage growth occurred in Record (Expt 7) and Saturna (Expt 8) crops in Suffolk in 1986, largely as a result of waterlogging, following very heavy rainfall (40 mm) in the short period immediately after the application of 25 mm irrigation water just after the second date of planting. Owing to the difficulties experienced in Expts 3, 5, 6 and 8, no samples were taken for estimation of seed tuber yields.

A previous paper (Allen & O'Brien 1987) discussed various methods of evaluating seed-potato crops and suggested that, as the optimum seed rate varies inversely with seed size, the real value of a seed crop is the number of hectares of an optimally-yielding ware crop which may be planted from 1 ha of a seed crop. This may be calculated as follows:

$$\sum \frac{\text{The number (or yield) of seed tubers in individual size fractions}}{\text{Optimum number/ha (or seed rate) for ware production for each size fraction}}$$

This was calculated for each experiment using both optimum number/ha and seed rate for different size fractions within the range 10–51 mm. Seed fractions as small as 10–20 mm were used for the calculations, as recent studies have demonstrated that small seed can give yields similar to those from larger seed (Allen *et al.* 1992). The appropriate optimum number of seed tubers/ha and optimum seed rate for each size fraction > 30 mm were obtained from the recommendations of the Ministry of Agriculture, Fisheries and Food (1982) for a seed:ware price ratio of 2:1. Number of tubers/50 kg in size grades < 30 mm exceeded the values in these recommendations and the optimum number of tubers/ha and optimum seed rate for these size grades was estimated from the results of experiments using such seed in East Anglia. The average weight of small tubers may vary widely within a narrow size range and therefore an average value of the number of tubers per 50 kg and tuber weight was first obtained for each size grade from results of experiments using a wide range of treatments.

RESULTS

In 1985 and 1986, tuber yields were low in experiments in Suffolk (Expts 1–8) but otherwise acceptable yields were produced. Similar effects of treatments were found in all experiments in that the earliest harvest was taken from crops from the first date of planting only, for there was no tuber yield at that date in crops from the second date of planting. At many late harvests, only crops from the second date of planting were harvested, but on at least one date crops from both dates of planting were harvested. On any date on which treatments from one planting date only were harvested, a single factor design was used for analysis of the data. Interactions in tuber yield between date of planting and seed rate were sometimes found where the second harvest of the early-July planting and the first harvest of the late-July planting were taken

Table 2. *Effect of date of planting and seed rate on number of mainstems and tubers (thousands/ha) and tuber yield (t/ha) at different dates of harvesting in Wilja, 1984 (Expt 1)*

Date of planting	Date of harvest	Seed rate (t/ha) 0·77	1·02	1·53	1·91	2·30	S.E.	Error D.F.
		Number of mainstems (thousands/ha)						
9 July	7 September	102	114	198	270	304	15·2	8
9 July	26 September	90	146	176	252	273	11·2	18
9 July	15 October	89	143	203	233	278	15·3	18
30 July	26 September	81	130	170	209	253	11·2	18
30 July	15 October	89	127	184	210	252	15·3	18
		Total number of tubers (thousands/ha)						
9 July	7 September	391	491	618	784	695	55·2	8
9 July	26 September	298	405	510	532	492	37·0	18
9 July	15 October	297	466	685	660	668	31·8	18
30 July	26 September	255	280	295	323	282	37·0	18
30 July	15 October	348	413	472	454	499	31·8	18
		Number of tubers 13–51 mm (thousands/ha)						
9 July	7 September	351	448	548	654	599	38·6	8
9 July	26 September	253	339	464	491	445	34·4	18
9 July	15 October	205	351	553	563	553	20·4	18
30 July	26 September	239	245	279	289	250	34·4	18
30 July	15 October	321	343	420	406	439	20·4	18
		Total tuber yield (t/ha)						
9 July	7 September	13·0	17·7	18·7	20·6	19·1	1·65	8
9 July	26 September	22·2	27·7	29·3	27·8	28·7	1·58	18
9 July	15 October	31·1	41·2	48·3	44·9	46·6	2·90	18
30 July	26 September	9·4	9·0	10·5	9·6	10·8	1·58	18
30 July	15 October	19·5	23·8	25·9	24·0	27·2	2·90	18
		Tuber yield 13–51 mm (t/ha)						
9 July	7 September	13·0	17·7	18·7	20·4	19·1	1·65	8
9 July	26 September	15·3	19·3	23·8	24·3	24·6	1·57	18
9 July	15 October	13·0	23·1	31·4	31·6	30·3	0·99	18
30 July	26 September	9·4	9·0	10·5	9·6	10·8	1·57	18
30 July	15 October	17·8	19·5	23·0	22·1	22·8	0·99	18
		Tuber yield > 51 mm (t/ha)						
9 July	26 September	6·9	8·4	5·5	3·5	4·1	0·78	8
9 July	15 October	18·1	18·1	16·9	13·3	16·3	2·59	18
30 July	15 October	1·6	4·3	2·8	1·8	4·3	2·59	18

together. These interactions were a consequence of tuber yields increasing with increasing seed rate from early-July plantings but showing no response to seed rate at the later planting. No interactions were found at other harvests, but for clarity the results are presented in two-way tables and the standard errors of the interaction are used for comparison of treatment combination means.

