An approach to determining optimum tuber planting densities in early potato varieties

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SUMMARY

Thirteen experiments conducted near Tenby, Dyfed, between 1973 and 1980, examined the effects of seed-tuber weight and within-row spacing on tuber yields of seven potato varieties grown for early production. These data have been used in an attempt to develop an approach to the determination of optimum tuber planting densities in early crops which will provide agronomists with logically applicable principles. Tuber planting densities, which maximized the net crop return (ware value minus seed cost), were estimated for eight ratios of seed cost to ware value ranging from 0·25 to 8·0. Optimum tuber planting densities decreased with the use of higher ratios of seed cost: ware value and heavier seed, except for ratios of 0·25 and 0·50 applied to yields of tubers > 25 mm harvested in June. In general, later harvesting together with the use of larger riddle sizes give a lower optimum density with ratios < 2·0. Optimum densities for Red Craigs Royal, Ulster Sceptre and Vanessa were higher than for the other varieties.

The results provide an illustration of how to approach the problem of selecting tuber planting densities in order to maximize net crop returns in early potato varieties.

INTRODUCTION

Early potatoes are traditionally grown in parts of the UK where mild, relatively frost-free springs produce crops which can be harvested early (O'Brien & Allen 1975) to command a high price per tonne; subsequently the price tends to fall as yields increase with later harvesting. As the season progresses, the minimum riddle size over which potatoes can be sold may be changed by the Potato Marketing Board depending upon market supplies. While maincrop varieties have recommended optimum tuber densities (MAFF 1985) information available for early varieties is limited. For example, Hessayon & Fenemore (1961) suggested planting about 30 cm apart in narrow rows; Cox (1967) recommended that all apically dominant seed should be spaced 30 cm apart as should multi-sprout seed graded 32–48 mm, while multi-sprout seed graded 48–57 mm should be planted 38 cm apart. In practice, a survey showed that 32% of the early potato acreage was planted < 28 cm apart, 49% was planted 28–36 cm apart and 19% was planted > 36 cm apart (Potato Marketing Board 1970). The average spacing of seed tubers was 29 cm, but this ranged from 24 cm in South Wales to 33 cm in the Lothians of Scotland. However, these reports merely describe spacings adopted in practice and do not represent any experimental determination of appropriate spacings for particular situations.

This paper uses data from seed weight and within-row spacing experiments of seven varieties to estimate for the first time the optimum tuber planting densities suitable for early crops harvested at different times and with a range of seed costs and ware values.

MATERIALS AND METHODS

Field experiments

Thirteen experiments examining the effects of seed-tuber weight and within-row spacing on tuber yields were conducted in a traditional early potato production area at the University College of Wales Field Station, Trefloyne, Tenby on Old Red Sandstone soils of the Pembroke Series using the seven potato cultivars Home Guard, Arran Comet, Red Craigs Royal, Maris Bard, Ulster Sceptre, Vanessa and Désirée. All cultivars were grown in rows 71 cm apart, except for Home Guard which had rows 66 cm apart. All experiments used three seed-tuber weights: a mean of $35 \pm 3{\cdot}5$ g, a mean of 70 ± 7 g and a mean of 105 ± 10 g. Each seed-tuber weight was planted at five within-row

Table 1. *Experimental details*

Experiment number	Cultivar	Year	Date of Planting	Date of Harvesting	Total yield (t/ha): mean of all treatments
1	Maris Bard	1979	18 Apr	25 Jun	26·2
				16 Jul	50·8
2		1979	20 Apr	26 Jun	19·2
				17 Jul	43·8
3	Arran Comet	1978	20 Mar	9 Jun	11·8
				7 Jul	40·6
4	Home Guard	1973	20 Mar	18 Jun	22·7
				2 Jul	29·7
				16 Jul	36.8
5	Ulster Sceptre	1977	29 Mar	13 Jul	27·8
6		1978	4 Apr	19 Jun	15·6
7		1979	26 Apr	28 Jun	24·0
				19 Jul	38·3
8	Désirée	1979	30 Apr	11 Jul	28·6
9		1980	7 Apr	10 Jul	40·7
10	Red Craigs Royal	1977	23 Mar	16 Jun	7·4
				12 Jul	12·9
		1977	23 Mar	15 Jul	20·1
11	Vanessa	1977	30 Mar	24 Jun	16·2
12				28 Jul	29·8
13		1979	26 Apr	2 Jul	27·1

