Effect of row spacing and plant population on maize yield and quality

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Abstract

The effects of row spacing and plant population on maize yield and quality (bulk density, thousand kernel mass) were examined in three different environments (Waikato, Hawke's Bay and Manawatu). Two maize hybrids differing in maturity (hyb. 36H36, medium season and hyb. Raissa, short season) were grown at seven populations (70, 80, 90, 100, 110, 120 and 140 thousand plants/ha) and a range of row spacings. In the Waikato and Manawatu, crops were grown at standard (75 cm) and narrow (50 cm) rows. A 25 cm row spacing was added in Hawke's Bay. Every combination of these treatments was applied in a fully randomised design at each location. In general, the influence of row spacing on maize yield and quality was minimal and inconsistent. By contrast, the effects of population on yield and quality were significant and generally predictable. There was no significant effect of row spacing on any component of yield or quality for crops grown at 'normal' plant populations (*ca* 90,000 plants/ha). Consequently, the results from this limited set of experiments suggest that, at the current 'standard' population, there is no benefit from narrow (25 or 50 cm rows) compared with standard (75 cm) row spacing. By contrast, increasing the population significantly increased yield (by an average 7% for every additional 10,000 plants/ha) up to a plateau that usually occurred at *ca* 120,000 plants/ha. Thousand kernel mass consistently declined with increased population (by about 1 g for every additional 10,000 plants/ha) whereas the response of bulk density to population was less predictable, and varied from nil to negative. There was consequently only a very small probability of economic benefit associated with narrower rows, but considerable scope for improving profitability by $100-1000/ha through adopting higher than current plant populations.

Additional key words: Zea mays, *bulk density, hybrids, thousand kernal mass*

Introduction

History is often more important than science in determining the way that crops are grown. In maize, row spacing was initially set at about 100 cm to accommodate the real horsepower required to pull the tillage and other implements of the early 1900s. Despite the fact that from the 1930s onwards horsepower was usually delivered by (John) Deeres rather than horses, the original 100 cm row spacing was adhered to until the 1960s, when it dropped to 76 cm. Similarly, despite a steady increase in the plant population at which maximum yield occurs, from *ca* 30,000 in the 1930s (Cardwell, 1982) to over 100,000 plants/ha today (Begna *et al.*, 1997; Stone *et al.*, 1998a; 1998b), most growers choose to grow at populations well below this maximum level.

Part of the reluctance to change from tried and true practices is related to growers' aversion to economic risk. Where risks are high or uncertain this aversion is sound business practice. Where risks are low or quantifiable, reluctance may be less easy to rationalise.

There are sound and readily identifiable reasons for the yield increase with plant population: more plants gives increased leaf area and more rapid canopy closure, which increases radiation interception and consequently growth and yield (Stone *et al.*, 1998a; 1998b). The same reasoning has been applied to narrower row spacings (closer plants give more rapid canopy closure, etc.), but the evidence supporting the theory is not as strong for row spacing as it is for population.

The aim of these experiments was to provide growers with information on the effects of row spacing and plant population on maize yield, quality and profitability, to enable them to assess the risks and benefits associated with growing crops in narrower rows and/or higher populations.

Materials and Methods

The experiments were undertaken at three locations, representing a typical range of North Island maize growing conditions. The Waikato site had been sown to maize about three weeks before the hybrid x row spacing x population experiment commenced. Part of the existing crop was ploughed in and our experiment was established in its place. Two maize hybrids differing in maturity (hyb. 36H36, medium season and hyb. Raissa, short season) were grown at two row spacings (50 cm and 75 cm) and seven populations (approximately 70, 80, 90, 100, 110, 120 and 140 thousand plants/ha), in a full-factorial design. On 11 November 1999, two seeds per position were sown using jab planters. Plants were thinned after emergence to give a uniform population within each plot. The experimental area was divided into 28 plots, each measuring 4.5 x 5 m. Weeds were controlled by a post-planting, pre-emergence application of 'Trophy' at a rate of 6 L/ha (2.4 kg/ha acetochlor). Urea (120 kg N/ha) was broadcast after sowing. The site had previously received 115 kg N/ha as part of the previous crop's fertiliser regime.

