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POPULATION RESPONSES OF MAIZE HYBRIDS IN THE MANAWATU

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ABSTRACT

The maize hybrids, Pioneer 3901, PX49 and XL35 were grown in the Manawatu during the 1983-84 and 1984-85 seasons. In each season, these hybrids were grown at five plant populations, 35555, 53333, 71111, 88888 and 106666 plants/hectare in a split-plot design with four replications. In the 1981-82 season, two of the hybrids, Pioneer 3901 and XL35, were grown in a similar experiment, but with two replications. In all trials, grain yield, grain moisture, stalk lodging and root lodging were measured.

For all hybrids in all seasons, grain yield increased with increasing plant population to 88888 plants/ha. For PX49 and XL35 in the 1983-84 season, and for all hybrids in the 1984-85 season, even higher yields were obtained at 106666 plants/ha. However, lodging increased with population and grain moisture was higher at 106666 plants/ha than at 88888 plants/ha.

The logarithm of grain yield/plant was linearly related to population which allowed optimum population and maximum yield to be estimated precisely. Estimates of optimum population were lower than the populations which produced the highest yields, but for the 1981-82 and 1983-84 seasons, the size of the bias was considered too small to affect practical recommendations.

Considering all factors, including seed cost, the seeding rate required to produce the highest economic return from Pioneer 3901 is probably close to the recommended rate of 85000 seeds/ha on high fertility sites. On poorer sites, 80000 seeds/ha is probably more appropriate. A rate of 75000-80000 seeds/ha should be appropriate for PX49 and XL35.

Additional Key Words: population density, optimum population, maximum grain yield, lodging, grain moisture, silking.

INTRODUCTION

The optimum plant population for grain yield of maize (*Zea mays* L.) varies with both cultivar and environment. Dungan *et al.* (1958) reviewed a large number of studies on maize populations and concluded that the optimum population was higher under conditions of high soil fertility and low moisture stress than under conditions of either nutrient or moisture stress. More recent studies in the northern USA using hybrids of a similar genetic background and maturity to hybrids commonly grown in the Manawatu support this conclusion (Andrew and Peek, 1971; DeLoughery and Crookston, 1979). In these studies maximum grain yields were usually obtained with populations between 40000 and 70000 plants/ha, but in the nonstress environment of Waseca, Minnesota in the study of DeLoughery and Crookston (1979), higher yields were obtained at 100000 plants/ha than at 50000 plants/ha.

Pioneer 3901 is an important hybrid in the Manawatu. Studies with this hybrid at Wilmar and Mankato in Minnesota at populations of 44000, 54000 and 64000 plants/ha showed grain yields increased from the lowest to the highest population, but the difference was only 3.8% (R.L. McConnell, Pioneer Hi-Bred International Inc., personal communication). At Woodstock, Ontario, grain yields of Pioneer 3901 increased from 49000 plants/ha to 62000 plants/ha, but declined slightly at 74000 plants/ha (McConnell, personal communication). Yields at 62000 plants/ha were 9.0% higher than at 49000 plants/ha, but were only 1.4% higher than at 74000 plants/ha. At all three sites, both stalk and root lodging increased with increasing population, which agrees with the general conclusion of Dungan *et al.* (1958). At both Minnesota sites, grain moisture at harvest increased with increasing population, while at Woodstock the lowest grain moisture was obtained at the intermediate population.

In New Zealand, Douglas *et al.* (1982) and Dyson and Douglas (1975) obtained maximum grain yields in the range of 80000 to 90000 plants/ha with the hybrid PX 610 in the Poverty Bay and Waikato regions. In the Manawatu, Edmeades (1972), by extrapolation, calculated an optimum population of 92000 plants/ha for the hybrid W575 and 158000 plants/ha for the early maturing hybrid K3, although the highest population used in his experiments was 79000 plants/ha.

The average sowing rate used by farmers in the Waikato region in 1983 was 84000 seeds/ha for Pioneer hybrids and this sowing rate produced an average population of 79000 plants/ha (Underwood, 1985). In the Manawatu region, the average sowing rate is about 80000 plants/ha (A.G. Collis, Manawatu planting contractor, personal communication), although some farmers have used sowing rates as high as 89000 seeds/ha (P.M. Walters, Manawatu maize grower, personal communication).