Number of stems and tubers

Only Record produced appreciable numbers of secondary stems but there was little effect of any treatment and these stems rarely bore tubers > 10 mm. In all experiments, the number of mainstems, and consequently above-ground stems, invariably increased linearly with increase in seed rate over the whole range at all dates of planting and harvesting (e.g. Tables 2 and 3). For each variety at equivalent seed rates, the number of mainstems was broadly similar for all dates of planting and harvesting and was highest in Maris Piper and lowest in Estima and Record. In all experiments, the total number of tubers generally increased with increasing seed rate but number of seed-size tubers frequently did not increase with the final increments in seed rate (e.g. Tables 2 and 3). For similar seed rates and seed weight (35 ± 5 g) the number of mainstems and maximum number of tubers in Record and Maris Piper were generally similar to those found in Scotland by Allen & O'Brien (1987). In all experiments, the number of seed-size tubers was close to the maximum early in growth when total tuber yield was between 10 and 25 t/ha (e.g. Tables 2 and 3). Number of seed-size tubers was

Table 3. *Effect of date of planting and seed rate on number of mainstems and tubers (thousands/ha) and tuber yield (t/ha) at different dates of harvesting in Wilja, 1987 (Expt 12)*

Date of planting	Date of harvest	Seed rate (t/ha) 1·64	2·05	2·46	3·28	4·92	S.E.	Error D.F.
		Number of mainstems (thousands/ha)						
8 July	3 September	131	152	203	265	342	14·5	8
8 July	14 September	128	157	197	264	351	15·6	18
31 July	14 September	124	159	193	224	341		
31 July	22 September	120	161	203	241	311	20·0	8
		Total number of tubers (thousands/ha)						
8 July	3 September	797	983	1083	1344	1384	61·9	8
8 July	14 September	713	857	1087	1210	1264	84·8	18
31 July	14 September	909	1195	1456	1280	1298		
31 July	22 September	945	936	1157	1150	1424	110·7	8
		Number of tubers 10–50 mm (thousands/ha)						
8 July	3 September	557	694	766	907	957	55·2	8
8 July	14 September	570	713	838	978	1061	52·2	18
31 July	14 September	522	643	725	658	719		
31 July	22 September	598	547	697	665	898	32·9	8
		Total tuber yield (t/ha)						
8 July	3 September	15·0	16·5	16·4	18·8	21·2	0·96	8
8 July	14 September	23·7	29·0	28·3	29·6	31·0	1·09	18
31 July	14 September	7·4	6·5	8·8	6·7	6·2		
31 July	22 September	17·6	14·4	18·7	17·6	20·5	1·31	8
		Yield of tubers 10–50 mm (t/ha)						
8 July	3 September	14·9	16·4	16·3	18·6	21·0	0·96	8
8 July	14 September	22·6	27·6	27·4	29·1	30·9	1·05	18
31 July	14 September	7·2	6·3	8·6	6·5	6·0		
31 July	22 September	17·6	14·3	18·7	17·6	20·5	1·31	8

higher in Maris Piper than in any other variety and from early- rather than late-July planting. The number of seed-size tubers usually decreased with delay in harvest, especially from the lower seed rates, as more tubers exceeded the upper limit (51 mm) of the seed-size range (Table 2).