spacings giving, in all cultivars except Home Guard, seed-tuber densities of 47000, 63000, 94000, 141000 and 188000/ha for 35 g seed, 31000, 47000, 70000, 94000 and 117000/ha for 70 g seed tubers and 31000, 47000, 63000, 78000 and 94000/ha for 105 g seed tubers. All seed-tuber weights of Home Guard were planted at seed-tuber densities of 33000, 40000, 50000, 66000 and 100000/ha. In all experiments, the treatments were arranged in a randomized block design with three replicates and where experiments were harvested on more than one occasion harvests were on subplots of a split-plot design with seed-tuber weight and spacing treatments on main plots. Further details of the experiments, including the dates of planting and harvesting and mean total yields, are shown in Table 1. Rates of application of fertilizer were 170 kg N, 76 kg P and 177 kg K/ha for Désirée and 150 kg N, 65 kg P and 158 kg K/ha for all other cultivars. All plants were harvested with a hand fork, the tubers were hand-graded over square mesh riddles and the number and weight of tubers in from five to eight grades, depending on the experiment and the time of harvesting, were recorded. The riddle sizes used were all Imperial, but varied from one experiment to another; grades had a size differential of either 6 or 12 mm.

Analyses of the data used the technique developed by Travis (1987) to estimate the yields in the current equivalent metric grades. This involved describing for each plot the size distribution of potatoes measured as the weight in discrete grades, by two parameters: the grade size at which there was most yield (μ) and a measure of the spread of yield across size grades (σ). In order to estimate μ and σ it was first necessary to carry out a weighting procedure to stabilize the variance in different size grades. Once μ and σ had been estimated, it was possible, by using the normal distribution function, to calculate the proportion of yield in any size grade and then from the total yield to estimate the actual yield in those grades. Here the yields > 25, > 30 and > 35 mm were estimated.

Estimation of optimum tuber planting densities

In order to be able to apply the results of the data analysis to a range of economic conditions, models fitted to the data initially took no account of the seed cost:ware value ratio and simply estimated the density at which the yield was maximized. The optima for different seed cost:ware value ratios ranging from 0·25 to 8·0 were then calculated by adjustment of the fitted parameter values as described below. The net crop return of each treatment was calculated as ware value minus seed cost, using a range of seed costs from £50 per tonne (once-grown seed) to £400 per tonne (certified seed of a new variety) and a range of ware values from £50 per tonne (oversupplied market) to £600 per tonne (price for earliest harvests).

For each combination of seed-tuber weight and ware size grade (> 25 mm for harvests up to 30 June, > 30 mm for harvests from 1 to 14 July and > 35 mm for harvests from 15 to 31 July), linear

$$y = bx + c$$

and square root

$$y = ax^{0.5} + bx + c$$

relationships (Wurr *et al.* 1990, 1992) were fitted between yield (y) and tuber planting density (x). The effects of the time from planting to harvesting on the parameters of these relationships were examined. In addition for ware > 25 mm, irrespective of when harvested, data were grouped according to cultivar and sprouting technique.

The variance of each planting density at which the yield was maximized was estimated using a Taylor series expansion. Optima for different seed costs were then calculated using the same equations as before, but substituting $(b-s)$ for b where s was the relative cost of the seed calculated as the seed cost : ware value ratio × the weight of one tuber in tonnes.

RESULTS AND DISCUSSION

Optimum tuber densities

The important feature of this work is that for the first time a logical attempt has been made to determine optimum tuber planting densities for early potato crops. The data are not an ideal set of systematic trials but the analysis techniques used have maximized the information available from them.

