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Determination of optimum tuber planting density for production of tubers in processing ware grades in the potato variety Record

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SUMMARY

A series of experiments examining the influences of size and spacing of planted potato tubers ('seed' tubers) on tuber yields was conducted at four sites in the UK in 1982–84. A new approach to data analysis was used to estimate the optimum tuber planting density for different ware grades. The optimum density, which maximized returns, decreased with increasing seed tuber weight and ratio of seed-tuber cost to ware value and with lower than average total tuber yields. Changing the required ware grade from 40–65 mm to 40–80 mm had a minimal effect on the optimum tuber planting density.

Optimum tuber planting densities were lower than in published recommendations but this disparity appeared to be accounted for by differences in the number of stems produced by each planted tuber. There was some evidence that, with lower seed-tuber weights, the optimum planting density differed with site and that at optimum economic densities small and medium seed tubers outyielded large seed tubers.

INTRODUCTION

Detailed recommendations for optimum planting densities of tubers of different weight for the potato variety Record have been available since 1970 (Anon. 1970) and were amended in 1978 (Ministry of Agriculture, Fisheries and Food 1978). However, other published data (Hart 1983) suggest that the original recommendations may not hold widely and in recent years the size specifications for processing potatoes have become more specific, precise requirements varying from processor to processor. Consequently, concern has been increasing that recommendations developed primarily from experiments conducted on silty loam or silt loam soils at Terrington Experimental Husbandry Farm, UK, may not necessarily apply on other soils and that optima may vary much more widely than previously thought.

In this paper, we describe a series of experiments studying the influence of size and spacing of planted tubers ('seed' tubers) on the yield of tubers in current processing grades. The results are used to update recommendations on the seed-tuber density required to achieve maximum yield, or maximum economic yield, in the tuber sizes required by processors, on a range of soil types.

EXPERIMENTS

In 1982, 1983 and 1984, a common seed-tuber stock of Record was grown on four soil types in the UK: medium loam soils of the Ashley-Hanslope Association for Nabisco Brands (Smiths Divison) in Suffolk, sandy soils of the Blackwood Association for United Biscuits in Lincolnshire and the Cuckney Association for Walkers in Nottinghamshire and on peat soils of the Adventurers I Association for Golden Wonder (then Imperial Tobacco) in Cambridgeshire. In 1982, seed tubers of $35 \pm 2{\cdot}5$ g were planted at within-row spacings of 40, 30, 22·5, 15, 10 and 7·5 cm and seed tubers of 105 ± 5 g were planted at 60, 45, 30, 22·5, 18 and 15 cm spacings. In 1983 and 1984, seed tubers of $35 \pm 2{\cdot}5$ g were planted at within-row spacings of 60, 45, 30, 20, and 15 cm, tubers of 70 ± 5 g were planted at 90, 60, 40, 30 and 20 cm and tubers of 105 ± 5 g were planted at 90, 60, 45, 30, and 24 cm within rows. At each site in each year, the treatments were arranged in a randomized-block design with three replicates. Rates of fertilizer application and crop culture were those normally used by the grower and the only crops not irrigated were those grown for United Biscuits. The row width, planting and harvest dates of each crop are shown in Table 1. The numbers of stems

Table 1. *Experimental details for the potato variety Record*

Year	Site	Row width (cm)	Date of planting	Date of harvest	Total yield (mean over all treatments) (t/ha)
1982	Walkers (Notts.)	86·4	24 Feb	21 Sep	34·9
	United Biscuits (Lincs.)	91·4	21 Apr	22 Sep	36·4
	Smiths (Suffolk)	76·2	12 May	21 Sep	39·1
	Golden Wonder (Cambs.)	91·4	16 Apr	22 Sep	31·1
1983	Walkers	86·4	15 Mar	4 Oct	50·1
	United Biscuits	91·4	24 May	3 Oct	23·5
	Smiths	76·2	19 May	3 Oct	45·0
	Golden Wonder	91·4	13 Jun	4 Oct	28·0
1984	Walkers	86·4	23 Mar	24 Sep	54·6
	United Biscuits	91·4	10 Apr	25 Sep	49·6
	Smiths	76·2	3 May	25 Sep	50·3
	Golden Wonder	91·4	4 May	25 Sep	46·0

on each site were determined by counting before harvest.

The tuber yields were estimated from 3.6 m of row harvested by hand. The tubers were hand graded over square-mesh riddles of 38, 44, 57, 64 and 76 mm in 1982; 13, 25, 38, 51 and 64 mm in 1983; and 13, 25, 38, 51, 64 and 76 mm in 1984. The number and weight of tubers in each grade were recorded.

