THE USE OF A SYSTEMATIC SPACING DESIGN IN PLANT POPULATION STUDIES

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SUMMARY

A systematic spacing trial using a design formulated by Nelder (1962) was conducted on a maize crop in the Waikato. Ten plant populations in the range from 47,000 to 222,000 plants per hectare were planted "on the square" by transplanting seedlings or dibbling in seeds. The latter method was more efficient.

The total dry matter curve was asymptotic but the grain yield was maximized at 90,000 plants per hectare although the curve was flat topped with little change from 75,000 to 110,000 plants per hectare.

Insufficient guard rows affected the trial particularly at the higher populations and restricted the evaluation of various postulated yield-population equations.

INTRODUCTION

With the use of selective herbicides it is now possible to control weeds in many crops without cultivation. As a consequence of this crops no longer need to be planted at row spacings governed by the availability of machinery for inter-row cultivation. Thus different patterns of plant arrangement and ranges of plant densities within these patterns can be considered for various crops.

Unfortunately, the task of varying large numbers of patterns and densities is formidable when considered in terms of conventional randomized block designs. One way to overcome this problem is the use of the systematic designs formulated by Nelder (1962). Originally Bleasdale (1960) postulated that:

"If crops were planted in rows which radiated from a point, with the distance between plants along the radii approximately equal to the distance between radii at that point then a large range of plant densities could be grown in a small area."

Using this theory Nelder (1962) developed a series of designs for spacing experiments.

The type 1a design of Nelder is based on a grid made by the points of intersection of concentric circles and equally spaced radii of the circles (Fig. 1). Plant populations are varied by the spacing of the plants on each radius. The ratio of between radii and within radii spacings (rectangularity, R) can be changed to study different patterns of plant arrangement. When the ratio is kept at 1, "on the square" planting is obtained.

There is some deviation from rectangularity inherent in the design caused by divergence of the radii. This is limited by restricting the size of the constant α which governs the rate of change of spacing along the radii. In particular, if deviations from squareness are to be kept below 5%, Nelder (1962) has shown that α should not exceed 1.11.

To calculate α, decisions have to be made on the number (N) of densities (arcs) which it is intended to use as well as the desirable areas to give individual plants at the least (A_N) and greatest (A_1) densities.

The formula $\frac{A_N}{A_1} = \alpha^{2N-2}$ is used.

The angle in radians (θ) between successive radii in the design is dependent on the rectangularity (R) and the α value. It is calculated from the formula:

$$\theta = R(\alpha - 1)/\sqrt{\alpha}$$

The advantages of a systematic design over an orthodox randomized design in spacing trials can be listed as:

(1) It spans a wide range of populations comprehensively.

(2) It occupies less area.

(3) Fewer guard rows planted to treatment specifications are needed.

The disadvantages are:

(1) It is rather difficult to incorporate fertiliser treatments and/or different varieties. If these are required the systematic design becomes analogous to the split plot design with populations the subplot factor.

(2) The trial must be planted and harvested by hand.

(3) It is desirable to obtain complete plant establishment as each plant affects the performance of plants at adjacent population levels.

(4) The area per "plot" is very much smaller at high plant populations because the same number of plants is harvested at each population density. Therefore the within variability can be expected to increase somewhat with population.

METHOD

The population range chosen for the trial laid down to evaluate the technique on maize was 47,000 to 222,000 plants per hectare spanned by 10 populations using an α value of 1.08. This corresponds to a 17% increase in plant population at each step. The rectangularity was kept at 1 with the angle between successive radii 0.0770 radians or 4.41°.

Once the decision on the populations to be studied had been made the laying down of the trial was simple. By use of a tape measure fixed at one end twenty radii were marked out with 52.5 cm between radii at 6.82 metres from the centre. Full circles were not sown but only 90° sectors (20 radii) which were orientated in different directions to give a balanced design. These quadrants were used as replicates. Four of the radii were considered as guard rows giving 16 plants at each population in each replicate.

Seeds or plants were sown at exact distances along each radii of 2.51, 2.71, 2.92, 3.16, 3.41, 3.68, 3.98, 4.30, 4.64, 5.01, 5.41, 5.84, 6.31 and 6.82 metres from the centre. The twc inside and two outside arcs were planned as guard rows giving 10 populations.