Inspection of the data showed that tuber yields varied greatly from one crop to another even within the specific ranges of harvest date previously described. Much of this could be accounted for by differences in the time from planting to harvest and various examples of this can be seen in Figs 1 and 2. These are also quantified in Table 2, which shows the residual mean squares from fitting successive models for each seed-tuber size to the data for yields > 25, > 30 and > 35 mm harvested respectively before 30 June, from 1 to 14 July and from 15 to 31 July. The c parameter from both the linear and square root models was greatly influenced by the interval from planting to harvest (i) and all subsequent models contain a term c_i to account for this. In comparison

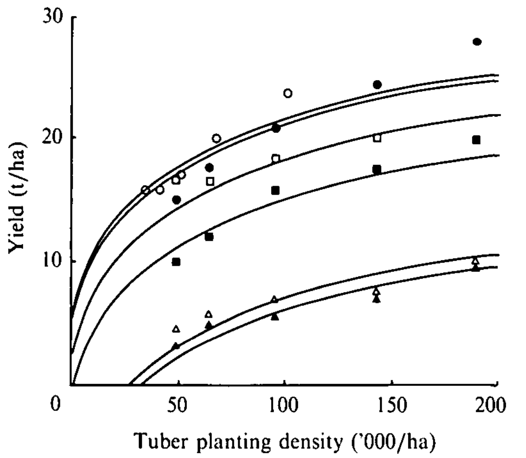

Fig. 1. Data values and fitted lines for yield > 25 mm from 35 g seed tubers harvested before 30 June plotted against seed-tuber planting density. Fitted lines are for the square root curve $y = ax^{0.5} + bx + c$ with c varying according to the number of days from planting to harvest. Data from experiments as follows: Expt 2 (□); Expt 3 (△); Expt 4 (○); Expt 7 (●); Expt 10 (▲); Expt 12 (■).

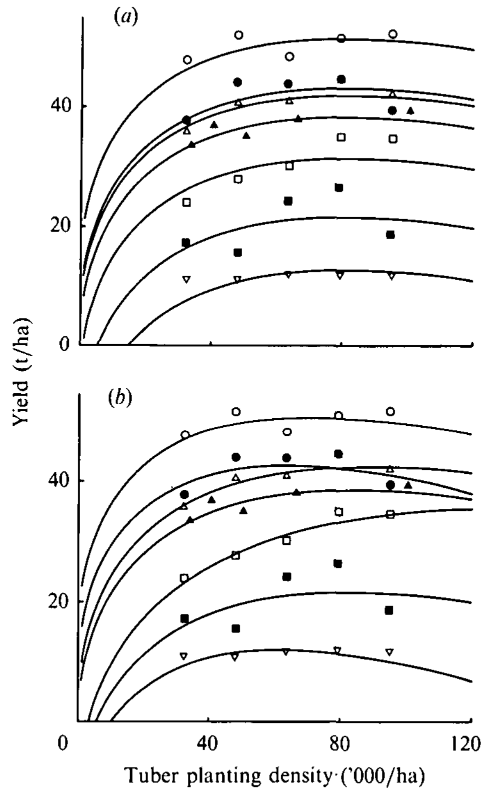

Fig. 2. Data values and fitted lines for yield > 35 mm from 105 g seed tubers harvested from 15 to 31 July plotted against seed-tuber planting density. Fitted lines are for the square root curve $y = ax^{0.5} + bx + c$ with (*a*) c varying according to the number of days from planting to harvest and (*b*) both b and c varying with time from planting to harvest. Data from experiments as follows: Expt 1 (○); Expt 2 (●); Expt 4 (▲); Expt 6 (▽); Expt 7 (△); Expt 11 (■); Expt 13 (□).

Table 2. *Residual mean squares from linear and square root models where* $i = 1 \ldots n$ *days from planting to harvest*

Fitting model	Seed-tuber weight (g) 35 R.M.S.	35 D.F.	70 R.M.S	70 D.F.	105 R.M.S	105 D.F.
	Ware > 25 mm harvested before 30 June					
$y = bx+c$	41·81	28	44·25	32	43·85	33
$y = bx+c_i$	2·55	23	3·69	26	2·26	27
$y = a\sqrt{x}+bx+c_i$	2·12	22	2·68	25	2·19	26
$y = a\sqrt{x}+b_ix+c_i$	0·39	17	1·11	19	1·86	20
$y = a_i\sqrt{x}+b_ix+c_i$	0·33	12	1·15	13	2·19	14
Total mean square	43·71	29	50·26	33	47·76	34
	Ware > 30 mm harvested 1 to 14 July					
$y = bx+c$	89·73	33	86·43	33	87·74	33
$y = bx+c_i$	24·33	28	17·87	28	19·78	28
$y = a\sqrt{x}+bx+c_i$	22·69	27	17·24	27	19·84	27
$y = a\sqrt{x}+b_ix+c_i$	25·00	22	20·16	22	22·47	22
$y = a_i\sqrt{x}+b_ix+c_i$	31·19	17	23·62	17	28·44	17
Total mean square	98·23	34	96·41	34	94·23	34
	Ware > 35 mm harvested 15 to 31 July					
$y = bx+c$	127·80	28	165·40	33	169·80	33
$y = bx+c_i$	6·74	23	9·95	27	6·97	27
$y = a\sqrt{x}+bx+c_i$	4·59	22	6·40	26	5·93	26
$y = a\sqrt{x}+b_ix+c_i$	3·49	17	4·10	20	5·36	20
$y = a_i\sqrt{x}+b_ix+c_i$	3·42	12	3·67	14	5·72	14
Total mean square	127·14	29	168·15	34	167·59	34