Estimation of yields in specific size grades

The riddles used were not the same in all 3 years and were Imperial rather than metric but these problems were overcome using a technique developed by Travis (1987). This involves describing the size distribution of potato tubers, measured as the weight in discrete grades, by two parameters: the grade size at which there is most yield (μ), and (σ), a measure of the spread of yield across size grades. However, in order to be able to calculate these parameters, it was first necessary to carry out a complex weighting procedure to stabilize the variance in different size grades. Once μ and σ had been calculated, it was possible, by using the normal distribution function, to estimate the proportion of yield in any specified grade and then, from the total yield, to estimate the actual yield in that grade. This enabled the yields in the 40–65, 40–70 and 40–80 mm grades, all of which may be required for crisping, to be estimated for each plot of every experiment.

Determination of optimum seed-tuber planting densities

The estimated yields in the 40–65, 40–70 and 40–80 mm grades were plotted against the number of tubers planted. Quadratic

$$y = a_1 x^2 + b_1 x + c_1$$

and square-root

$$y = a_2 x^{0.5} + b_2 x + c_2$$

curves were fitted separately for each combination of site, year and tuber size (32 data sets in all). These related the estimated yields (y) to the numbers of tubers planted (x), a_1, b_1, c_1, a_2, b_2 and c_2 being the regression coefficients of the fitted curves. A comparison of the percentage variance accounted for showed that, for data sets and grades for which curves gave a good fit, the square-root curves accounted for a higher proportion of the variance than the quadratic curves in two-thirds of all cases. For the fitted square-root curves, the expression $a_2^2/4b_2^2$ was calculated, this being the tuber planting density at which it was estimated that the yield in the chosen grade would be greatest. Some data sets were extremely variable and altogether, for total yield and the three size grades, 63 were unsuitable for determining optimum seed-tuber planting densities.

The optimum seed-tuber planting density (P_o) was estimated for each specified grade and for total yield, from as many data sets as possible. The variance of each estimated optimum planting density was then itself estimated using a Taylor series expansion and, using the reciprocal of the estimated variance of the optimum planting density as a weight, mean optimum planting densities for each tuber size were determined. These P_o values represent the best estimates of the planting densities of each tuber size at which yield in each specified grade was greatest but they make no allowance for the relative cost of seed tubers and value of ware. Each increment in tuber planting density results in a smaller increase in tuber yield, so there is a point on the curve, at a lower planting density than that for maximum crop yield, at which the additional cost of an increment of seed tubers produces additional output of the same value. This planting density is known as the optimum economic density (P_e) (Jarvis & Rogers-Lewis 1976) and was calculated for each data set using the fitted square-root curves and seed-tuber cost:ware value ratios of 1·5:1 and 2:1. Its variance was estimated as above by Taylor series expansion. The use of a higher tuber planting density than the P_e value only succeeds in producing ware whose value is less than that of the additional seed tubers used.

RESULTS

Optimum tuber planting densites

Mean P_e and mean P_o values are shown in Table 2. The optimum seed-tuber planting density decreased with increasing seed-tuber weight and as the cost of seed tubers increased relative to the value of ware. Optimum planting densities for different ware grades differed only slightly and there was no evidence that, to produce tubers graded 40–65 mm, the target planting density should be very different from that used for tubers graded 40–80 mm.

However, there was evidence that the optimum planting density was influenced by the total yield in each experiment. The weighted values of P_o and P_e for the ware grades 40–65, 40–70 and 40–80 mm were regressed on total tuber yield, fitting independent straight lines for 70 and 105 g seed tubers. It was not possible to fit lines for 35 g seed tubers because there were insufficient data to give a reliable fit. The data show that, with change in total yield relative to the mean, the tuber planting density should also be changed, though only to any great extent when using 70 g seed tubers. Based on the regression coefficients, Table 3 shows, for example, that, with tubers graded 40–65 mm at P_o, planting densities should be increased by 360 tubers/ha for each t/ha increase in total yield. As the P_e ratio increased, the suggested changes in optimum planting density for 70 g seed tubers were slightly reduced.

