COMPARISON OF SYSTEMATIC SPACING AND RANDOMISED BLOCK DESIGNS IN A MAIZE POPULATION STUDY

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ABSTRACT

A trial conducted in Waikato, New Zealand, comparing systematic radial and orthodox square spacing of maize grown for grain gave these results.

The regression equations of grain yield per unit area on logarithm of population density were not significantly different though each showed highly significant quadratic and linear terms. There was a significantly better fit on the radial blocks than on the necessarily more widely spaced orthodox plots.

Adequate definition of the population corresponding to maximum grain yield was quite acceptably determined by either style of square spacing, although the calculated maxima differed by 12%.

Examination of individual straight row yields adjacent to a large population jump showed that the interface effect seemed, on square spacing, to be negligible beyond about 1.2 metres from the interface. If such a result can be translated to trials planted in 76 cm rows it implies that one guard row is not quite sufficient to prevent between-plot interference where large population jumps, as in randomised block population trials, are involved.

INTRODUCTION

In an earlier paper to the society Douglas and Dyson (1972) described a trial planted in 1970 designed to investigate the efficacy of one of Nelder's (1962) systematic radial spacing designs in maize. In the discussion following the presentation of the paper two criticisms emerged.

1. The rate of increase of grain yield per unit area with population was, at lower populations (40000 to 80000 plants per ha), markedly less than had been generally achieved from conventional randomised block trials (1).
2. Because of the substantial curvature of the higher population arcs, inflated yields would result from the plant's being in a falsely open situation compared with a straight row at the 'same' density.

In addition the authors had pointed out the inadequacy of the guard rows used, particularly at high populations. Also, because the number of plants was constant in each arc, the yields at higher populations, with their decreasing area per arc, could be expected to be more variable and should be weighted accordingly in any strict analysis.

As a result a further trial was planned in an attempt to improve the design of a systematic spacing trial so that it would be at least as sound as a randomised block whilst retaining the advantages of the systematic design, namely the intensive examination of a wide range of plant densities on a relatively small area of land.

Trials laid down in 1971 and 1972 failed due to drought.

METHOD

The 1973 trial was hand planted using the hybrid PX 610 on an Otorohanga silt loam out of pasture at Waikeria on 31 October. All planting was on the square, strictly for the orthodox plots and within acceptable limits for the radial blocks with two seeds planted at each position, later being thinned to one. Where no plants grew transplants were made.

The comparison of the randomised block and systematic layout consisted of:-

(a) Two systematically-spaced semicircular blocks of radius 8.2 m facing in opposite directions. Ratio of radii of successive arcs 1.08 and of successive populations $(1.08)^2 = 1.166$. Designated SA (replicate A) and SB (replicate B).

(b) Two replicates of orthodox rectangular plots 12 m long at five populations, replicate A progressing systematically from low (40 000/ha) to high (160 000/ha) population in five steps and replicate B demonstrating large population jumps in pseudo random fashion.

(c) One systematically-spaced high density radial block of less curvature, at the same population level, than (a). Ratio of radii of successive arcs 1.039, of successive populations 1.08. Designated C.

(d) A narrow very high density rectangular plot as a transition from the extremely high density side of block C to 160 000 plants per ha.

(e) A very low density rectangular plot which provided an extremely large population jump from its 22 500 plants per ha to the adjacent 160 000 per ha.

A band of guard plants at least 3 m wide, planted at 90 000 per ha, surrounded the trial.

The order of the populations along the trial site was: SA, 40 000, 62 500, 90 000, 122 500, 160 000, 62 500, 122 500, 40 000, 90 000, C, 160 000, 22 500, SB. The population jumps between SA and 40 000, 90 000 and C, 22 500 and SB were trivial.

Each radius in (a) was continued via systematic spacing to complete the circumscribing rectangle; each arc on meeting the base diameter was continued in a straight line for two metres to form guard rows at the same spacing. The central part of the semicircular area was planted up at a population about that of the inside arc (1.90 m radius, 470 000 plants per ha). The whole planted area incorporating each semicircular arc was thus a rectangle of 16.4 m x 10.2 m. There were 42 plants in each of 18 arcs in each semicircle for reliable estimates of yield, the two outside and three inside arcs being disregarded as guard rows.

The width of the replicate A orthodox plots was 4 metres except for 160 000 per ha which was, with the replicate B plots, 6 metres. The purpose of this was to ensure that a reliable yield estimate would be obtained from the central 2 m portion of each plot representing exactly 4, 5, 6, 7 and 8 rows of the 50, 40, 33.33, 28.57 and 25 cm spacings respectively. The spacing of the 22 500 plot was 66.67 cm, to give 3 rows per 2 metres. A one metre band was removed from each end of the orthodox plots at harvest.