The objective of the current study was to evaluate responses to plant population and to estimate the optimum populations for maize hybrids currently of commercial importance in the Manawatu region.

MATERIALS AND METHODS

Field procedures and data collection

One trial was conducted in each of the 1981-82, 1983-84 and 1984-85 seasons. The 1981-82 trial was grown at Tokomaru on the farm of Mr R.G. Mabin and the 1983-84 and 1984-85 trials were grown near Kairanga on the Aorangi Farm of DSIR. Sowing dates, harvest dates, soil types and previous crops are presented in Table 1.

Plots were 4 rows wide and 3.75m long with 0.75 m spacings between rows. Pathways were 0.75m wide. Two hybrids, Pioneer 3901 and XL35 , were grown in the 1981-82 trial and three hybrids, Pioneer 3901, PX49 and XL35, were grown in the 1983-84 and 1984-85 trials. In each trial, five populations were obtained by sowing seeds at spacings of 0.375m, 0.25m, 0.1875m, 0.15m and 0.125m in the row. Two seeds were sown

Table 1. Sowing date, harvest date, soil type and previous crop for trials grown in each of 3 seasons.

Season	Sowing Date	Harvest Date	Soil type	Previous Crop
1981-82	2 Nov 1981	15 May 1982	Opiki peat	maize
1983-84	28 Oct 1983	14 June 1984	Kairanga silt loam	barley
1984-85	26 Oct 1984	27 May 1985	Kairanga silt loam	barley

with a jab planter at each position in the row and at the 4-5 leaf stage the trials were thinned to 1 plant at each position. This gave plant populations of 35555, 53333, 71111, 88888 and 106666 plants/ha. After thinning, plant numbers in all trials were close to these populations.

Weed control was obtained using Eradicane plus atrazine in the 1981-82 season and with Primextra in the 1983-84 and 1984-85 seasons. The compound fertiliser 10:18:8 (N:P:K:) was applied at 375 kg/ha in the 1981-82 season and 10:18:7: (N:P:K:) was applied at 225 kg/ha in the 1983-84 season and at 170 kg/ha in the 1984-85 season. These fertilisers were applied in bands just after seedling emergence. In the 1983-84 and 1984-85 seasons, urea at 200 kg/ha was side-dressed five weeks after sowing.

In the 1981-82 season, a randomised complete block design with three replications was sown. However, one replication was flooded, so data were obtained from two replications. In the 1983-84 and 1984-85 seasons, a split-plot designs with four replications was used. In the split-plot designs, plant populations were whole plots and hybrids were subplots. The whole plots were arranged in a randomised complete-block design with the restriction that the 35555 and 106666 populations were not adjacent.

Data for grain yield and grain moisture at harvest were obtained from all trials. In the 1981-82 trial, ears from the end plants of each plot were removed and discarded and then the ears from the centre two rows were hand harvested, husked and weighed. A sample of five ears was taken from each plot for determination of ear moisture and shelling percentage. A sample of grain from the centre of a further five ears was taken for grain moisture determination. Grain and ear moisture were determined by drying to constant weight at 80° C in a forced-draught oven. Grain yield at 15% moisture was calculated from ear weight, ear moisture and shelling percentage. In the 1983-84 and 1984-85 trials, ears from the end plants of each plot were removed immediately before harvest except for the highest population, where ears from the end two plants were removed. The ears from the centre two rows were then hand harvested and shelled using a Haban husker-sheller. The grain was weighed and grain moisture was determined using a DICKEY-john GAC II grain analysis computer. Grain yield at 15% moisture was calculated from grain weight and grain moisture.

Root lodging and stalk lodging were determined immediately before harvest. Root lodging was determined by counting the plants leaning more than 30° from the vertical and stalk lodging by counting the plants where the stalk had broken at or below the ear-bearing mode. Both were expressed as a percentage of the total number of plants in each plot.

Silking date was recorded in the 1984-85 season as the number of days after 31 December when silks were first visible on 50% of the plants in each plot.

Statistical analyses

The data were analysed using standard analysis of variance procedures (Steel and Torrie, 1960).