Tuber yield

In Expts 1–10, which used the lower range of seed rates, total and seed tuber yields increased moderately with increasing seed rate over most of the range at all harvests from the early-July planting and at all except the first harvest from the late-July planting (e.g. Tables 2 and 3, Appendix 1). The first two increments in seed rate had the greatest effect and effects on yield were usually small at seed rates above 1·5 t/ha and from the late-July planting there was usually no effect of seed rate on tuber yield in any size fraction at the first harvest. In 1987, with higher seed rates, total and seed tuber yields of Wilja increased only slightly with increasing seed rate over most of the range from both harvests of the early-July planting (Table 3) but there were no effects of increasing seed rate in Estima, Record or Maris Piper. From late-July plantings there were no effects of seed rate in any variety at either harvest. In all experiments, seed yield increased with delay in harvesting at all except the lowest seed rate (0·8 t/ha) from the early-July plantings, where tubers rapidly exceeded the upper size limit of the seed fraction. Maximum seed tuber yields of *c.* 30 t/ha were produced in Wilja, Estima and Maris Piper and 20 t/ha in Record from early-July plantings and of *c.* 20 t/ha in all varieties from late-July plantings. Maris Piper, generally, produced the highest seed tuber yield and, at seed rates > 2 t/ha, most of the total yield was within the seed size fraction even at final harvests (Appendix 1). In Record and Wilja, a substantial proportion of the total yield exceeded the upper size limit for seed tubers (51 mm) for all seed rates of the earliest planting at harvests in October (Table 2).

Value of crops

The optimum number of seed tubers/ha and seed rates used for the different size fractions and varieties are shown in Table 4. The values of crops calculated from optimum number/ha and seed rates were broadly similar and are presented for optimum numbers (for 8 experiments) in Tables 5 and 6 and

Table 4. *Estimated mean number of tubers per 50 kg (thousands), optimum planting density (thousands/ha) and optimum seed rate (t/ha) for ware crops for a range of seed sizes*

Seed size (mm)	Estima	Wilja	Maris Piper	Record
	Mean number of tubers/50 kg (thousands)			
10–20	16·6	12·5	14·1	15·8
20–30	3·6	3·0	3·7	3·8
30–40	1·5	1·1	1·2	1·4
40–50	0·7	0·5	0·6	0·6
13–19		8·4		9·8
19–25		3·9		4·6
25–31		2·0		2·6
31–38		1·1		1·6
38–44		0·7		0·9
44–51		0·5		0·6
	Optimum planting density (thousands/ha)			
10–20	140·6	108·2	93·7	117·2
20–30	78·1	58·6	50·2	67·0
30–40	71·0	45·0*	43·3*	54·3*
40–50	53·0*	32·5*	29·1*	34·8*
13–19		93·7		100·4
19–25		70·3		82·7
25–31		50·2		61·1
31–38		45·0*		54·1
38–44		38·0*		42·5*
44–51		32·5*		34·8*
	Optimum seed rate (t/ha)			
10–20	0·43	0·43	0·33	0·37
20–30	1·10	0·98	0·67	0·87
30–40	2·40	2·00*	1·70*	1·90*
40–50	3·80*	3·30*	2·20*	2·90*
13–19		0·57		0·52
19–25		0·92		0·90
25–31		1·28		1·18
31–38		2·00*		1·78
38–44		2·70*		2·40*
44–51		3·30*		2·90*

* Taken from Ministry of Agriculture, Fisheries and Food (1982) recommendations.

Appendix 2 and for optimum seed rates in Appendix 3 (Expt 10). However, discrepancies arose because yields in grades sometimes comprised substantially more tubers than expected from the overall average weight taken from all experiments and led to a lower average tuber weight per grade. As calculations used the actual number of tubers in each size fraction and the average optimum population, they frequently resulted in more replantable hectares than from use of grade yields and average optimum seed rates.

In all experiments except Expts 10 and 14 (Maris Piper), the number of replantable ware hectares increased with initial increases in seed rate, but effects were usually small at the upper end of the range at all except the first harvest from the late-July planting (Tables 5 and 6, Appendix 2). At the earliest harvest of the late-July planting there were usually only small effects of seed rate. In Maris Piper at all dates of planting and harvesting in both experiments, the number of replantable hectares increased with increasing seed rate over the whole range (Table 6, Appendix 2). In all experiments, the number of replantable hectares increased, except from the two lowest seed rates with delay in harvesting for both dates of planting, but for all seed rates from early-July plantings the numbers were frequently close to their maximum at the first harvest. For any seed rate at harvests in September, the number of replantable hectares was considerably higher from early- than from late-July plantings (Tables 5 and 6). When harvesting was delayed to October, the number of replantable hectares from the late planting increased and approached those from the early planting. Maximum replantable areas of *c.* 15, 15, 20 and 25 ha were found in Record, Estima, Wilja and Maris Piper, respectively. In all experiments, the seed-size fraction containing most replantable hectares increased with delay in harvest (Table 7). Few replantable hectares were produced in the largest size grade even at the last harvest from late-July plantings.