Experimental design and crop husbandry were similar at Hawke's Bay, with a few important exceptions. The crop was sown on 8 October 1999. An additional row spacing (25 cm) was used and the 110,000 plants/ha population treatment was deleted. N fertiliser was applied at a rate of 160 kg N/ha. The crop was irrigated on demand (after 50 mm potential ET) from sowing to maturity.

Experimental design and crop husbandry at Manawatu were similar to that at Waikato, with some exceptions. The crop was sown on 19 November 1999. N fertiliser was applied at a rate of 100 kg N/ha (70 kg as urea and 36 kg as 12:10:10). The crop received 30 kg P/ha and 30 kg K/ha applied at sowing as 12:10:10. Weeds were effectively controlled using 'Trophy' at 5 L/ha (2 kg/ha acetochlor) and atrazine at 1 L/ha.

Grain yield was measured on 30 plants from each plot after shelling using a 'Ransomes' automated sheller. Grain bulk density was measured using freshly shelled grain according to the standard method (Canadian Grain Commission, 1999). Thousand kernel dry mass was determined by weighing 100 randomly selected kernels. Grain moisture content was determined by drying the entire bulk density sample in a fan-forced oven at 75°C until a constant mass was attained. All grain results are expressed on a 14% moisture content basis. Stem diameter was measured as the widest axis in the middle of the third internode.

The gross margin (profit made from the variable costs invested in the crop) was calculated for each treatment, taking into account the effect of plant population on cost of seed, cartage and drying and returns from yield. Gross margins have been calculated using a seed price of $3.40 per 1000 seeds, a grain price of $250/t and cartage and drying costs of $9 and $19/t, respectively.

Results

Waikato

Yield. There was no effect of row spacing on grain yield of either hyb. 36H36 or hyb. Raissa grown at a standard (80-90,000 plants/ha) population (Fig. 1a & b). Above the normal population range, however, there was a marked response to row spacing in both hybrids. In hyb. 36H36, narrower rows appeared to increase yield at populations of 110-120,000 plants/ha, and reduce yield at 140,000 plants/ha. For hyb. Raissa, 50 cm rows increased yields at populations of 120-140,000 plants/ha, compared with 75 cm rows. Narrower rows increased the response of hyb. 36H36 to population (from 35 (r^2=0.85) to 120 (r^2=0.98) kg/ha of grain for every 1000 plants/ha). In hyb. Raissa there was no significant effect of narrow rows, and yield increased by an average of about 50 kg/ha for every additional 1000 plants/ha, up to 120,000 plants/ha (r^2=0.83).

Grain yields were constrained by the drier than average season in the Waikato: rainfall during the November-March growing season totalled 361 mm, 68% of the 30 year average of 531 mm recorded at Hamilton.

Bulk density. There was no systematic effect of either row spacing or population on grain bulk density (test weight) which, at an average of ca 67 kg/hL, was generally below average for both hybrids (data not shown). This was most likely caused by the lower than average rainfall during the growing season.

Thousand kernel mass and grain moisture content. There was no effect of row spacing on thousand kernel mass (TKM) in either hyb. 36H36 or hyb. Raissa, but there was a strong response to population in both hybrids (Fig. 2), such that TKM dropped by approximately 1 g