In addition, the logarithm of the average yield per plant was regressed against plant population. If this relationship is linear, then the model

$$Y = NAK^N + \text{error}$$

where Y = grain yield, N = plant population and A and K are constants provides a useful description of the relationship between grain yield and population (Duncan, 1958; Carmer and Jackobs, 1965). Using this model, the optimum plant population can be calculated from

$$N_{opt} = -1/\ln K$$

and the maximum grain yield from

$$Y_{max} = 0.36787\, N_{opt}\, A$$

(Carmer, 1974).

Regression analyses were conducted for each hybrid in each season (using means across replications) and also on an individual replication basis. The computational method used was method 1 of Carmer (1974) which assumes the linear equation

$$\ln(Y/N) = \ln A + N \ln K + \text{error}.$$

Population optima calculated for each year-hybrid - replication unit were then analysed using analysis of variance procedures for a randomised complete block design (Steel and Torrie, 1960).

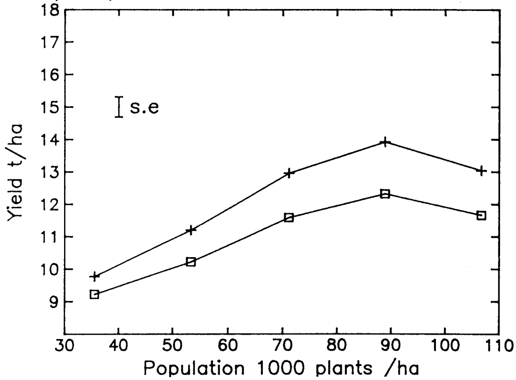

Figure 1. Relationship between grain yield and plant population in the 1981-82 trial. + = Pioneer 3901, □ = XL35. s.e. = standard error of a hybrid mean at any population.

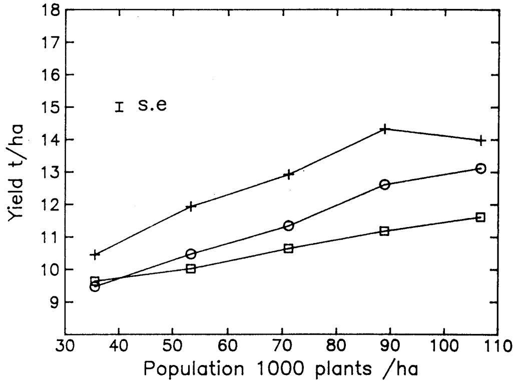

Figure 2. Relationship between grain yield and plant population in the 1983-84 trial. + = Pioneer 3901, o = PX49, □ = XL35. s.e. = standard error of a hybrid mean at any population.

Table 2. Mean grain yield, grain moisture, root lodging, stalk lodging and day of silking for trials grown in each of 3 seasons.

Season	Grain yield t/ha	Grain moisture %	Root lodging %	Stalk lodging %	Silking days
1981-82	11.6	24.7	14.4	-	-
1983-84	11.6	25.2	-	9.4	-
1984-85	12.5	21.8	-	10.4	20.9

Table 3. Mean squares for grain yield, grain moisture and stalk lodging for 3 hybrids grown at 5 populations in the 1983-84 and 1984-85 season.

Source	df	Grain yield	Grain moisture	Stalk lodging
Seasons	1	25.14**	335.25**	26.6
Residual a	6	0.73	1.00	194.0
Populations	4	49.31**	14.50**	999.4**
Seasons x populations	4	2.91**	0.42	117.6
Residual b	24	0.43	0.38	51.5
Hybrids	2	37.29**	27.69**	6928.2**
Seasons x hybrids	2	0.89*	1.30	234.5
Populations x hybrids	8	1.74**	0.40	797.5**
Seasons x populations x hybrids	8	0.75*	0.66	125.0
Residual c	60	0.28	0.60	94.8

* Significant at 5% probability level using the appropriate residual for the F test.