with the effect on c there was relatively little effect of this time interval on either the a or b parameters. Although the model varying both b and c according to the time from planting to harvesting in some cases had a lower residual mean square than that varying b alone, this was not necessarily a significant improvement in fit and the simpler model was preferred. Overall, the most appropriate model was that varying c

$$y = ax^{0.5}+bx+c_i$$

and this model is used subsequently. However, since the object of these analyses was to determine optimum tuber planting densities using several crops, the absolute level of yield was not important and indeed Fig. 2 shows that over a very wide range of yields from 10 to 50 t/ha, optima did not differ greatly.

Another problem illustrated by these data is that with early experimental harvests it is not possible to determine sensible densities at which yield was maximized because yields continued to rise over the whole range of densities used. This is illustrated in Fig. 1 which shows data for 35 g seed tubers and yield > 25 mm harvested before 30 June. The fitted lines are for the square root curve previously described: with c varied according to the number of days from planting to harvest.

Inevitably, the standard errors of the optima for these early harvests are very large because the fitted optima are at densities considerably greater than the highest planting density used. For crops harvested from 1 to 14 July the errors were still large but for crops harvested from 15 to 31 July they were well within the range of errors from maincrop varieties harvested at maturity (Wurr *et al.* 1992). Indeed Table 2 and Fig. 2(*a*) show that the model

$$y = ax^{0.5}+bx+c_i$$

fits data well from 105 g seed tubers and yield > 35 mm harvested from 15–31 July and that the fit was not significantly improved by the model varying both b and c (Fig. 2(*b*)). The density at which yield was maximized in Fig. 2(*a*) was 81500 while in Fig. 2(*b*) it was 84300, so differences between the two models were unimportant for estimating optima.

The size of the errors found with later harvests suggests that there is nothing inherently more variable about these trials than any others and raises an important question. Do we attempt to show optima for early varieties only from relatively late harvests or do we also present optima for earlier, more relevant harvests knowing that the associated errors are large? Because there are no published recommendations for planting density in early varieties, we have chosen to

Table 3. *Seed-tuber densities ('000/ha) at which yield was maximized (seed cost: ware value = 0) and optima for different seed cost: ware value ratios for different times of harvesting and ware grade*

Seed-tuber weight (g)	Seed cost: ware value ratio	Ware > 25 mm harvested before 30 June	S.E.	D.F.	Ware > 30 mm harvested 1–14 July	S.E.	D.F.	Ware > 35 mm harvested 15–31 July	S.E.	D.F.
35	0·00	341	237·5	22	173	62·9	27	156	23·3	22
	0·25	267			160			144		
	0·50	215			148			133		
	0·75	177			137			123		
	1·00	148			128			115		
	2·00	82			98			88		
	3·00	52			78			70		
	4·00	36			63			57		
	8·00	13			32			29		
70	0·00	143	39·0	25	144	96·4	27	94	9·3	26
	0·25	122			126			88		
	0·50	105			111			82		
	0·75	92			99			76		
	1·00	80			88			72		
	2·00	51			60			56		
	3·00	36			43			45		
	4·00	26			32			37		
	8·00	11			14			20		
105	0·00	317	615·1	26	134	143·2	27	82	13·1	26
	0·25	182			111			73		
	0·50	118			94			66		
	0·75	83			80			60		
	1·00	61			69			54		
	2·00	25			42			39		
	3·00	14			28			29		
	4·00	9			20			23		
	8·00	3			8			10		

present the optimum densities estimated from the most appropriate analysis of the available data including information from harvests made over all three periods mentioned here. These at least give the grower some guidance as to what density he should consider for crops which may be harvested over a relatively long period of time.