The monetary value of late-season seed crops of Record (Expt 2) and Maris Piper (Expt 10) was calculated for a fixed price per tonne and from a seed cost per replantable ware hectare for comparison with values obtained by Allen & O'Brien (1987) for seed crops in Scotland. In the valuations, prices of £100 and £70/t were assumed for tubers graded 10–51 and > 51 mm, respectively. Yields in these size grades in Expts 2 and 10 are shown in Appendix 1. For valuations based on number of replantable hectares, a seed cost of £250/ha was taken for seed graded 10–51 mm, which is equivalent to £100/t at a seed rate (2·5/ha) close to that in the middle of the range recommended by the Ministry of Agriculture, Fisheries and Food (1982) for seed graded 25–55 mm. As the progeny of late-season seed crops would normally be used only to plant ware crops, no allowance was made for the value of seed retained for multiplication of a subsequent seed crop. However, in the valuations, the cost of certified seed (at £150/t) used for the different seed rates in Expts 2 and 10 was deducted from the total value of the crops, giving sale values net of seed costs. The calculated sale values of seed crops for different dates of planting and harvesting for a range of seed rates in Expts 2 and 10 are shown in Tables 8 and 9.

The sale value of crops priced per replantable hectare was substantially higher at early harvests in Record and at all harvests in Maris Piper than values from pricing per tonne (Tables 8 and 9). At early

Table 5. *Effect of date of planting and seed rate (t/ha) on number of replantable hectares from one hectare of seed graded 13–51 mm in 1984 (Expts 1 and 2)*

				Seed rate (t/ha)						
Expt	Variety	Date of planting	Date of harvest	0·77	1·02	1·53	1·91	2·30	S.E.	Error D.F.
1	Wilja	9 July	7 September	7·4	9·3	11·1	13·1	12·0	0·45	8
		9 July	26 September	6·3	8·2	11·2	11·6	10·4	0·49	18
		9 July	15 October	5·0	8·8	13·3	13·5	13·2	0·78	18
		30 July	26 September	5·0	5·1	5·8	5·9	5·3	0·49	18
		30 July	15 October	7·3	7·9	9·8	9·3	10·0	0·78	18
2	Record	9 July	7 September	6·5	7·0	9·0	9·2	9·0	0·79	8
		9 July	26 September	5·6	8·3	8·8	8·6	10·0	0·57	18
		9 July	15 October	5·7	8·6	9·9	9·8	10·2	0·44	18
		30 July	26 September	4·5	4·6	6·1	6·1	7·2	0·57	18
		30 July	15 October	6·3	6·7	8·0	9·1	10·1	0·44	18

Table 6. *Effect of date of planting and seed rate (t/ha) on number of replantable hectares from one hectare of seed graded 10–50 mm in 1987 (Expts 11–14)*

				Seed rate (t/ha)						
Expt	Variety	Date of planting	Date of harvest	1·64	2·05	2·46	3·28	4·92	S.E.	Error D.F.
11	Estima	8 July	3 September	7·2	8·6	8·0	9·8	11·9	0·67	8
		8 July	14 September	6·7	8·8	9·2	11·2	14·5	0·38	18
		31 July	14 September	4·1	5·5	5·0	5·8	6·8		
		31 July	22 September	6·6	7·4	7·6	9·1	10·0	0·36	8
12	Wilja	8 July	3 September	10·1	12·3	12·9	15·3	16·7	0·85	8
		8 July	14 September	12·0	14·9	16·4	19·0	20·5	0·86	18
		31 July	14 September	7·5	8·4	10·3	8·7	9·1		
		31 July	22 September	10·9	9·8	12·5	12·0	15·4	0·65	8
13	Record	7 July	1 September	8·0	8·6	9·4	10·6	13·2	0·85	8
		7 July	15 September	9·7	11·7	13·7	13·9	15·3	0·56	18
		30 July	15 September	8·0	9·3	8·9	10·0	9·6		
		30 July	23 September	9·2	9·9	10·6	11·4	12·6	0·57	8
14	Maris Piper	7 July	2 September	14·3	15·4	18·8	18·1	22·9	1·19	8
		7 July	16 September	15·4	17·3	17·7	21·2	25·4	1·29	18
		30 July	16 September	11·1	12·8	13·3	14·0	14·6		