Since in the current analysis some data sets were excluded because they were too variable, it is difficult to make comparisons between individual sites but, nevertheless, some trends were apparent. In contrast to the opinion held generally by both growers and processors, the effect of the site of production on both P_o and P_e was inconsistent and, on average, small and the data are not presented here. There did appear to be an interaction between site and tuber size which suggested that the Smiths' and Walkers' sites had higher optimum planting densities, with 70 g (medium) and 35 g (small) seed tubers, while with 105 g (large) seed tubers there was no effect of site. In fact, total yields at the Smiths' and Walkers' sites were

Table 2. *Estimated optimum seed-tuber planting densities* ($\times 10^3$/*ha*)* *for the potato variety Record*

Ware grade (mm)	Seed-tuber weight planted (g) 35	70	105	S.E.	D.F.
	Optimum density, P_o				
40–65	47·8	41·3	32·5	1·49	28
40–70	48·0	41·9	35·3	1·34	33
40–80	46·0	42·8	35·1	1·00	34
Total	49·3	40·6	32·5	0·37	37
	Optimum economic density, P_e 1·5†				
40–65	43·9	34·4	28·6	0·94	28
40–70	43·3	33·8	29·8	0·72	33
40–80	42·2	35·6	30·1	0·60	34
Total	47·2	35·5	29·7	0·27	37
	P_e 2·0†				
40–65	42·7	33·2	27·5	0·85	28
40–70	42·1	31·7	28·4	0·62	33
40–80	41·4	33·3	28·5	0·52	34
Total	46·5	33·9	28·7	0·25	37

* Weighted mean calculated using the reciprocal of the variance of each year–site value as the weighting factor.
† Ratio of seed-tuber cost:ware value.

Table 3. *Estimate of the change* (+ *or* −) *in optimum seed-tuber planting density/ha required for each tonne of total yield respectively* > *or* < *the average* (*40·7 t/ha*) *for seed tubers of two weights for the potato variety Record*

Ware grade (mm)	Seed-tuber weight planted (g) 70	105
	Optimum density, P_o	
40–65	+360	−190
40–70	+330	+ 40
40–80	+310	+ 90
	Optimum economic density, P_e 1·5	
40–65	+310	− 60
40–70	+270	+ 70
40–80	+250	+140
	P_e 2·0	
40–65	+300	- 30
40–70	+230	+ 70
40–80	+230	+130

Table 4. *Estimate of yield (t/ha) at optimum seed-tuber density* for the potato variety Record*

Ware grade (mm)	Seed-tuber weight planted (g)				
	35	70	105	S.E.	D.F.
	Optimum density, P_o				
40–65	40·0	34·4	39·8	2·69	28
40–70	40·2	41·8	35·8	2·37	33
40–80	40·4	47·7	34·6	1·83	34
Total	51·9	52·2	56·8	1·46	37
	Optimum economic density P_e 1·5				
40–65	39·9	35·6	35·2	4·29	28
40–70	36·9	44·0	34·0	4·23	33
40–80	38·8	47·9	33·3	2·94	34
Total	50·7	51·0	56·2	3·02	37
	P_e 2·0				
40–65	39·9	36·7	32·7	4·42	28
40–70	37·6	44·6	32·6	4·30	33
40–80	39·6	48·0	32·6	3·08	34
Total	50·0	50·9	55·7	3·31	37

* Weighted mean calculated using the reciprocal of the variance of each year–site value of the optimum seed-tuber planting density as the weighting factor.

higher than at the other sites, so a higher optimum planting density was perhaps to be expected from the evidence above.

Many farmers are interested in knowing whether yields differ according to the seed-tuber size used. Here, the yield of tubers at the optimum seed-tuber planting density was calculated for all tuber size–yield grade–P_o and –P_e combinations (Table 4) using a weighted analysis with the reciprocal of the variance of the optimum planting density as a weight. There was some evidence that yields at the optimum planting density for each tuber size differed. For ware tubers 40–65 mm in diameter, 35 g seed tubers outyielded 70 g and 105 g seed tubers; for ware tubers graded 40–70 mm and 40–80 mm, both 35 g and 70 g seed tubers gave higher yields than 105 g seed tubers, confirming the lower value of large seed-tubers reported by Jarvis (1977).

Influence of numbers of stems/seed tuber and daughter tubers/stem

The distribution of tuber size ultimately depends on the number of tubers produced by the crop, which is determined by the number of daughter tubers formed/stem and the number of stems produced by each seed tuber. The number of stems/seed tuber was 3·0, 3·8 and 5·3 for 35, 70 and 105 g tubers, respectively, averaged over all year–site combinations, whereas, in the original Agricultural Development and Advisory Service trials at Terrington, 36 g tubers produced only 2·2 stems/tuber and 102 g tubers produced only 3·6 stems/tuber. Indeed, if the number of stems/ha at the optimum tuber planting density are calculated using, first, Agricultural Development and Advisory Service recommendations (Ministry of Agriculture, Fisheries and Food 1978) and Terrington numbers of stems/seed tuber (Jarvis & Rogers-Lewis 1974) and, secondly, data from the work described here, the stem densities for the two situations are similar for small and medium seed-tubers but, with large seed-tubers, Agricultural Development and Advisory Service stem densities are > 30000/ha lower (Table 5).