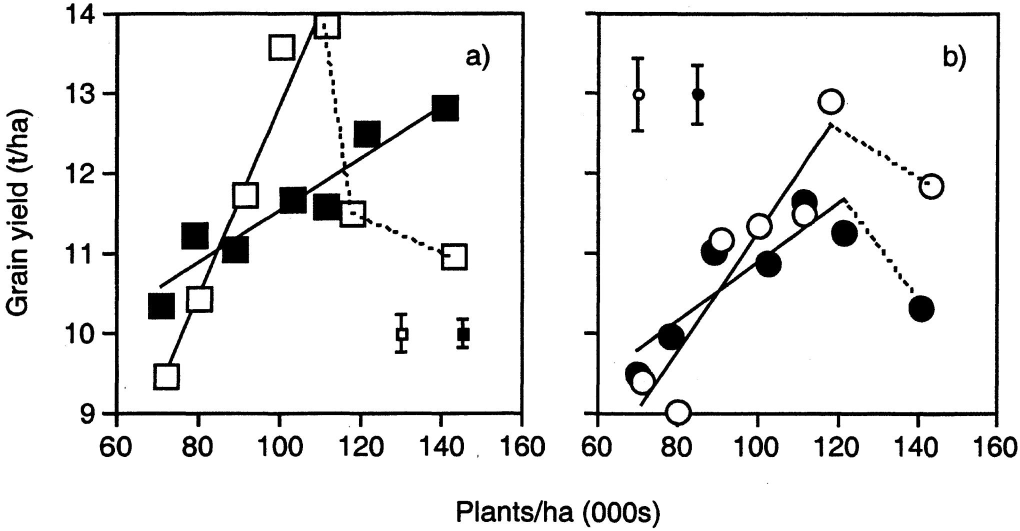

Figure 1. The effect of row spacing and plant population on grain yield of maize grown in Waikato, 1999/00. a) hyb. 36H36: □ 50 cm row spacing; ■ 75 cm row spacing. b) hyb. Raissa: ○ 50 cm row spacing; ● 75 cm row spacing. Bars are RMS errors for each linear fit. Hatched lines indicate data without clear or significant relationship with population.

for every 10,000 plants/ha (r^2=0.87). There was no significant effect of row spacing or population on grain moisture content (data not shown).

Gross margin. For both hybrids, maximum gross margins occurred at populations greater than the current standard (*ca* 90,000 plants/ha), with an additional $100-400/ha available at higher populations (Fig. 3a & b). For hyb. 36H36, maximum gross margins occurred at 110,000 and 140,000 plants/ha for 50 and 75 cm row spacings, respectively (Fig. 3a). It is interesting to note that despite the sharp yield decline at high populations in the 50 cm treatment, the gross margin occurring at 120,000 plants/ha was still higher than that at 90,000 plants/ha. For hyb. Raissa, maximum gross margins occurred at 125,000 and 105,000 plants/ha for 50 and 75 cm row spacings, respectively (Fig. 3b).

The effects of row spacing on gross margin closely reflect the effects of row spacing on yield, as it was assumed that there were no changes to variable costs associated with different row spacings.

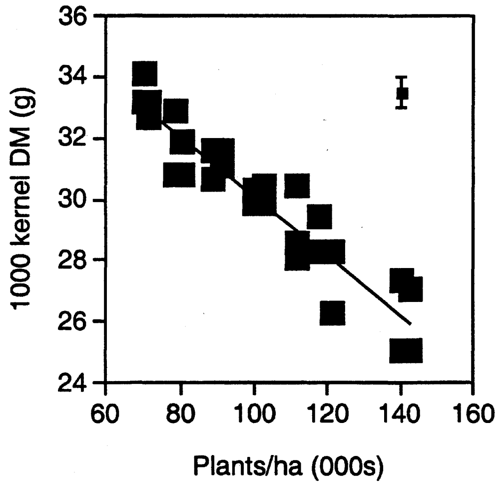

Figure 2. The effect of plant population on bulk density of maize grain grown in Waikato, 1999/00. Data are pooled for all treatment combinations. Bar is RMS error for linear fit.