** Significant at 1% probability level using the appropriate residual for the F test.

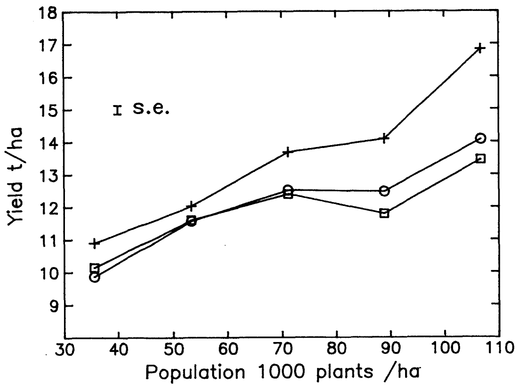

Figure 3. Relationship between grain yield and plant population in the 1984-85 trial. + = Pioneer 3901, o = PX49, □ = XL35. s.e. = standard error of a hybrid mean at any population.

RESULTS

High grain yields were obtained in all trials (Table 2). Stalk lodging was negligible in the 1981-82 trial and root lodging was negligible in the 1983-84 and 1984-85 trials.

Highly significant differences were obtained among hybrids and among populations for grain yield and grain moisture in all trials (data not presented). The combined analysis of variance for the 1983-84 and 1984-85 trials showed significant season x population and season x hybrid interactions for grain yield but not for grain moisture or stalk lodging (Table 3). Significant population x hybrid interactions were obtained for grain yield and stalk lodging but not for grain moisture (Table 3). For this statistical reason, and because of the economic importance of grain yield, the response of each hybrid to population is presented for each season for grain yield, while the pooled response is presented for grain moisture. Although the population x hybrid interaction was significant for stalk lodging, for simplicity a pooled response is presented.

In the 1981-82 season, grain yield increased with increasing population to 88888 plants/ha, but declined at 106666 plants/ha (Figure 1). This trend occurred with both Pioneer 3901 and XL35. A similar trend occurred with Pioneer 3901 in the 1983-84 season, but not with PX 49 and XL35 (Figure 2). For PX49 and XL35 in the 1983-84 season, the highest grain yields were obtained at the highest population, 106666 plants/ha (Figure 2). The 1983-84 season produced very high grain yields (Table 2) and the highest grain yields of all hybrids were obtained at 106666 plants/ha (Figure 3).

The regression of the logarithm of average yield/plant against plant population was highly linear for each hybrid in each season, with correlation coefficients ranging from -0.958 to -0.993. Only one of the eight correlation coefficients exceeded -0.980. Therefore, population optima were estimated using the method of Carmer (1974).

The optimum plant populations ranged from 80300 plants/ha for XL35 in the 1983-84 season to 106800 plants/ha for Pioneer 3901 in the 1984-85 season, with a mean of 92100 plants/ha (Table 4). There were significant differences among hybrids, with Pioneer 3901 and PX49 having a higher optimum population than XL35. Optimum populations (Table 4) were generally lower than populations which produced the highest yields (Figure 1, Figure 2 and Figure 3), especially for the 1984-85 season. The possible reasons for these discrepanceies will be discussed later.

For all hybrids in all seasons, maximum grain yields estimated by regression were lower than the highest grain yields obtained at any population (Table 5). However, the differences were small and of no practical significance in the 1981-82 and 1983-84 trials.

In the 1981-82 season, root lodging increased with population from 53333 plants/ha to 106666 plants/ha (Figure 4) and these differences were approaching statistical significance (analysis not presented). However, root lodging was higher at 35555 plants/ha than at 53333 or 71111 plants/ha, probably due to sampling error. In the 1983-84 and 1984-85 seasons, stalk lodging showed an almost linear increase with population (Figure 4) and differences among populations were statistically significant (Table 3).

Days to 50% silking of the main culms increased almost linearly with population (Figure 5). and differences among populations were statistically significant (analysis not presented). Grain moisture, however, was higher at the 35555 and 106666 plants/ha populations than at the intermediate populations (Figure

Table 4: Optimum plant populations[1] for grain yield (t/ha) for 3 hybrids in each of 2 seasons and 2 hybrids in 1 season.

Hybrid	Season 1981-82	1983-84	1984-85	Mean
Pioneer 3901	95000	92900	106800	99800
PX49		95400	93200	94300
XL35	87000	80300	84300	82300
Standard error[2]	11000	3000	3000	2100

[1] Calculated by the method of Carmer (1974)
[2] Standard errors for the 1983-84 and 1984-85 seasons were calculated from a combined analysis of variance.