The number of daughter tubers formed/stem was calculated for each treatment and plotted against the number of tubers planted. The number of tubers/stem declined with increasing tuber planting density and so linear and quadratic regression models of tubers/stem on seed-tuber planting density were fitted to the data. The best model was a quadratic relationship fitted separately to each seed-tuber size; this was then used to predict the number of tubers/stem formed at 40000 seed tubers/ha. An arithmetic mean of tubers/stem for each seed-tuber size would have been misleading because each tuber weight was grown at a different mean seed-tuber density and the number of tubers/stem declined with increasing seed-tuber planting density. Consequently, estimating the number of tubers/stem at a constant tuber planting density avoided confounding seed-tuber weight with seed-tuber planting density.

Table 6 shows that the numbers of tubers/stem declined with increasing seed-tuber weight and that there were large differences between years and sites in the number of tubers formed/stem. These differences are likely to have contributed to variation in the optimum tuber planting density from one experiment to another but their cause was not identified here.

Relationships between yield and stem density

Linear, quadratic and square-root regression relationships of total yield and yield in the ware grades 40–65, 40–70, and 40–80 mm on stem density were fitted for each trial. The percentage variance accounted for was, on average, greatest when using a square-root relationship

$$(y = ax^{0{\cdot}5} + bx + c),$$

and for this curve the optimum stem density was calculated for each data set. The optimum stem densities for each of the ware grades on each site and overall (Table 7) were then estimated by the weighted mean of the optima, using the reciprocal of the variance of each optimum (calculated as before using

Table 5. *Comparison between experimental results and Agricultural Development and Advisory Service (ADAS) data for optimum economic seed-tuber densities* (P_e), *number of stems/tuber and stem densities for the potato variety Record*

Our experimental results					ADAS data				
Average seed-tuber weight (g)	P_e 1·5:1 (40–80 mm ware) ($\times 10^3$/ha)	Planting rate (t/ha)	Number of stems/tuber	Stem density ($\times 10^3$/ha)	Average seed-tuber weight (g)	P_e 1·5:1 ($\times 10^3$/ha)*	Planting rate (t/ha)*	Terrington Number of stems/tuber†	Stem density ($\times 10^3$/ha)
105	30·1	3·2	5·31	159·8	102	33·8	3·4	3·64	123·0
70	35·6	2·5	3·80	135·3	71	40·0	2·9	—	—
—	—	—	—	—	64	42·9	2·7	3·02	129·5
35	42·2	1·5	3·01	127·0	36	59·7	2·1	2·15	128·3

* Ministry of Agriculture, Fisheries and Food 1978.
† Jarvis & Rogers-Lewis 1974.

Table 6. *Estimated number of tubers formed/stem at a planting density of 40000 seed tubers/ha for the potato variety Record*

Site	Year	Seed-tuber weight planted (g) 35	70	105	S.E. D.F. = 6
Walkers (Notts.)	1982	—	—	—	—
	1983	8·5	7·9	6·9	0·89
	1984	5·0	4·5	3·9	0·29
United Biscuits (Lincs.)	1982	3·0	—	3·2	0·23
	1983	5·3	5·0	3·9	0·21
	1984	4·3	4·5	3·6	0·49
Smiths (Suffolk)	1982	4·2	—	2·5	0·09
	1983	5·0	3·6	4·2	0·27
	1984	—	—	—	—
Golden Wonder (Cambs.)	1982	1·9	—	1·5	0·18
	1983	3·9	3·5	3·3	0·27
	1984	5·6	5·0	4·8	0·66

Table 7. *Optimum stem densities* ($\times 10^3$/ha)* *for the potato variety Record*

	Site					
Ware grade (mm)	Walkers (Notts.)	United Biscuits (Lincs.)	Smiths (Suffolk)	Golden Wonder (Cambs.)	Overall weighted mean	S.E. D.F. = 121
40–65	113	234	188	196	164	10·8
40–70	124	167	219	164	157	8·8
40–80	145	145	275	159	153	7·5
Total	144	144	301	326	152	9·6

* Weighted mean calculated using the reciprocal of the variance of each year–site value as the weighting factor.

a Taylor series expansion) as a weighting factor. There were differences in the optimum stem density for different ware grade sizes and sites but the overall weighted means did not differ greatly because little account was taken of values with a large variance.