harvests, when no tubers exceeded the upper seed-size limit (51 mm) sale values from pricing per replantable hectare were up to 2 and 7 times higher in Record and Maris Piper, respectively, than those from a fixed price per tonne. With delay in harvesting, differences in sale value between the two methods of pricing markedly decreased in Record as tuber yields increased while the number of replantable hectares varied little. However, in Maris Piper, substantial advantages in pricing per replantable hectare were found even at the latest harvest as relatively few, less valuable, oversize (51 mm) tubers were present. In both varieties, when near maximum numbers of replantable hectares were produced, sale values from pricing per replantable hectare were approximately double those from pricing per tonne (Tables 5–9, Appendix 2). These differences in sale value from the two pricing methods are substantially greater than those found by Allen & O'Brien (1987) for Record and Maris Piper crops grown in Scotland and support their view that seed growers would increase their financial returns by pricing their crop on the basis of the number of ware hectares that it can replant rather than on a fixed price per tonne of seed tubers. In Expt 10, sale values (net of seed costs) of up to £5600/ha were achieved in Maris Piper, which were similar to the maximum values for this variety in experiments in Scotland. These sale values were almost double the highest found in Record (Expt 2) which also generally produced similar sale values to those of Record crops in Scotland (Allen & O'Brien 1987). Effects of date of planting and harvesting and seed rate in Expts 2 and

Table 7. *Effect of seed rate (t/ha) on number of replantable hectares from different size grades at three dates of harvesting in Wilja, 1986 (Expt 9)*

Date of planting	Date of harvest	Seed size (mm)	Seed rate (t/ha) 0·82	1·09	1·64	2·05	2·46	S.E.	Error D.F.
8 July	9 September	10–20	0·74	0·95	1·66	1·42	1·68	0·152	8
		20–30	1·85	2·98	4·69	4·74	5·58	0·419	
		30–40	2·19	4·21	5·67	5·36	5·85	0·640	
		40–50	0·87	0·95	0·75	0·83	0·44	0·368	
		10–50	5·6	9·1	12·8	12·4	13·5	0·97	
8 July	23 September	10–20	0·29	0·80	0·71	0·77	0·83	0·373	18
		20–30	0·98	1·58	1·82	1·96	1·80	0·552	
		30–40	2·02	3·17	4·21	5·96	5·53	0·289	
		40–50	3·10	4·96	4·64	6·63	7·11	0·275	
		10–50	6·4	10·5	11·4	15·3	15·3	0·92	
8 July	9 October	10–20	0·12	0·51	0·33	0·49	0·69	0·132	18
		20–30	0·58	1·31	1·38	1·82	1·85	0·383	
		30–40	1·30	2·25	1·90	4·09	3·92	0·456	
		40–50	3·02	4·13	7·07	7·74	7·66	0·410	
		10–50	5·0	8·2	10·7	14·2	14·1	0·71	

Table 8. *Effect of date of planting and seed rate (t/ha) on sale value* (£) of crops net of seed costs at different dates of harvesting in Expt 2 (Record) and Expt 10 (Maris Piper)*

Expt	Date of planting	Date of harvest	Seed rate (t/ha) 0·77	1·02	1·53	1·91	2·30	S.E.	Error D.F.
2	9 July	7 September	938	991	1127	1046	1054	58·2	8
	9 July	26 September	1383	1760	1653	1801	1803	81·0	18
	9 July	15 October	2396	2721	2531	2659	2916	179·9	18
	30 July	26 September	479	448	555	530	648	81·0	18
	30 July	15 October	1549	1354	1922	1616	1865	179·9	18
			Seed rate (t/ha) 0·82	1·09	1·64	2·05	2·46		
10	8 July	9 September	866	1271	1118	1237	1197	75·2	8
	8 July	23 September	1466	2204	2673	2770	2669	115·5	18
	8 July	9 October	2771	3448	3389	3720	3774	130·0	18
	29 July	23 September	329	186	269	469	405	115·5	18
	29 July	3 October	716	745	850	1196	1401	92·8	8
	29 July	9 October	1375	1230	1556	1828	1878	130·0	18

* Seed 10–51 mm valued at £100/t and tubers > 51 mm at £70/t.

10 on the sale value of crops from pricing per tonne and per hectare were inevitably similar to effects on tuber yields and number of replantable hectares, respectively.

DISCUSSION

A wide range of tuber yields was produced in the experiments, which allows evaluation of late-season seed potato crops under contrasting circumstances. In two years, 1985 and 1986, low yields were produced in Suffolk largely because of poor crop husbandry. In all other experiments, acceptable tuber yield was produced which frequently reached 30 t/ha for the seed fraction and 40–50 t/ha for total yields. These yields achieved over the short period of 14 weeks from planting are similar to those frequently produced in Scotland (Allen & O'Brien 1987) and illustrate that highly productive and economic seed potato crops can be produced following earlier harvested crops in southern UK from plantings in July. The results

Table 9. *Effect of date of planting and seed rate (t/ha) on sale value* (£) of crops net of seed costs at different dates of harvesting in Expt 2 (Record) and Expt 10 (Maris Piper)*