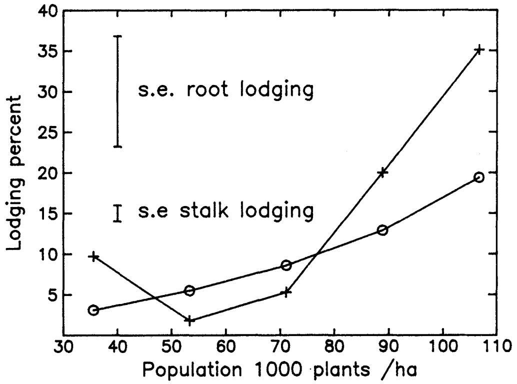

Figure 4. Relationship between root lodging and plant population in the 1981-82 trial. Relationship between stalk lodging and plant population in the 1983-84 and 1984-85 trials. + = root lodging, o = stalk lodging.

Table 5. Maximum grain yields (Ymax[1])calculated from a combined analysis of variance.

Hybrid	Season 1981-82 Ymax	1981-82 Highest	1983-84 Ymax	1983-84 Highest	1984-85 Ymax	1984-85 Highest
Pioneer 3901	13.9	14.0	14.3	15.4	16.8	13.5
PX49	-	-	12.6	13.2	13.3	14.1
XL35	12.0	12.3	11.4	11.6	12.9	13.5
Standard Error	0.5	-	0.2	-	0.2	-

[1] Calculated by the method of Carmer (1974).
[2] Standard errors for the 1983-84 and 1984-85 seasons were calculated from a combined analysis of variance.

6) and these differences were statistically significant (Table 3). To explain this result, a count of ear-bearing tillers was made for Pioneer 3901 in the 1984-85 season. Tillering was highest at 35555 plants/ha and entirely absent at 88888 plants/ha and 106666 plants/ha (data not presented). Because a tiller silks later than the main culm of a maize plant, grain from tillers would have a higher grain moisture at harvest than grain from main culms. If present in sufficient numbers, ear-bearing tillers would therefore raise grain moisture at harvest and this probably occurred at 35555 plants/ha. The increased grain moisture at 106666 plants/ha was probably the result of delayed silking.

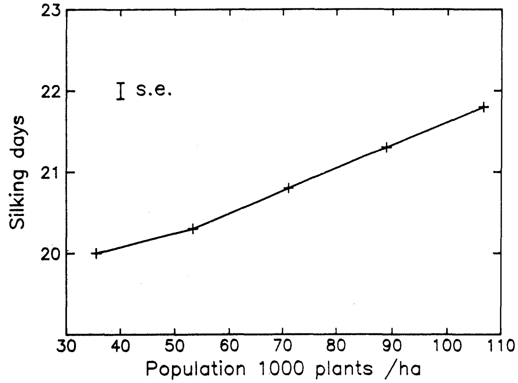

Figure 5. Relationship between days to 50% silking of the main culms and plant population in the 1984-85 trial.

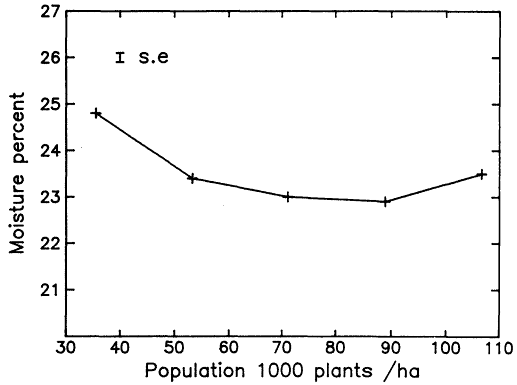

Figure 6. Relationship between grain moisture at harvest and plant population in the 1983-84 and 1984-85 trials.

DISCUSSION

Sources of bias

The experiments reported in this paper used small plots of the type commonly used in plant breeding programmes. Two types of bias can be recognised from the use of this type of plots. Firstly, bias can be caused by edge effects due to adjacent plots of different populations, and secondly, end effects due to pathways.