Two systems of planting were compared for their effectiveness in overcoming the problems of germination failure to which the design is susceptible. Four quadrants were sown with plants established in peat pots and transplanted and two quadrants were sown with two seeds dibbled in at each centre and later thinned to one plant. If a plant did not establish a transplant was made from replacement plots sown at the same time.

Seeds were sown into peat pots on 28 October 1970 and transplanted on 17 November. Dibbled seed was sown on 18 November. The trial was hand-weeded throughout and harvested on 21 May 1971.

Cobs were separated from the plants, the grain threshed and the grain and cores over dried. Two typical plants from each arc were chopped up and oven dried to estimate the total dry matter yields.

RESULTS

The trial design proved a useful technique to define yield relationships over a wide range of plant populations. The results of the grain and total dry matter yields are shown in Fig. 2 and yields per plant in Fig. 3.

Analysis showed the grain yield data fitted (significant at 5%) a quadratic regression.

Y (kg/ha) = $8520 + 445P - 24.6\ P^2$ where P is plants/sq. m.

The calculated maximum yield was Y max = 10,600 kg/ha at 90,000 plants/ha. However, yields within one percent of Y max were obtained for the plant population range 75,000 to 110,000 plants/ha (i.e. 37 to 30 cm plant spacing). This corresponds to a per plant grain dry matter production of 140 to 100 g (i.e. cob weights of about 300 to 200 g).

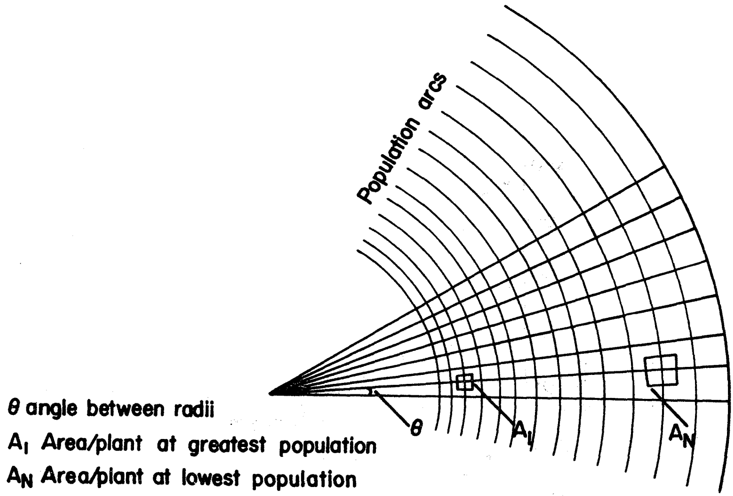

FIG. 1. Layout of a Systematic Spacing Design Experiment.

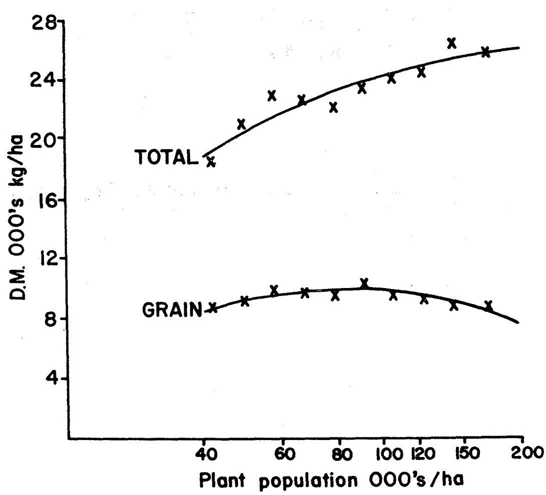

FIG. 2. Grain and Total Dry Matter Yields 000 kg/ha.