Expt	Date of planting	Date of harvest	Seed rate (t/ha)					S.E.	Error D.F.
			0·77	1·02	1·53	1·91	2·30		
2	9 July	7 September	1501	1599	2015	2018	1894	112·2	8
	9 July	26 September	1615	2148	2146	2276	2434	120·3	18
	9 July	15 October	2542	2935	2850	3016	3357	195·9	18
	30 July	26 September	1013	973	1299	1244	1462	120·3	18
	30 July	15 October	1679	1740	2136	2054	2368	195·9	18
			Seed rate (t/ha)						
			0·82	1·09	1·64	2·05	2·46		
10	8 July	9 September	1825	2883	2938	3767	4042	166·7	8
	8 July	23 September	2185	3409	4458	4840	5268	214·6	18
	8 July	9 October	3334	4281	4533	5375	5647	226·3	18
	29 July	23 September	1910	1755	2711	3134	3097	214·6	18
	29 July	3 October	2181	2004	3323	3990	4742	230·4	18
	29 July	9 October	2590	2286	3696	4413	4882	226·3	18

* Seed valued at £250 per replantable hectare and yield > 51 mm at £70/t.

suggest that a substantial proportion of the UK seed potato requirement could be produced from late-season crops from the area of land left fallow from July to October following earlier harvested crops. This area is considerably larger than that currently used for production of certified seed tubers (26000–27000 ha; Potato Marketing Board 1986). Wherever seed potato crops are produced, the greatest returns should clearly be obtainable from a shorter growing season than currently used. As date of planting influences the timing of the end of dormancy in progeny tubers (E. J. Allen, J. L. Jones & P. J. O'Brien, unpublished), the manipulation of these factors has considerable commercial opportunities which have not been pursued. For overseas markets, the end of dormancy could be timed to allow transportation of dormant tubers to occur. In the UK, a delay in end of dormancy would cheapen storage for many growers and avoid unnecessary sprout growth where no deliberate sprouting is required.

For all harvests, except the first from late-July plantings, total and seed tuber yields increased with increasing seed rate up to 1·5–2 t/ha in all experiments and further increases usually had little effect on yields. The varieties were of contrasting types and the results suggest that, when tuber yield is the criterion in valuing seed crops, seed rates of 1·5–2 t/ha (*c.* 40000–60000 plants/ha) are sufficient for maximizing tuber yields in late-season seed crops using seed weighing up to 40 g. These optimum seed rates are less than half those (4·6–5·4 t/ha) calculated by Wurr *et al.* (1990) for tuber yields graded 25–55 mm from the data of Allen & O'Brien (1987) for Record seed crops grown in Scotland from similar size seed. Tuber yields were generally higher in Scotland than in these experiments in East Anglia and the optima of Wurr *et al.* (1990) were derived from curve fitting with square root functions. For the experiments in East Anglia, the optimum was taken as the lowest seed rate for which yields were not statistically different from those of any higher seed rate, as in many cases the limited response to increasing seed rate precluded curve fitting. Tuber yield was low (< 15 t/ha) in all varieties at the first harvest of the late-July planting and the results suggest that seed rates of 1–1·5 t/ha would be sufficient for such yields. For seed rates of 2 t/ha and above, most of the total yield was within the seed-size range in all varieties. However, a substantial proportion of total yield exceeded the upper size limit (51 mm) for seed tubers for all seed rates when total yield reached 30 and 40 t/ha in Record and Wilja, respectively. In these and similar varieties, defoliation of seed crops must occur early in growth if most of the yield is to remain within the seed-size fraction. Defoliation may occur later in Maris Piper seed crops, especially at seed rates > 2 t/ha, for this variety produced few oversize tubers when total yield was between 40 and 50 t/ha.

Allen & O'Brien (1987) suggested that in most circumstances there are benefits to seed potato growers in evaluating the seed crop in terms of the number of ware hectares that can be planted from it rather than on a tuber yield basis. A similar approach was used in this work, but the optimum number of tubers planted per hectare rather than optimum seed rates were used for the calculations, as the average tuber weight per size grade varied with dates of planting and harvesting. For all varieties except Maris Piper, the total number of replantable ware hectares from 1 ha of a seed crop increased with increasing seed rate over much of the range for all except the earliest harvests. Only at very early harvests from the late-July planting were responses to seed rate absent for many varieties. In Maris Piper in both experiments, increases were found over the whole range of seed rates at all harvests. The effect of increasing seed rate were least in Record. The results suggest that, for high multiplication rates from the late-season seed crops valued as replantable hectares, seed rates of 2–3 t/ha are required for all except very early defoliation for most varieties, but seed rates up to 5 t/ha may be justified in Maris Piper. These suggested optimum seed rates are similar (for a similar size of seed) to those observed in seed crops of Maris Piper in Scotland by Allen & O'Brien (1987) but are generally lower than those found in Scotland in Record.