The population ranges in the radial blocks from which viable yield estimates were obtained were: blocks SA and

SB 30 000 to 300 000 plants/ha; block C 130 000 to 450 000 plants/ha; and all the orthodox plots, i.e. 22 500 to 160 000.

Cobs were handpicked in early May, each arc or row being harvested separately, and whole plant data obtained from plots SA and SB. Some bird and rat damage was apparent and the lowest density arc of block SA was discarded. Elsewhere, damaged cobs were replaced by undamaged cobs of similar size from guard rows. The largest proportion of replaced cobs in a row was 22%.

RESULTS

Figure 1 shows DM grain yields/ha from the central 2 m width, i.e. 20 m^2, of each of the orthodox plots and the yields from approximately 20 m^2 bands of the radial blocks SA and SB combined obtained by an increasing amalgamation of arcs towards the higher populations. The population density is presented on a logarithmic scale.

The linear term (i.e. coefficient of X) in each equation was significant, for Y_1 at the 1% level and for Y_2 at the 5% level, but they were not significantly different from each other. The same is true of the quadratic terms, the significance levels being 0.1% and 1% respectively.

To examine the effect on grain yields of markedly different populations in adjacent plots the grain yields of individual rows, expressed as yields relative to the central portion of the plot mean = 100, abutting a population jump are given in Table 1.

A quadratic regression fitted to the 'lower population' data gives a very slow approach towards 100, reaching 95 at 119 cm and 96 at 130 cm. The fit is much more satisfactory with the 'higher population' data giving a value of 105 at 104 cm and 100 at 129 cm. Clearly the determination of "where the effect ceases" is rather subjective. A distance of 120 cm corresponds to a mean yield error of less than 4%.

TABLE 1 Relative grain yields of individual ros (plot mean = 100)

Lower Population							Higher population						
Population per ha	Plot centre mean	5th row	4th row	3rd row	2nd row	end row	end row	2nd row	3rd row	4th row	5th row	Plot centre mean	Population per ha
22 500	4080	99	105	93	97	91	143	147	103	96	93	6080	160 000
40 000	6570	112	96	90	100	90	125	126	125	119	108	6880	90 000
40 000	6570	86	87	103	89	65	129	118	115	106	85	6630	112 500
62 500	7920	102	88	95	81	76	141	102	114	96	95	6630	112 500
62 500	7920	97	105	97	86	83	117	131	112	105	104	7420	160 000
Mean	6610	99	96	96	91	81	131	125	114	104	97	6730	
Standard error of mean : 3.4										5.1			
Mean distance of row from interface (cm)		217	167	118	69	19	19	47	76	104	132		

The device of combining data from blocks SA and SB ensured that the aggregation of yields from high density arcs spanned a lesser number of arcs compared with aggregating within the two blocks separately. A fertility gradient present in the orthodox plots was corrected for in place of a simple replicate effect. Thus replicate differences are totally obscured in the presentation of yield data in fig. 1. A significantly (5% level) higher proportion of variation was removed in the quadratic regression fitted to the radial blocks than in that fitted to the orthodox blocks.

The equations were:

Radial spacing: $Y_1 = 4011 + 1003X - 54.1X^2$, $R^2 = 0.965$ ***cv = 3.8%

Orthodox blocks: $Y_2 = 4184 + 828X - 49.0X^2$, $R^2 = 0.810$ ** cv = 7.8%

where Y = grain yield, DM kg/ha

X = arc number increasing with population density,

i.e. effectively log population with X=O corresponding to a population of 21 600 plants/ha, with an increase of 1 in X multiplying the population density by 1.166.

Total plant yield per hectare, when plotted against log population in figure 2, conformed to the conventional asymptotic curve. Total plant yield levelled off at a population in the vicinity of that giving maximum grain yield.

DISCUSSION

The significantly better fit of the grain yield-population regression in the radial blocks is attributed to the consistency between adjacent (whether or not aggregated) arcs when contrasted with differences between plots which are several metres apart. The non-independence of the yields of adjacent plots in crops is a moot point and the controversy between Fisher, Gosset and Hudson in the 1930's testifies to the delicate nature of the issues involved. Nelder (1962) defends the systematic arrangement of rows provided care is taken to avoid fertility trends being confounded with changes in population.

