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THE EFFECT OF VARYING THE NUMBER OF DRILLS PER PLOT AND THE AMOUNT OF REPLICATION ON THE EFFICIENCY OF POTATO YIELD TRIALS

P. D. S. CALIGARI, J. BROWN and C. A. MANHOOD*

Scottish Crop Research Institute, Pentlandfield, Roslin, Midlothian, EH25 9RF, Scotland

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SUMMARY

The effect on yield trials of altering plot size was examined by investigating plots with varying numbers of drills (each with six tubers) planted. No evidence was found of the ware yield per drill being affected by different plot sizes nor any effect attributable to neighbouring drills, whether these were planted with another clone or left unplanted. Increasing the number of drills per plot did increase the precision of the estimated clone means as did, of course, increasing the number of replicates. It appeared, however, that increasing the number of replicates was a more efficient way to increase precision. Thus it was concluded that the most efficient utilization of limited planting space was to grow single drill plots with maximum replication.

INTRODUCTION

In any potato breeding programme it is necessary to carry out trials which contain plots of many genetically different potato clones. One of the most important characters to be assessed in such trials is yield and from the results clones are selected. In common with most breeding programmes, restrictions of space and facilities impose limitations on the amount of material that can be handled. One limiting factor is the land available for such trials. Within such limitations the size of plot and the number of times that each clone is to be replicated has to be decided.

It is well established (FISHER, 1970) that the higher the level of replication, the greater the degree of precision with which any mean can be estimated i.e.

$$\sigma_{(\bar{x})} = \sigma_{(x)}/\sqrt{n}$$

where $\sigma_{(\bar{x})}$ = the standard deviation of the mean, $\sigma_{(x)}$ = the standard deviation of a single observation, and n = the number of replicates. It therefore follows that the theoritically optimal design would be single plant plots with a high degree of replication. This, however, ignores the possible agricultural or biological differences that are introduced by growing single plants as opposed to plots which contain more than one plant (as noted by ENGLAND, 1977). For instance, if single plants are grown they

* Present address: North East London Polytechnic, Romford Road, London, E15, UK.

have to be spaced sufficiently to allow tubers produced in each plot to be harvested separately, which is of course, a wider spacing than would be used in normal agricultural practice and could affect tuber number, size, etc (ALLEN, 1978). Also, the question arises as to what effects competition will have, since when grown commercially whole fields will be planted with a single clone. This means that only intra-genotypic effects will be present whereas with the randomisation of single plants, inter-genotypic effects also come into account (CALIGARI, 1980; MATHER et al., 1982; SPITTERS, 1983). Although there is little information about the extent of such effects in potatoes most potato breeding programmes rely on plots of more than a single plant for yield trials, one reason for this being that larger plots allow mechanical harvesting.

Accepting the desirability of plots on general grounds, the question still remains open as to what size of plot should be used and with what level of replication. In this paper we examine the question of whether, with a constant plot length, increasing the number of tubers per plot by increasing the number of drills (i.e. rows) affects the results of yield analysis. A secondary aspect which is examined is how in actual practice the number of replicates affects the precision of the observed means.

MATERIALS AND METHODS

In the trial, six potato clones (genotypes) were examined, two of these being commercially grown cultivars, Pentland Crown and Maris Piper, while the remaining four were unnamed clones from the Commercial Potato Breeding Programme at the Scottish Crop Research Institute, Pentlandfield. The six clones were chosen to represent the range of yields and tuber sizes occurring in the yield trials normally grown by the above breeding department. All six clones were planted in plots of four different sizes. The plots were of uniform length with six tubers planted 45 cm apart in each drill. Plot sizes were varied by altering the number of consecutive drills planted with the same clone. The drills were drawn with 75 cm between centres. The four plot sizes used were one, two, four and eight drills. The area of land allocated to the experiment was divided into two blocks of equal size. Each of the six genotypes was represented by 2 single-drill plots, 2 two-drill plots, 1 four-drill plot and 1 eight-drill plot in each block. Each block consisted of 14 plots down and 8 planted drills across. The two drills immediately adjacent to the experiment were left unplanted. A lattice structure was then imposed on the two blocks, dividing each into 28 sub-units of 1 plot by 4 drills. The sub-units were randomly allocated to contain either single-, two-, four- or eight-drill plots, with the constraint that if a sub-unit was allocated as having half of an eight-drill plot, the adjacent sub-unit contained the same genotype, thus giving an eight-drill plot. If a sub-unit was allocated to be a four-drill plot, the whole sub-unit contained a common genotype. If a sub-unit was allocated to two-drill plots, two genotypes were grown adjacent to each other, and if the sub-unit was allocated to single-drill plots, four different genotypes were grown, one per drill. This accounted for 27 out of the 28 sub-units in each block, the spare sub-unit was planted as a discard plot. Within each plot size the genotypes were allocated positions at random.