Near maximum numbers of seed-size tubers and replantable hectares were produced early in growth and the main disadvantage perceived by growers from defoliating early is forfeiting income from the sale of any oversize tubers. This disadvantage may be small where high seed rates are used and in varieties such as Maris Piper in which the majority of tubers remained within the seed-size fraction even at late harvests and these tubers can no longer be accepted as part of seed multiplication. The benefits of early defoliation include a crop of small seed tubers with the consequent lower handling costs per hectare which ware growers increasingly seek, a likely reduction in tuber-borne diseases if such crops are harvested soon after defoliation (Spencer & Fox 1979; Hide 1987) and maximum value of the crop if sold on the basis of number of replantable hectares.

Net multiplication rates of up to 15, 15, 20 and 25 were found in the experiments in Record, Estima, Wilja and Maris Piper, respectively. These rates are considerably higher than those from commercial crops in Scotland but are similar to those for experiments in seed crops planted earlier in the season in Scotland (Allen & O'Brien 1987). For Maris Piper, the most widely grown variety, the multiplication rates from late-season crops were three to four times those recently achieved for all varieties in commercial Scottish seed crops (Table 11; Allen & O'Brien 1987). This result reinforces the conclusion of Allen & O'Brien (1987) that a large reduction in the seed-potato area in the UK is immediately possible. Using insecticides and fungicides, seed-potato crops with very low levels of disease could be produced throughout the UK and there is no strong agronomic argument for seed crops to be produced in any one region. The incidence of tuber-borne diseases is increasingly important but there is evidence that early defoliation and harvesting, as practised in these experiments, would reduce many tuber diseases (Spencer & Fox 1979). Thus, the production of short-season seed crops grown at high densities and harvested quickly after defoliation would increase seed multiplication rate and minimize tuber-borne diseases.

The highest multiplication rates (25–30) achieved in the experiments in East Anglia and in Scotland (Allen & O'Brien 1987) are substantially higher than those (11–15) reported for seed crops grown from mini-tubers (Knutson 1988). If such high rates were achieved in commercial potato crops, any advantages in using mini-tubers would accrue from the reduction (if any) in tuber-borne diseases. The high initial cost (50–70 p/tuber) of mini-tubers necessitates field multiplication for several seasons for the system to be economically viable and, therefore, some disease infection of tubers may occur from those organisms (e.g. *Rhizoctonia solani*, *Spongospora subterranea*, *Streptomyces scabies* and *Erwinia* spp.) which are resident in many soils and stores. If similar multiplication rates to those obtained in the experiments reported here were achieved by seed growers using conventional seed material, they would permit a reduction in the period between the beginning and end (sale) of the existing commercial seed multiplication cycle which would be expected to reduce amounts of tuber-borne diseases.

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REFERENCES

ALLEN, E. J. & O'BRIEN, S. A. (1987). An analysis of seed weight, seed rate and date of harvest on the yield and economic value of seed-potato crops. *Journal of Agricultural Science, Cambridge* **108**, 165–182.

ALLEN, E. J., O'BRIEN, P. J. & FIRMAN, D. (1992). An evaluation of small seed for ware potato production. *Journal of Agricultural Science, Cambridge* **118**, 185–193.

HIDE, G. A. (1987). Effects of irrigation and seed tuber size on yield and infection of potatoes from commercial and healthier seed stocks. *Potato Research* **30**, 637–649.

JARVIS, R. H. (1977). An assessment of the value of different sizes of seed potatoes of maincrop varieties. *Experimental Husbandry* **32**, 102–114.

KNUTSON, K. W. (1988). Implications of new technologies for seed potato certification programs and seed growers. *American Potato Journal* **65**, 229–235.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1982). Seed rate for potatoes grown as maincrop. *Short Term Leaflet* 653.

POTATO MARKETING BOARD (1986). Potato Statistics in Great Britain 1981–85, 23 pp.

SOIL SURVEY OF ENGLAND AND WALES (1984). *Soils of England and Wales. Bulletin no.* 11. Soil Survey Unit, Rothamsted Experimental Station, Harpenden.

SPENCER, D. & FOX, R. A. (1979). The development of *Rhizoctonia solani* Kühn on the surface of the potato tuber. *Potato Research* **21**, 291–300.