The very high R^2 value for the radial spacing curve

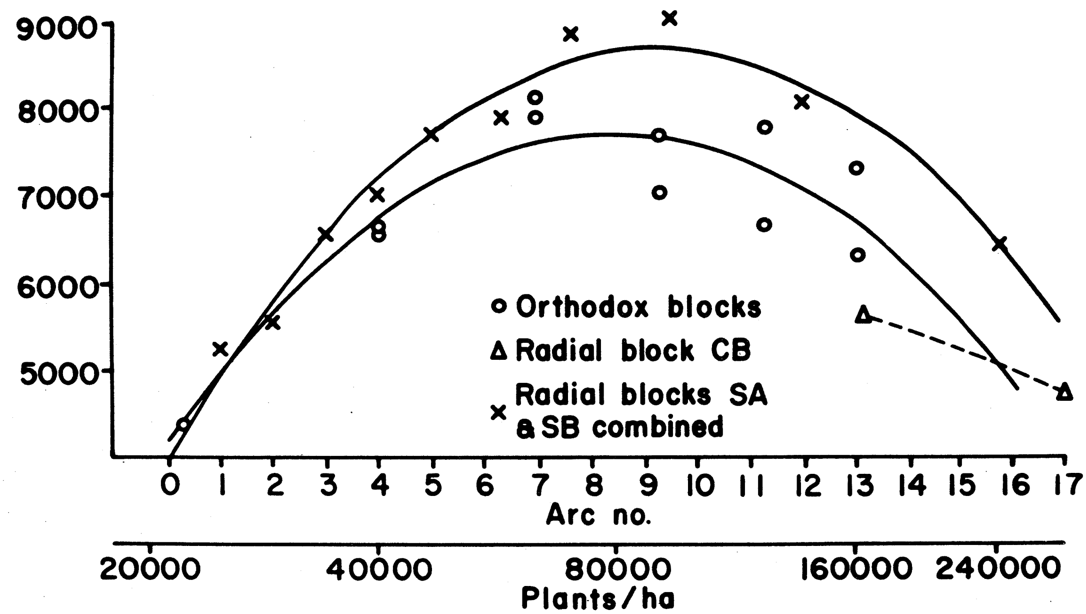

Figure 1. Grain yield, DM kg/ha

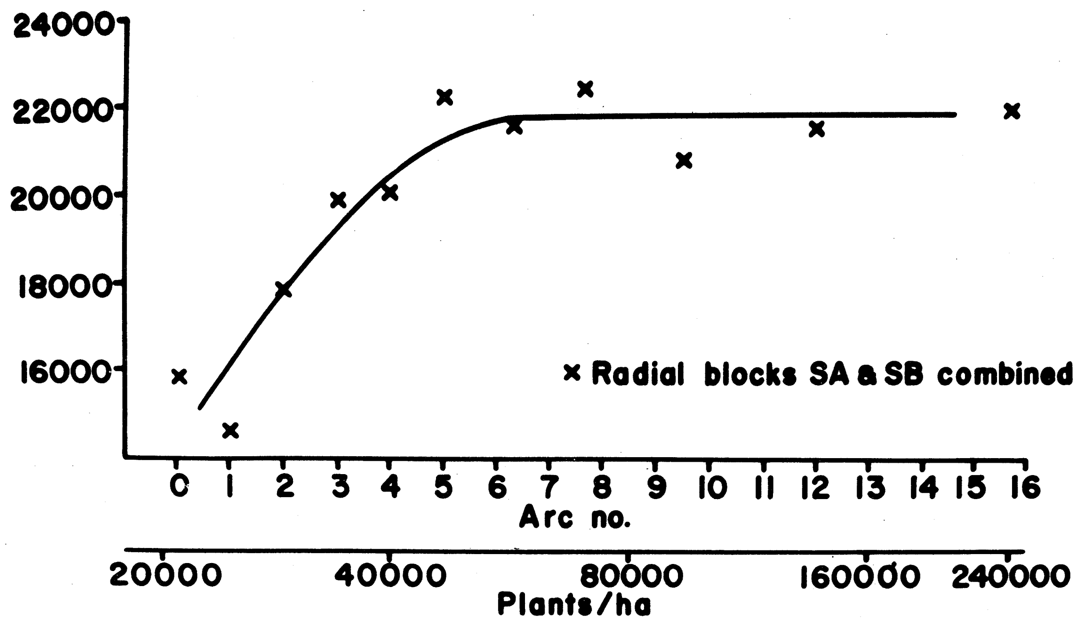

Figure 2. Total plant yield, DM kg/ha

justifies the quadratic form's appropriateness to describe the maize grain yield on log population regression so that the lower R^2 value on the orthodox blocks is regarded as random variation rather than the result of attempting to fit the wrong kind of curve.