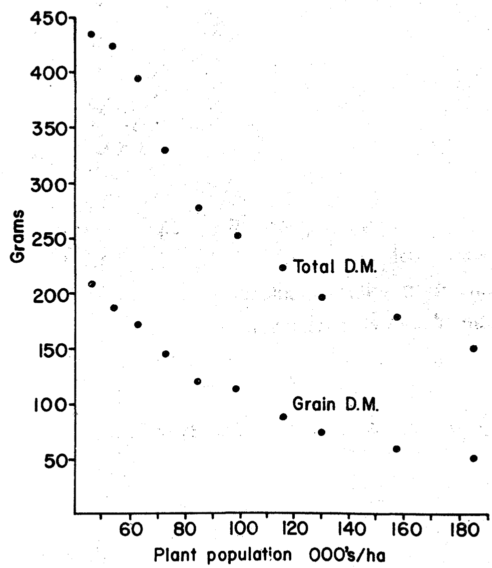

FIG. 3. Single Plant Grain and Total Dry Matter Yields g/plant.

The total crop yield-plant population relationship conformed to that described in the literature (Holliday 1960) although the range of populations did not extend high enough to reach the yield asymptote.

While grain production on an area basis showed little change throughout the population range, on a per plant basis the yield dropped steeply. Yield per plant was halved at the plant population of 120,000 plants/ha compared with that of 50,000 plants/ha.

DISCUSSION

Dibbling in two seeds per grid position and later thinning to one plant proved a much quicker and more efficient system to establish the trial than transplanting pot grown seedlings.

The individual replicates were insufficiently protected from the prevailing south-west winds. Orientation of the quadrants was varied in order that an unbiased result would be obtained but individual replicates gave substantially different results with the wind adversely affecting two replicates relatively exposed on the west side. When these two replicates were excluded from the analysis the results showed a similar pattern but with the grain and total plant yields being 5% and 7% higher, respectively.

Not only were there insufficient guard rows around the trial as a whole but also within the individual replicates themselves. The under-estimation of the need for guard plants particularly in the centre of each quadrant meant the data obtained from the highest populations were unreliable. This restricted the range of populations compared and limited the evaluation of various postulated yield-population equations.

For total plant dry matter production the expected form is towards an asymptotic maximum as the population increases (Holliday 1960). The result from this trial was of the expected form although there was little firm evidence to indicate that the curve was flattening out at the higher populations. The lack of sufficient guard rows is thought to have affected the relationship at the highest populations. The sampling for plant less cob dry matter was also not entirely satisfactory and contributed to the variation recorded in total plant D.M. No smoothing of the dry matter proportion data was attempted, though this would improve the form of the upper curve in Fig. 2.

The parabolic relationship between grain and plant population was also defined with a maximum at about 90,000 plants per hectare. The production curve was rather flat topped with only small decreases in yield at both sides of the optimum. In 76 cm spaced rows the effect on grain yield of plant population increases has been largely linear except in droughty situations in the range from 40,000 to 80,000 plants per hectare (Douglas et al 1971).

Lodging appeared to be greater above 70,000 plants per hectare and barren plants were more prevalent above 100,000 plants per hectare, with the proportion of the total plant dry matter production which was in the grain decreasing from that point.

This systematic designed trial was conducted on an area of 220 square metres although with adequate guard rows plants on the perimeter of the trial an area of perhaps 400 square metres would be more realistic. This should be compared with the area required for a randomized block design of say six treatments and four replicates with individual plots of 3 metres x 10 metres which would give a total area of 720 square metres but again adequate guard rows would increase this to about 1100 square metres. In such a trial, half of the plants would be in the guard rows.

CONCLUSIONS

The systematic spacing trial is relatively simple to conduct and provided critical factors such as complete plant establishment and adequate guard rows are taken care of there appear few reasons why reliable information cannot be obtained.

The wide range of plant populations which can be included in a trial is a distinct advantage in defining the response of a crop to population changes. The extreme populations studied assist in the determination of production curves and give a more complete picture of a crop's reaction to its environment.

Particularly for row crops such as maize, soyabeans, sunflowers and brassicas, which have had little plant population research conducted on them in New Zealand, the use of systematic designs provide a suitable way to define the general area of optimum population. By varying the rectangularity of the systematic designs it would also enable the experimenter to evaluate whether or not improvements in crop production could be obtained by changing the pattern of planting away from the conventional methods.

From this initial work systematic spacing trials have a valuable role to play in the definition of factors which affect crop yields.

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