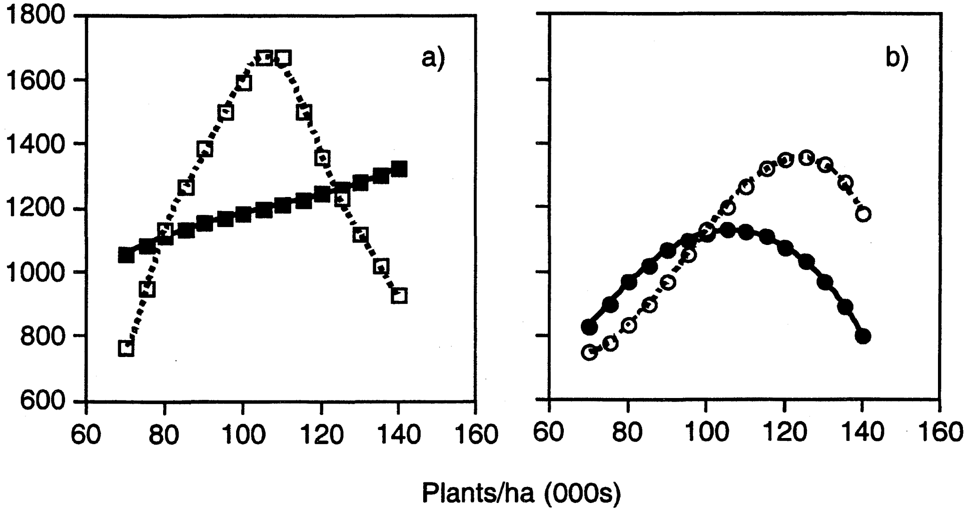

Figure 3. The effect of row spacing and plant population on gross margin from maize grown in Waikato, 1999/00. a) hyb. 36H36: □ 50 cm row spacing; ■ 75 cm row spacing. b) hyb. Raissa: ○ 50 cm row spacing; ● 75 cm row spacing.

Hawke's Bay

Yield. There was no significant effect of row spacing on grain yield of either hyb. 36H36 or hyb. Raissa, despite the fact that both showed significant responses to population (Fig. 4a & b). Grain yield of hyb. 36H36 increased more or less linearly with population across the 70-140,000 plants/ha range, by about 0.65 t/ha per 10,000 plants/ha. The response was similar in hyb. Raissa (r^2=0.92), although a yield plateau was reached at around 120,000 plants/ha.

Yields were much higher at Hawke's Bay than at the Waikato site mainly because irrigation ensured that plants at the former site suffered no moisture stress.

Bulk density. The response of bulk density (test weight) to row spacing and population varied between hybrids. For hyb. 36H36, there was no significant effect of either factor on bulk density of grain, which averaged 72 kg/hL (data not shown). For hyb. Raissa, narrower (25 and 50 cm) rows increased bulk density at lower (70-80,000 plants/ha) populations, but there was no effect for populations of 90,000 plants/ha or above (Fig. 5). For hyb. Raissa grown in 75 cm rows, there was no effect of population on bulk density.

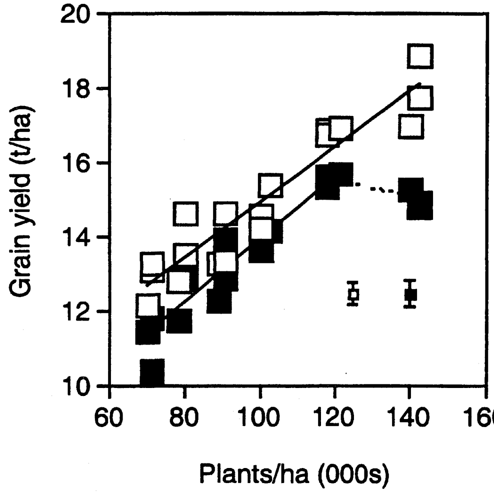

Figure 4. The effect of plant population on grain yield of maize grown in Hawke's Bay, 1999/00. □ hyb. 36H36; ■ hyb. Raissa. Bars are RMS errors for each linear fit. Hatched line indicates data without clear or significant relationship with population.

Thousand kernel mass and grain moisture content. As in the Waikato, there was no effect of row spacing on thousand kernel mass in either hybrid, despite the strong decline in TKM with population (*ca* 1.5 g for every 10,000 plants/ha (r^2=0.88); Fig. 6). TKM was higher in hyb. 36H36 than hyb. Raissa.