DISCUSSION

In this paper, we first estimated yields in the diameter grades of interest using the technique of Travis (1987). These estimated yields were then regressed on the seed-tuber planting density using a square-root relationship, allowing optimum planting density to be estimated for each combination of seed-tuber size and seed-tuber:ware price ratio. This technique is related to, but distinct from, those used by Pohjonen & Paatela (1976) and Sands & Regel (1983). Pohjonen & Paatela (1976) fitted a Gompertz curve to the cumulative frequency distributions of individual tuber weights. This was then used to estimate economic yield per plot, which was, in turn, related to planting density by a modified rectangular hyperbola, which was used to estimate optimum planting density. Sands & Regel (1983) used a truncated cumulative normal distribution curve to model the relationship between yield and individual tuber weight and estimate yield in weight grades. Both these techniques are therefore primarily concerned with optimization of yield in weight-limited grades. Using the technique of Mackerron *et al.* (1988) for converting diameters to weights provides a possible extension of the published methods to solving our problem, that of maximizing yield in size-limited grades. However, since size-limited grades were measured in our data, we prefer to model yields in size-limited grades directly, rather than introduce additional error by converting to and from weight-limited grades.

Our series of experiments showed that a wide range of seed-tuber planting density optima occurs in practice when trials are performed under a range of conditions. In the past, the possibility of such variation has gone largely unrecognized and the object of the analyses here has been to summarize these optima into commercially usable recommendations. The P_0 values are of interest agronomically because they demonstrate the potential of the crop, yet have no economic input. From a commercial point of view, the P_e values are the only ones relevant because they take economic responses into account. The optimum planting densities that our analyses have produced are lower than those suggested in Agricultural Development and Advisory Service literature and Table 5 shows the published Agricultural Development and Advisory Service recommendations (Ministry of Agriculture, Fisheries and Food 1978) for a ratio of 1·5:1 and our recommendations for approximately similar tuber weights. The data show that our recommended tuber planting densities are *c.* 11, 11 and 29% below the recommendations (Ministry of Agriculture, Fisheries and Food 1978) for large, medium and small seed-tubers, respectively, and even further below the original Terrington recommendations (Anon. 1970). However, since 1970 there has been some evidence that optimum seed-tuber densities were lower than previously thought. Data from the West Midlands (Munro *et al.* 1973) showed that, for all seed-tuber sizes, increases to > 29600 seed tubers/ha gave only small increases in total and ware yield and at Gleadthorpe Experimental Husbandry Farm (Hart 1983) planting densities > 35600 seed tubers/ha gave no yield advantages with 59 and 72 g seed tubers in 2 years.

Differences in recommended tuber planting densities may also result from different analysis techniques. Jarvis & Rogers-Lewis (1976) fitted quadratic curves to their data, while here square-root curves gave a better fit to the data. This might change the interpretation of the data of Jarvis & Rogers-Lewis (1976) because the square-root function gives a curve which rises to a maximum more steeply than the quadratic but declines more slowly at high planting density (Willey & Heath 1969). Thus, the square-root function may give optima that are lower than those from the quadratic curve and, had the Ministry of Agriculture, Fisheries and Food data been analysed using a square-root function, lower optima might have resulted. Jarvis & Rogers-Lewis (1976) also reduced the yields they observed in experiments by 20% in order to allow for lower yields on headlands of commercial crops. Having carried out these trials in commerical crops, we have not reduced the yields in this way because we consider that good commercial yields are now as high as experimental yields. However, had we reduced the yields by 20%, the recommended optimum economic planting densities would have been even lower than those suggested here.

Here we have also produced recommendations of optimum tuber planting densities for different processing grades but there was no evidence that the target densities would change materially. However, for grades showing a wider range of tuber sizes than those considered here, or for grades with a very different mean size, it is anticipated that differences in optimum planting density will occur. For example, the same analysis techniques were applied to the data of Allen & O'Brien (1987) from experiments with Record in Scotland, which had higher planting densities than here, and the results showed that the weighted mean value of P_e 1·5 for tubers graded 25–55 mm was, at the final harvest, 132000 seed tubers/ha for 35 g and 51000 seed tubers/ha for 105 g seed tubers.