Edge effects would positively bias yields of high population plots and negatively bias yields of low population plots (Dyson and Douglas, 1975). However, in these experiments, four-row plots were used with only the centre rows harvested, populations were blocked in a split-plot design in two of the three seasons and the highest and lowest populations were never adjacent. An examination of plot residuals from the analyses of variance showed no relationship between the size or direction of the residual and the population of the adjacent plot, suggesting that edge effects were not important.

Bias due to end effects could have been more important. The pathways between plots were 0.75cm wide and except for the highest population in the 1983-84 and 1984-85 seasons, ears from only one plant at the end of each row of each plot were removed before harvest. At the highest population in the 1983-84 and 1984-85 seasons, ears from two plants were removed. End effects would positively bias the yields of all plots and this would not influence the estimation of optimum population unless the bias was differential. Because of greater competition among plants in high population plots, bias could be greater for these plots, and estimates of optimum populations would be inflated.

Optimum populations caculated using Duncan's method (Duncan, 1958; Carmer, 1974) were lower than optimum populations expected from graphical representation, especially for the 1984-85 season. Because Duncan's method uses data from all populations, this result is compatible with a differential bias in grain yield at higher populations. However, maximum yields calculated from Duncan's method were only slightly lower than the highest yields obtained in the 1981-82 and 1983-84 trials, suggesting that optimum populations calculated from these trials would produce yields very close to maximum in similar environments. Discrepances were larger in the 1984-85 trial, indicating that optimum populations determined from these trials should be considered with caution.

Comparison with previous experiments

The mean optimum plant population across seasons and hybrids was 92000 plants/ha, which was the same as the optimum estimated for W575 in the Manawatu by Edmeades (1972) and only slightly higher than the optima estimated for PX610 in the Poverty Bay and Waikato regions (Dyson and Douglas, 1975; Douglas *et al.*, 1982). Even following for bias in my experiments, the optimum plant population for Pioneer 3901 under the same type of high fertility conditions used in my experiments is probable not less than 90000 plants/ha in the Manawatu. This is markedly higher than the optimum population for the same hybrid in the northern USA and Canada, where it was bred and is widely grown (McConnell, personal communication). This indicates that information on plant population from the USA is of no predictive value in New Zealand. However, the question of whether the relative ranking of optimum populations for hybrids in the USA is of predictive value in New Zealand remains unanswered. This is of considerable practical importance because new hybrids are regularly introduced from the USA and information on their optimum population relative to older hybrids is usually available.

The almost linear relationship between population and silking date in maize has been observed previously (Edmeadcs and Daynard, 1979). For populations too high for ear-bearing tillers, increasing population delays silking which probably delays maturity and increases grain moisture at harvest.

The increased risk of lodging at high populations has also been observed previously (Dungan *et al.*, 1958; McConnell, personal communication) and is probably general in maize.

Practical recommendations

The problem for the maize grower is to sow the population which will produce the highest economic return. The actual sowing rate to use will depend on the particular site, especially the fertility and moisture holding capacity of the soil, the hybrid to be grown, the cost of the seed and the expected value of the grain at harvest. The cost of seed and expected value of grain at harvest are important because near the population optimum yield changes slowly as plant population is altered so that the extra cost of seed cannot be recovered by the extra value of grain harvested. Risk of lodging varies with both hybrid and environment (Eagles and Sinclair, 1987), but regardless, increases with population. This means that the most desirable sowing rate will be lower than the rate required to produce the maximum yield.

Currently, Genetic Technologies Ltd., the marketers of Pioneer hybrids, recommend a sowing rate of 85000 seeds/ha for Pioneer 3901 (Anonymous, 1987). This should produce a population of approximately 80000 plants/ha (Underwood, 1985). For sites with high fertility and good moisture holding capacity, such as those used in my trials, this is probably close to the rate which will produce the highest economic return, but for poorer sites, 80000 seeds/ha, which is currently used by growers (Collis, personal communication), is probably more appropriate. From the experiments reported in this paper a lower seeding rate should be used for XL35, possibly between 75000 and 80000 seeds/ha. A lower rate could also be appropriate for PX49 because of the tendency for stalk lodging of this hybrid (Eagles and Sinclair, 1987).

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