Using the model described, the densities at which crop yield was maximized and the optima for different ratios of seed cost:ware value were calculated. Existing advice (Hessayon & Fenemore 1961; Cox 1967) did not distinguish between varieties and it therefore seems sensible initially to consider all varieties together. Thus Table 3 shows the planting density at which yield was maximized (seed cost: ware value = 0) and the optimum tuber planting densities for ware > 25, > 30 and > 35 mm, harvested respectively before 30 June, from 1 to 14 July and from 15 to 31 July using data from all crops harvested within the specified time period. Optima are presented separately for each tuber weight and for ratios of seed cost:ware value ranging from 0·25 to 8·0. Those for 35 g seed tubers lifted before 30 June with seed cost:ware value ratios of 0·25 and 0·50 had optima beyond the range of densities used in the experiments and must therefore be treated with caution.

The data show that optimum densities varied considerably and reveal several important principles which will be relevant in practice. As seed became more expensive relative to ware, so the optimum tuber planting density decreased. Optima also decreased with the use of heavier seed (except for yields in June at seed cost:ware value ratios of 0·25 and 0·50). In general, for all seed-tuber weights at seed cost:ware value ratios of < 2·0, later harvesting, together with the use of larger riddle sizes, resulted in lower optimum planting densities. These findings are in contrast with those of Bean (1981), who showed that the optimum seed rate for Home Guard increased with later harvesting, although he made comparisons at a constant riddle size and his harvesting started earlier than here. Certainly our data show that for

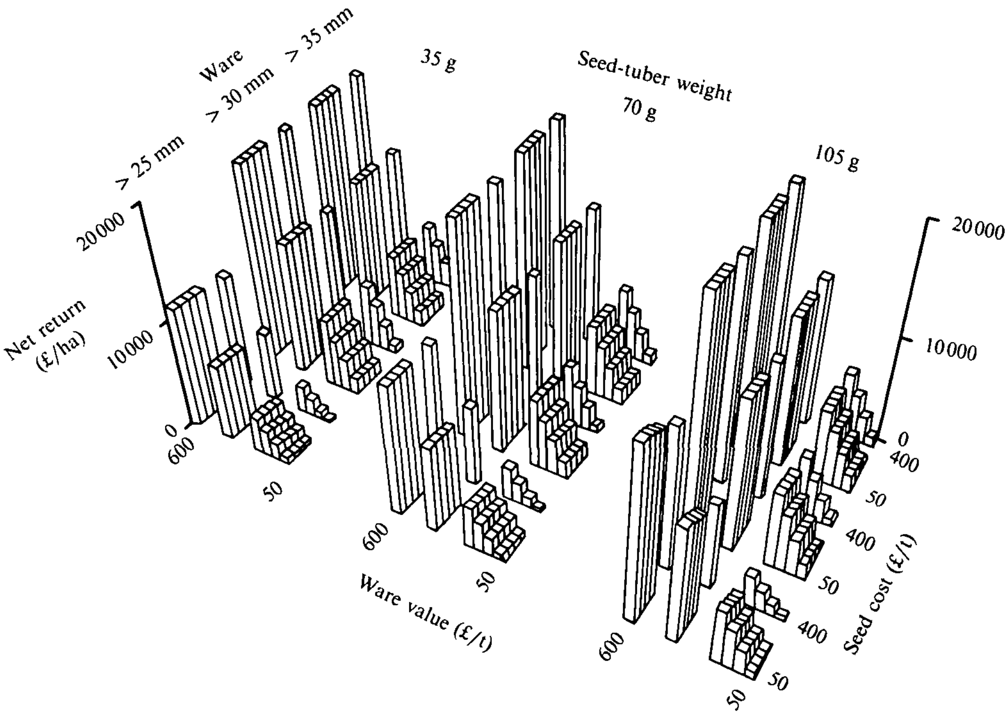

Fig. 3. Three-dimensional diagrams showing the net returns (ware value minus seed cost) at the optimum seed-tuber planting density for nine seed-tuber weight and ware grade/harvest date combinations.

seed cost:ware value ratios $\geqslant 2{\cdot}0$, harvesting from 1 to 14 July had a slightly higher optimum tuber planting density than harvesting in June, but any further changes in optimum tuber planting density for harvests made from 15 to 31 July were negligible.