There was no effect of row spacing or population on grain moisture content at harvest, for either hybrid (data not shown). Grain moisture content averaged 20.2 (±0.1)% at harvest.

Stem diameter. There was no consistent effect of row spacing on stem diameter in either hybrid. In hyb. 36H36 stem diameter showed no significant response to population (data not shown). In hyb. Raissa the response of stem diameter to population was far more predictable, and showed a generally linear decrease from 70,000 to 120,000 plants/ha over which range stem diameter declined by about 4 mm (Fig. 7; r^2=0.76). This reduced stem diameter did not result in any propensity to lodge at either root or stem, despite the occurrence of winds strong enough to flatten an adjacent sweet corn crop.

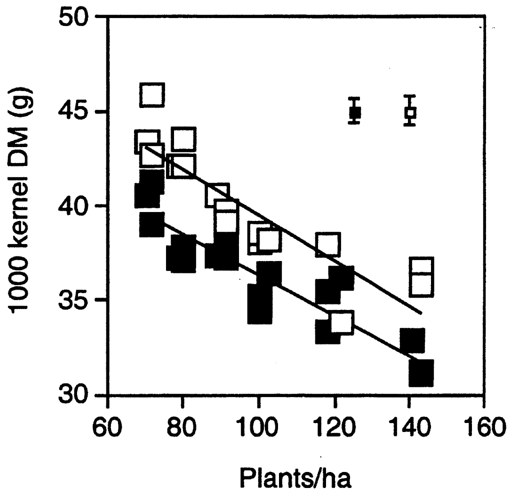

Figure 6. The effect of plant population on thousand kernel mass of maize grown in Hawke's Bay, 1999/00. □ hyb. 36H36; ■ hyb. Raissa. Bars are RMS errors for each linear fit.

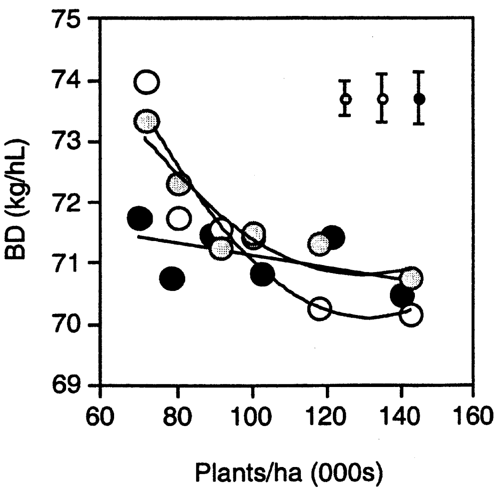

Figure 5. The effect of row spacing and plant population on bulk density of hyb. Raissa maize grain grown in Hawke's Bay, 1999/00. ● 25 cm row spacing; ○ 50 cm row spacing; ● 75 cm row spacing. Bars are RMS errors for each linear fit.

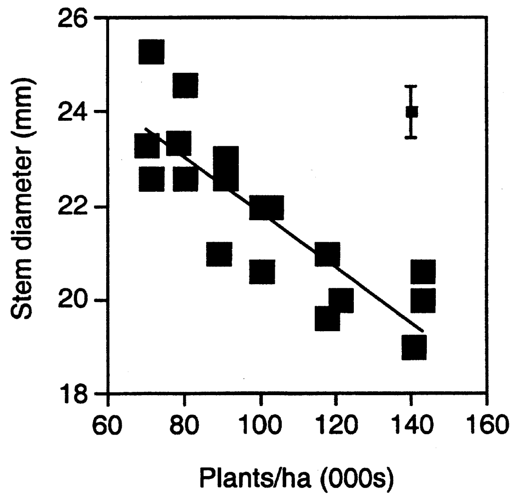

Figure 7. The effect of plant population on stem diameter of hyb. Raissa maize grown in Hawke's Bay, 1999/00. Data are pooled for all combinations of row spacing. Bar is RMS error for linear fit.