Each drill of the trial was harvested separately with a mechanical harvester. The produce from each drill was graded into the tuber size fractions of less than 40 mm (chats), 40 to 80 mm (ware) and greater than 80 mm (outsize), and the weight of each

Table 1. The analysis of variance for ware yield (kg per drill) from two replicates in four different plot sizes.

Source	df	M.S.	V.R.	P
Genotypes (G)	5	55.65	11.10	<0.1%
Plot size (P)	3	7.39	1.47	N.S.
G × P	15	3.29	0.66	N.S.
Error	24	5.015		

size fraction was recorded in kg. Although all three size grades are of interest the most important is obviously the ware fraction and this is the one mainly considered in this paper.

RESULTS AND ANALYSES

The analysis of ware yield was carried out over the four plot sizes in two blocks (for the one and two drill plots, two of the possible four replicates were taken at random). The basic datum was mean yield of one drill averaged over all the drills in a plot. Results are given in Table 1, from which it can be seen that the only significant item is the one ascribed to genotypes. There is no evidence of any effect associated with the differing plot sizes or their interaction with genotypes. Thus, the clones not only remain constant in their rankings, but also their actual ware yields per drill remain constant over all the plot sizes.

The above analysis may not however represent the complete picture for the effect of the varying plot sizes since the analysis is based on the averages over the drills in a plot. The eight-drill plots had one drill (outer) at each end of the plot which were adjacent to an empty drill and the remaining drills have their own genotype planted in the drills on either side of them. The four-drill plots, on the other hand, have three types of drill, one which is an outside drill and hence has a blank drill on one side, two drills (inners) which have the same genotype in the drills on either side and one drill (mixed) which has its own genotype on one side but a different genotype in the drill on the other side. These different types of drills may produce different yields, but with their effects balanced and therefore masked by taking the averages.

The effect of differing drill types on ware yield can be estimated using orthogonal comparisons, as can the sums of squares accounted for. Such comparisons have been applied to the data from the four- and eight- drill plots and the analyses are presented in Table 2. For the eight-drill plots the comparison was simply outside versus inside drills while for the four-drill plots the three comparisons were: 1) outer versus the one inner one, 2) the other inner versus the mixed one and 3) the remainder. In this table the basic datum was the yield of a single drill. As can be seen none of the items for the character ware was significant for either the four- or eight- drill plots. Thus there was no evidence of any difference between outer and inner drills, nor does competition from adjacent drills appear to have any effect. To investigate this further two other characters, yield of chats and of outsize tubers were investigated. As is shown in Table 2, only two effects were found to be significant, and these were only so at

Table 2. Analysis of variance for four and eight drill plots for components of yield (kg per drill) to compare different types of drills.

	df	Ware M.S.	Chats M.S.	Outsize M.S.
4 Drill plots				
Drills	3	0.74	0.03	3.27*
outer *v* inner (1)	1	0.22	0.01	3.56*
inner (2) *v* mixed	1	0.13	0.06	2.94
remainder	1	1.87	0.02	3.31
Genotypes (G)	5	81.67***	0.20**	6.75***
Drills × Genotypes	15	1.91	0.04	0.71
outer *v* inner (1) × G	5	1.44	0.02	0.18
inner (2) *v* mix × G	5	2.50	0.07	0.46
remainder × G	5	1.79	0.12*	1.49
Error	23	1.691	0.045	0.803
8 Drill plots				
Drills	7	4.73	0.09	0.83
outer *v* inner	1	0.06	0.02	3.71
remainder	6	5.42	0.10	0.35
Genotypes (G)	5	132.78***	0.44***	21.95***
Drills × Genotypes	35	3.56	0.05	1.01
outer *v* inner × G	5	6.51	0.05	2.18
remainder × G	30	3.17	0.05	0.81
Error	47	3.767	0.065	1.233