Figure 3 presents three-dimensional diagrams showing the net returns of ware value minus seed cost at the optimum density for a range of seed costs from £50 to £400/t and ware values from £50 to £600/t. Returns are presented for all nine seed-tuber weight and ware grade/harvest date combinations. The diagrams show that returns increased with increasing ware value but were hardly affected by seed cost. Effects of seed weight were not large and as all seed-tuber weights were planted into the same depth of furrow, the heavier seed tubers were effectively planted more shallowly than the lighter seed tubers. This may have affected early growth and contributed to the small advantage of heavy seed (Allen *et al.* 1992). In general, net returns increased with the use of heavier seed tubers and, on average, returns from using 105 g seed tubers were 19% higher than from using 35 g seed tubers. This agrees with the statement of Scott & Younger (1972) that large seed was most valuable to early growers because of the early yield advantage that it conferred. They were referring to equal numbers of seed tubers of different sizes, whereas our data show that when each seed-tuber weight is planted at its own optimum density there is an advantage in using large seed tubers. This provides limited support for the commonly held belief that large seed tubers are necessary for early crops, which Bean (1981) pointed out was not justified in the literature. Returns also increased with later harvesting, although in practice ware values would almost certainly have dropped over the same period.

Optimum tuber densities for grouped data

Table 3 presents data derived from all seven cultivars, yet it may be unrealistic to group them all together since they can produce different numbers of daughter tubers. Accordingly, analyses were confined to tubers > 25 mm, irrespective of when harvested, using data from all available crops. The linear and square root models previously described were fitted to the data, varying *c* according to the time from planting to harvest and in the square root model varying both *a* and *b* according to cultivar grouping. The cultivars were put into the following two groups on the basis of the mean number of tubers/ha that they produced: (i) Red Craigs Royal, Ulster Sceptre and Vanessa (producing respectively $282 \pm 20{\cdot}4$, $483 \pm 30{\cdot}8$ and $427 \pm 21{\cdot}6$ thousand tubers/ha) and (ii) Maris Bard,

Table 4. *Residual mean squares for linear and square root models where i = 1 ... n days from planting to harvest and cv = 1 ... 2 cultivar groupings, Red Craigs Royal, Ulster Sceptre and Vanessa versus other cultivars for ware > 25 mm harvested before 31 July*

	Seed-tuber weight (g)					
	35		70		105	
Fitting model	R.M.S.	D.F.	R.M.S.	D.F.	R.M.S.	D.F.
(1) $y = bx + c$	118·50	93	133·90	102	138·80	103
(2) $y = bx + c_i$	10·83	76	9·74	83	9·02	84
(3) $y = a\sqrt{x} + bx + c_i$	9·20	75	7·74	82	8·56	83
(4) $y = a\sqrt{x} + b_{cv}x + c_i$	9·04	74	7·39	81	8·23	82
(5) $y = a_{cv}\sqrt{x} + b_{cv}x + c_i$	9·14	73	7·43	80	8·30	81
Total mean square	124·68	94	142·51	103	144·47	104

Table 5. *Seed-tuber densities ('000/ha) at which yield was maximized (seed cost:ware value = 0) and optima for different seed cost:ware value ratios for Red Craigs Royal, Ulster Sceptre and Vanessa pooled together and for all other cultivars pooled. Ware > 25 mm harvested before 31 July*

Seed tuber weight (g)	Seed cost:ware value ratio	Red Craigs Royal Ulster Sceptre Vanessa	S.E.	D.F.	Other cultivars	S.E.	D.F.
35	0·00	210	46·4	74	168	30·1	74
	0·25	190			154		
	0·50	173			141		
	0·75	158			130		
	1·00	144			120		
	2·00	106			90		
	3·00	80			70		
	4·00	63			56		
	8·00	30			28		
70	0·00	142	29·4	81	111	14·6	81
	0·25	126			100		
	0·50	113			91		
	0·75	102			83		
	1·00	93			76		
	2·00	65			55		
	3·00	48			42		
	4·00	37			33		
	8·00	17			15		
105	0·00	185	131·2	82	116	43·0	82
	0·25	145			95		
	0·50	116			80		
	0·75	95			67		
	1·00	80			58		
	2·00	44			35		
	3·00	28			23		
	4·00	19			16		
	8·00	7			6		