Gross margin. There was no reliable effect of row spacing on gross margin for crops grown in Hawke's Bay (Fig. 8a & b). Population, by contrast, had a major effect on profitability, with an additional $300-1000/ha available at populations higher than the current standard. For hyb. 36H36 maximum gross margins occurred at 130-140,000 plants/ha, whereas for hyb. Raissa they occurred in the 120-125,000 plants/ha range.

Manawatu

Yield. There was no significant effect of row spacing on grain yield (Fig. 9). In both hybrids grain yield increased more or less linearly with plant population until about 120,000 plants/ha. Yield of both hybrids increased by *ca* 40% as population increased from 70,000 to 100,000 plants/ha (r^2=0.76).

Bulk density. The effects of row spacing and plant population on grain bulk density (test weight) were negligible for both hybrids, and averaged 68 and 71 kg/hL, for hyb. 36H36 and hyb. Raissa, respectively (data not shown).

Thousand kernel mass and grain moisture content. Thousand kernel mass declined with increasing population for all treatments, with the exception of hyb. 36H36 grown in 50 cm rows, for which there was no consistent response to population (Fig. 10a). For all other treatments, thousand kernel mass declined by approximately 1 g for every 10,000 plants/ha (r^2=0.67) (Figs. 10a & b). There was no consistent response of grain moisture content to row spacing or population for either hybrid (data not shown).

Gross margin. The effect of population on gross margin was much greater than that of row spacing (Fig. 11a & b). For hyb. 36H36 an additional $600/ha was available from crops grown above the standard population. Narrower rows increased the maximum gross margin available from hyb. 36H36, a reflection of the yield increase achieved (Fig. 11a). For hyb. Raissa an additional $400-500/ha was available from crops grown at higher than standard population (Fig. 11b).

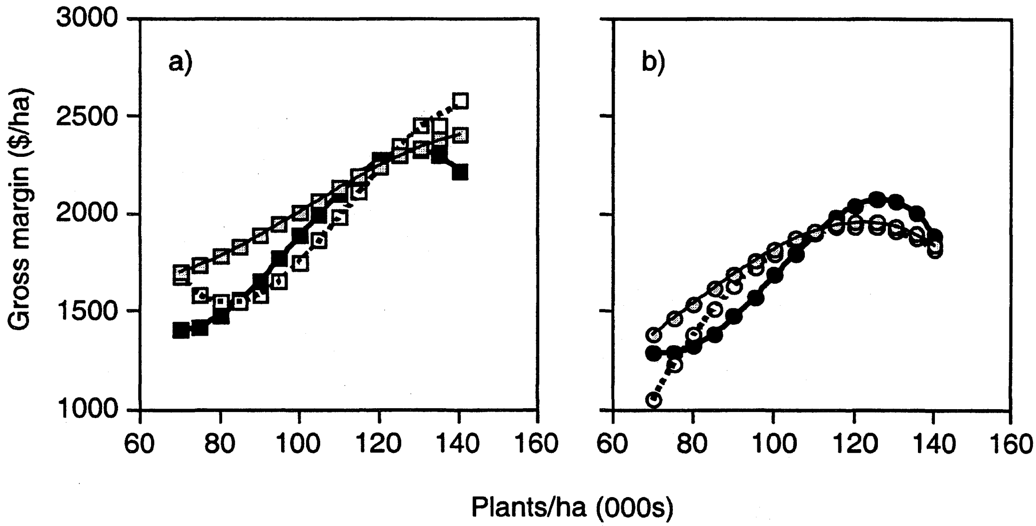

Figure 8. The effect of row spacing and plant population on gross margin from maize grown in Hawke's Bay, 1999/00. a) hyb. 36H36: ■ 25 cm row spacing; □ 50 cm row spacing; ■ 75 cm row spacing. b) hyb. Raissa: ● 25 cm row spacing; ○ 50 cm row spacing; ● 75 cm row spacing.