* indicates 0.01 < P < 0.05; **0.001 < P < 0.01; *** P < 0.001.

the 5% probability level. One of these, that for chats, was the interaction of genotypes with remainder. Since the partition of the drills effect did not show this item to be significant and it is, in any case, a three-way interaction it cannot be viewed as providing strong evidence of effects such as are being tested. The other significant item, that for the character yield of outsize, is only significant at the 4.6% level and must be regarded with considerable caution as it is expected that 1 in 20 such tests will give significance at this level of probability merely by chance, and 48 such tests have been carried out here.

The effect on the standard deviation of the mean of increasing the number of replicates, while the number of drills is kept constant, can be seen from Table 3. Here the standard deviations of the means ($\sqrt{s_e^2/n}$) of ware yield of any clone are presented for single and two drill plots. The error variances of such estimates are known to be large, but for both plot types the standard deviation decreases with increasing replication as expected, except between the two replicates and three replicates in the two drill plots. This could reasonably be attributed to error. The expected decrease in the standard deviation of the mean between two and four replicates is of course $1/\sqrt{2} = 0.707$ (FISHER, 1970). The observed decrease is less than this for the one drill plots and greater than this for the two drill plots, thus overall giving no indication of any departure from expectation.

Since it has been shown that increasing plot size by additional drills does not have any detectable effect on a per drill basis, it follows that such an addition will simply

Table 3. Standard deviation of the mean ware yield (kg per drill) of any clone from the single and two drill plots with two, three and four replicates.

Number of replicates	1 Drill plots	2 Drill plots
2	0.98	1.04
3	0.89	1.07
4	0.81	0.56

Table 4. Standard deviations of the mean ware yield (kg per drill) of any clone from two replicates of each of the four plot sizes.

Plot size	$s.d._{(\bar{x})}$
1 drill	0.98
2 drill	1.04
4 drill	0.74
8 drill	0.65

Table 5. Standard deviations of the mean ware yield (kg per drill) of any clone with different partitions of four and eight drills.

Number of drills	Partition	$s.d._{(x)}$
4	1 drill × 4 reps.	0.81
	2 drills × 2 reps.	1.04
8	2 drills × 4 reps.	0.56
	4 drills × 2 reps.	0.74

increase the accuracy of estimation of the plot means, in a way analogous to increasing the number of replicates. The estimates of the standard deviations of the clone means are given in Table 4. The two replicates in the single and two drill plots were again taken at random from the four that were grown. Again there is a trend of decreasing standard deviation with increasing number of drills, except between single drills and two drills where the standard deviation increased. From the expected relationship between the four standard deviations, it would appear that the one for the single drill plots has been underestimated.

DISCUSSION AND CONCLUSIONS

It appeared that the precision of estimating the mean yield per drill can be increased by increasing the number of drills of each clone that is included in the trial irrespective of how these are partitioned. This could be examined directly in this experiment, where equal drill numbers are grown but differently partitioned (see Table 5). As can be seen the partition with the greatest number of replicates has a standard deviation less than its counterpart, although in both cases the number of drills is the same.

From the experiment described it appeared that differences in the number of drills per se in a plot does not have any effect on ware yield per drill. No evidence of differences was found between drills whether their adjacent drill was empty, or contained the same genotype or a different genotype. Since there are no such effects and, for a fixed total number of drills, increasing replication leads to greater precision, it seems that the most efficient design for potato yield trials is a single drill with as many replicates grown as can be handled.

The present results were obtained from one experiment in one year and cannot therefore be taken as providing a definitive answer for all such trials. They do, however, show that the generally accepted opinion of 'the larger the plot the better' because 'bigger plots reflect more accurately agricultural conditions' is not necessarily right. The assumptions underlying such opinion, for instance concerning intra- and inter-genotypic competition, can easily be tested as has been shown in this paper. Clearly there is a need to test such theoretical assumptions more widely on an empirical basis.

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