One finding of this work which has considerable practical implications is that the optimum planting density for a grower to use is influenced by the total yield expected. Yield in any finite size grade is determined by total yield and the number of tubers produced. If total yield increases, the number of tubers must also increase in order to maintain the same mean tuber size and, in practice, this is achieved by increasing the planting density. The much greater change in density required with 70 g seed tubers than with 105 g seed tubers must be due to the lower numbers of stems, and therefore tubers, produced by each 70 g seed tuber. To achieve any change in the daughter tuber density requires more 70 g than 105 g seed tubers. A logical inference from these data would be that the density of 35 g seed tubers would need to be increased more than that of 70 g seed tubers in order to achieve the same change in stem density. However, it is not possible to make that comparison directly from these data. Thus, where higher total yields than the average here (40·7 t/ha) are produced, the optimum tuber planting density will need to be increased when using 70 g seed tubers. These results can, however, only be applied within the limits explored here, i.e. up to 55 t/ha total yield. They appear to explain why 70 g and 35 g seed tubers at Smiths' and Walkers' sites had a higher optimum planting density than at the other two sites.

Although recommendations for planting densities vary with circumstances, in practice the precision with which these can be carried out is limited on most modern planters. If the minimum spacing adjustment is taken to be 2·5 cm, this is equivalent to a change of *c*. 2000–4000 tubers/ha depending upon row width and target density. Thus, until much more precise mechanical control of tuber spacing can be assured, differences of at least 2000–4000 tubers/ha from the target density are likely to occur, so there is little merit in being concerned with differences of that magnitude in recommendations.

One possible explanation of the differences in optimum tuber planting density between those found here and previous Ministry of Agriculture, Fisheries and Food recommendations is that small seed tubers, in particular, are now healthier than when the original trials were done and so the reductions in optimum planting density are greater for small than for large seed-tubers. The restricted number of suitable data sets available for small seed tubers means that the reliability of our estimates of optimum planting density with small seed-tubers may be limited. However, the number of stems produced by each seed tuber was much greater in the current trials than it was at Terrington (Jarvis & Rogers-Lewis 1974) and this largely explains the observed differences in optimum planting density.

Thomas (1988) emphasized the importance for the control of tuber size of the number of tubers produced/unit area and its components: number of stems/unit area and number of tubers/stem. He found that the former could be predicted with reasonable accuracy in some varieties from seed-tuber weight and physiological age but he did not use the variety Record. Using data from experiments in Scotland with Record reported by Allen & O'Brien (1987), the numbers of stems/tuber produced by 35 g and 105 g seed tubers were calculated to be, on average, 2·6 and 4·4, respectively, which was less than in the English trials reported here but still more than at Terrington. Thus, variation in the number of stems/tuber is one cause of variation in optimum tuber planting density from one experiment to another.

The idea of relating yield to stem density (Bleasdale 1965) is fundamental in understanding the growth of potato crops. It is a useful tool for agronomic interpretation of how different crops have performed, though it has no direct economic relationship unless the cost of seed tubers is directly proportional to the number of stems produced by unit seed-tuber weight. The data here (Table 3) show how the optimum stem density varied according to site, as might be expected but, for practical purposes, the weighted mean data provide a sensible target density which is related quite closely to those suggested from economic interpretations in Table 5. The value of the optimum stem density for total yield, at 152000/ha, is remarkably close to the 150000/ha which Marshall & Taylor (1988) found to be the upper limit of influence of stem density on total yield.

Table 6 shows that the number of tubers/stem varied considerably in the current experiments. However, the data from Scotland of Allen & O'Brien show that the number of tubers/stem, at 40000 seed tubers/ha, calculated as previously described, was 4·5 for 35 g tubers and 3·9 for 105 g tubers, similar to the mean numbers in our experiments. This is an interesting result for crops grown under what would be expected to be cooler, wetter conditions, likely to result in more tubers (Borah & Milthorpe 1959; Thomas 1988; Mackerron & Jefferies 1986). Nevertheless, we need to understand better the causes of variation in number of tubers from one situation to another, because this might lead to better control of the number of tubers and therefore tuber size.

The analyses described here attempt to provide a balanced interpretation of the influence of seed-tuber planting density on graded yields. We have succeeded in reducing a wide spread of data to simple usable recommendations which accord with published data, where comparison is possible. This should provide a sound basis for commercial exploitation and sufficient understanding of the factors influencing the interpretation of the data to allow for change in recommendations as a result of changing agronomic constraints.

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