WURR, D. C. E., FELLOWS, J. R., SUTHERLAND, R. A. & ALLEN, E. J. (1990). Determination of optimum tuber planting density for production of tubers in processing ware grades in the potato variety Record. *Journal of Agricultural Science, Cambridge* **114**, 11–18.

Appendix 1. *Effect of date of planting and seed rate (t/ha) on tuber yield (t/ha) at different dates of harvesting in Expts 2 and 10*

Expt		Date of planting	Date of harvest	Seed rate (t/ha)					S.E.	Error D.F.
				0·77	1·02	1·53	1·91	2·30		
2	13–51 mm	9 July	7 September	10·6	11·3	13·4	13·1	13·9	0·58	8
		9 July	26 September	11·7	16·7	17·0	16·7	20·0	0·74	18
		9 July	15 October	12·8	19·4	21·6	20·9	21·2	1·59	18
		30 July	26 September	5·2	6·0	7·8	8·2	9·9	0·74	18
		30 July	15 October	14·3	12·9	17·9	18·4	20·1	1·59	18
	> 51 mm	9 July	7 September	0	0	0	0	0	—	—
		9 July	26 September	4·7	3·4	2·6	3·0	2·1	0·43	8
		9 July	15 October	17·6	13·8	8·6	12·2	16·4	2·11	18
		30 July	26 September	0	0	0	0	0	—	—
		30 July	15 October	3·3	3·1	5·1	0·9	2·9	2·11	18
				Seed rate (t/ha)						
				0·82	1·09	1·64	2·05	2·46		
10	10–50 mm	8 July	9 September	9·9	14·4	13·6	15·5	15·7	0·75	8
		8 July	23 September	15·8	23·6	29·2	30·8	30·4	1·16	18
		8 July	9 October	17·9	24·6	26·1	33·5	37·2	1·43	18
		29 July	23 September	4·5	3·5	5·2	7·9	7·9	1·16	18
		29 July	3 October	8·4	9·1	11·0	15·0	17·7	0·93	8
		29 July	9 October	15·0	13·9	18·0	21·4	22·5	1·43	18
	> 50 mm	8 July	9 September	0	0	0	0	0	—	—
		8 July	23 September	4·6	5·4	3·1	2·3	0·6	0·51	8
		8 July	9 October	15·8	16·5	14·7	9·7	6·1	0·86	18
		29 July	23 September	0	0	0	0	0	—	—
		29 July	3 October	0	0	0	0	0	—	—
		29 July	9 October	0	0	0	0	0	—	—

Appendix 2. *Effect of date of planting and seed rate (t/ha) on number of replantable hectares from different dates of harvesting in Expts 4, 7 and 10*

Expt	Date of planting	Date of harvest	Seed rate (t/ha)					S.E.	Error D.F.
			0·77	1·02	1·53	1·91	2·30		
4	10 July	8 October	8·0	10·1	12·1	13·8	16·5	0·61	18
	31 July	8 October	6·8	9·0	10·3	11·3	10·2		
7	7 July	10 September	2·8	3·3	4·9	5·3	6·3	0·62	8
	7 July	25 September	3·9	5·3	7·5	8·3	9·9	0·57	18
	28 July	25 September	1·9	2·8	3·8	4·8	5·5		
	28 July	2 October	2·7	3·7	5·3	6·1	7·0	0·46	8
			Seed rate (t/ha)						
			0·82	1·09	1·64	2·05	2·46		
10	8 July	9 September	7·8	12·2	12·7	16·3	17·6	0·67	8
	8 July	23 September	9·2	14·3	18·8	20·6	22·5	0·86	18
	8 July	9 October	9·4	13·2	15·0	20·0	22·4	0·98	18
	29 July	23 September	8·1	7·7	11·8	13·8	13·9	0·86	18
	29 July	3 October	9·2	8·7	14·3	17·2	20·4	0·91	8
	29 July	9 October	10·9	9·8	15·8	18·9	21·0	0·98	18

Appendix 3. *Effect of date of planting and seed rate (t/ha) on number of replantable hectares calculated from optimum seed rates, Expt 10*

Date of planting	Date of harvest	Seed rate (t/ha)					S.E.	Error D.F.
		0·82	1·09	1·64	2·05	2·46		
8 July	9 September	7·6	11·6	11·5	14·7	15·5	0·65	8
8 July	23 September	10·2	15·5	19·3	21·3	21·7	0·83	18
8 July	9 October	9·0	12·6	13·3	17·0	19·9	0·95	18
29 July	23 September	7·8	7·1	10·2	12·7	14·0	0·83	18
29 July	3 October	8·6	8·6	13·4	16·1	19·5	0·78	8
29 July	9 October	11·4	10·6	16·3	18·9	21·2	0·95	18