That the two regressions in figure 1 are not significantly different in such relatively insensitive circumstances does not affirm that they are really the same. The second criticism of the introduction suggests that the curves should coincide at lower populations and that the radial spacing yields would be biased upwards at higher populations. This did in fact happen though not in the way anticipated. The linear terms would have been expected to be similar and the quadratic terms different with the orthodox spacing curve showing a more rapid decline. That the greatest difference found was between the linear terms corresponds to the curves parting company at low populations where the arc curvature effect would be considered minimal. An explanation — other than random effects — is not evident. The limited information provided by radial block C, with curvature intermediate between the Y_1 and Y_2 curves, would tend to support the criticism of too slow a fall-off of yield at high populations.

Let it be noted, however, that both Y_1 and Y_2 yield-population relationships determine the population density which gives within 1% of maximum grain yield to quite acceptable agreement. The ranges were 74 000 to 109 000 for the systematic blocks and 65 000 to 96 000 for the orthodox plots. However the respective calculated maxima, 8670 and 7680 DM kg/ha were somewhat different. Probably block SB was sited in an advantageous position, being at the foot of a slope.

The other criticism referred to the relative flatness of the previous radial spacing yield response curve, Douglas and Dyson (1972), at low populations. This criticism was not supported by the present trial by virtue of the difference in linear terms in the regressions being (non-significantly) in the opposite direction. That results from randomised block trials may have been biased is not ruled out by the finding that for square spacing the effect of a large population jump, as can occur in population trials whose plots for different populations are positioned at random, would appear to be manifest at up to about 1.2 metres into the plot from the interface. If this result were to hold for 76 cm rows then one guard row between the yield rows and the interface would not be sufficient to remove all bias, and such bias would steepen the yield population curve at the lower populations, since yields of low population plots would be depressed by adjacent higher population plots and yields in high population plots would be correspondingly inflated. In this trial plots were wide enough to avoid this bias, in retrospect.

Lodging occurred in a well-defind population range. There was virtually no lodging below 100 000 plants/ha and little lodging above 200 000 but quite extensive (up to 70%) lodging in between. This critical range corresponds to almost all plants bearing cobs but being very thin in the stalk. At 200 000 plants/ha, the proportion bearing cobs was about 80% and at 300 000 between 55 and 60%. However above 200 000/ha many cobs were little more than notional, though some were quite well formed and at the highest populations, at about 400 000/ha, the grain yield was dominated by the contributions of as few as 10% of the plants. Data were not recorded on this point but the evidence was clear — relative between-plant variation in terms of grain yield increases with population.

The place of a non-randomised block design with populations proceeding systematically from high to low to high and vice versa is worth serious consideration. The use of the two end rows of precisely drilled adjacent plots could give yield data on an intermediate population so that there would, in fact, be very few guard rows in the body of the trial and, for example, data on seven population levels could be obtained from four sown populations. Even if these 'extra' populations are not feasible the systematic arrangement of the plots would lead to less guard rows needed and better fit obtained to the yield-population regression than with randomised blocks. The associated statistical tests are much closer to those for randomised blocks than the tests which were forced on the radial systematic design data of this trial, which relied solely on lack of fit, there being no contributions from differences between replicates.

A post-priori hypothesis suggested by Table 1 is only just rejected at the 5% level. This is that the yield benefit expressed in the higher population rows more than offsets the yield depression in the lower population rows. If this is a real effect it would suggest that yields might be raised by interspersing drill runs at a lower population with drill runs at a higher population. Whether lodging would be more or less of a problem would seem to depend on the direction of any prevalent wind tendencies.

CONCLUSION

The systematic radial spacing designs put forward by Nelder (1962) are, by comparison with orthodox randomised block design, more economical in area, more efficient in terms of the proportion of plants giving viable yield data and more precise. They may, however, give not quite the same answer but the difference, if any, in maize trials is deemed unimportant. Care must be taken with the choice of block layout to counter any lack of site uniformity and planting must, of course, be by hand. If a reliable precision planter is available the straight row analogue of these radial designs should provide good results though the problem of providing adequate guard plants at high populations, successfully overcome with the radial designs, will give a decrease in efficiency. The use of machines at planting and harvesting should however more than make up for this. Where it is anticipated that a full stand may be difficult to achieve, a more robust orthodox trial is recommended.

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