Arran Comet, Désirée and Home Guard (producing respectively 1123±58·8, 597±37·9, 696±25·5 and 1147±49·9 thousand tubers/ha). Table 4 shows that the model varying *b* according to cultivar grouping and *c* according to the time from planting to lifting gave the best fit with all three seed-tuber weights. This model was then used to calculate the densities at which yield was maximized and the optimum planting densities (Table 5) using the range of seed cost:ware value ratios previously described. As in Table 3, a higher ratio of seed cost:ware value gave lower optimum planting densities, while heavier seed tubers gave lower optimum planting densities, except at seed cost:ware value ratios of 0·25 and 0·50. The cultivar group containing Red Craigs Royal, Ulster Sceptre and Vanessa required a higher planting density than the other group. Although from a competitive point of view this might be expected, since these cultivars produced fewer daughter tubers than the other cultivars, it is a useful practical result which provides growers with a novel principle that they can apply to their crops.

Models were also fitted separating Maris Bard and Arran Comet from the other cultivars on the basis that these two cultivars now make up the bulk of the early crop acreage and may therefore have a distinct response. However, there was no significant improvement in the fit of the model, suggesting that these cultivars did not have a separate density response.

Using data on tubers > 25 mm from all crops, irrespective of when harvested, models were fitted varying parameters according to sprouting technique, but there was no significant improvement in fit.

Conclusions

These analyses show how, in principle, the optimum tuber planting density is affected by seed cost, ware value, seed weight, time of lifting and variety. The errors associated with analyses of data of this type are inevitably large, but at least the results give a grower some quantitative advice where none existed before. The choice of tuber planting density appears complex, yet may be simplified by considering the production system logically. A grower will have decided which type of seed to buy and therefore how much it will cost. He will have a target harvesting date and ware value and can thus select the appropriate tuber planting density according to the variety and tuber count (number of seed tubers/50 kg) of his seed batch. Such a course of action, based on the analysis of many experiments, provides the first attempt at a logical basis for selecting seed-tuber planting densities for early crops and is an advance on the limited information hitherto available. If new experimental work were to be carried out on a more systematic basis, it might be possible to provide a wider range of recommendations for optimum densities, although it is unlikely that the associated errors would be appreciably smaller than those here and difficulties would still be experienced with recommendations for early harvests.

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REFERENCES

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.

BEAN, J. N. (1981). *Density studies with early potato cultivars.* PhD thesis, University College of Wales, Aberystwyth.

COX, A. E. (1967). *The Potato: A Practical and Scientific Guide.* London: W. H. & L. Collingridge.

HESSAYON, D. G. & FENEMORE, P. G. (1961). *Potato Growers Handbook.* Waltham Abbey: Pan Britannica Industries and London: Charles Lennig & Company (GB).

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1985). Seed rate for potatoes grown as maincrop. *MAFF leaflet 653.*

O'BRIEN, P. J. & ALLEN, E. J. (1975). Effect of area of seed production and date of lifting of seed crops on the performance of the progeny tubers. In *Proceedings of the 6th Triennial Conference of the European Association for Potato Research*, pp. 41–42.

POTATO MARKETING BOARD (1970). *Survey of Early Potatoes 1968.* London: Potato Marketing Board.

SCOTT, R. K. & YOUNGER, A. (1972). Potato agronomy in a changing industry. *Outlook on Agriculture* **7**, 3–9.

TRAVIS, K. Z. (1987). Use of a simple model to study factors affecting the size distribution of tubers in potato crops. *Journal of Agricultural Science, Cambridge* **109**, 563–571.

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.

WURR, D. C. E., FELLOWS, J. R. & ALLEN, E. J. (1992). Determination of optimum tuber planting density in the potato varieties Pentland Squire, Cara, Estima, Maris Piper and King Edward. *Journal of Agricultural Science, Cambridge* **119**, 35–44.