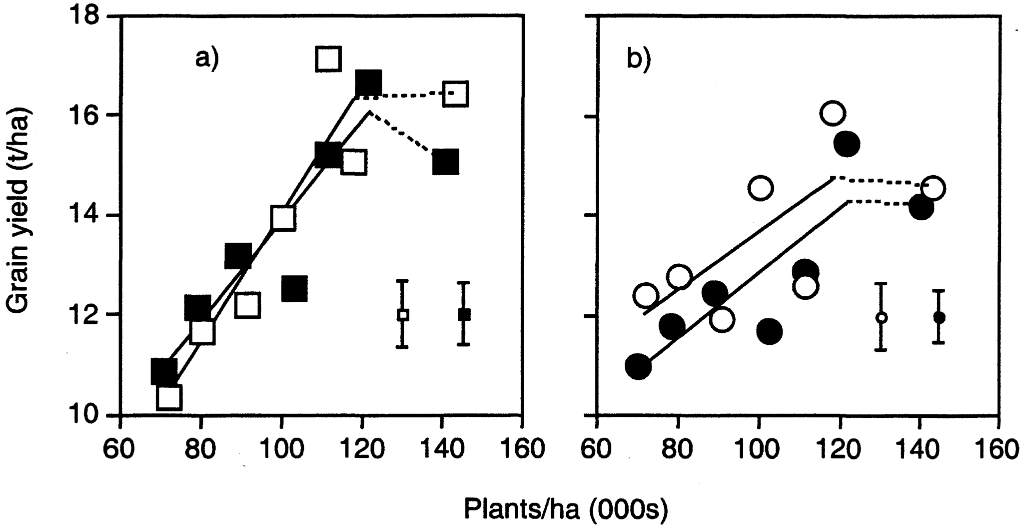

Figure 9. The effect of row spacing and plant population on grain yield of maize grown in Manawatu, 1999/00. a) hyb. 36H36: □ 50 cm row spacing; ■ 75 cm row spacing. b) hyb. Raissa: ○ 50 cm row spacing; ● 75 cm row spacing. Bars are RMS errors for each linear fit. Hatched lines indicate data without clear or significant relationship with population.

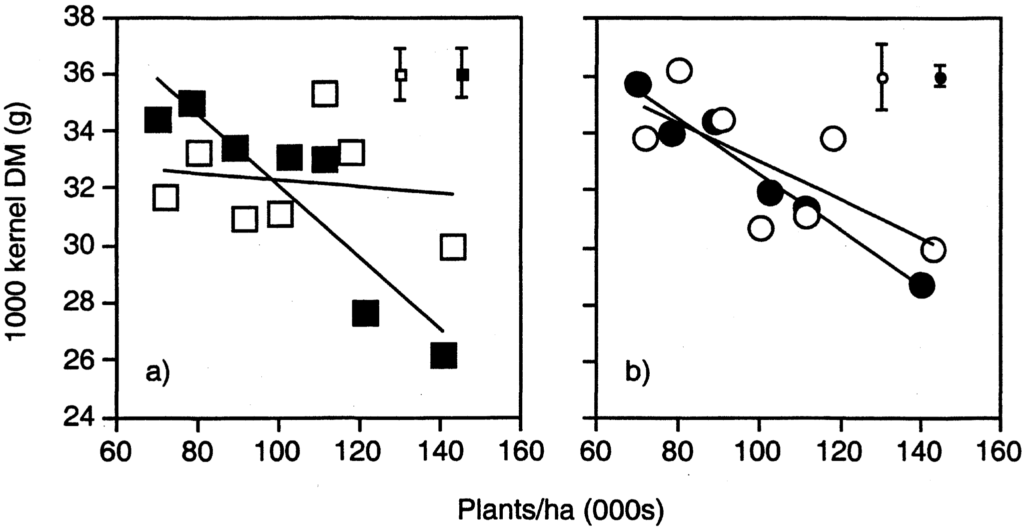

Figure 10. The effect of row spacing and plant population on thousand kernel mass of maize grown in Manawatu, 1999/00. a) hyb. 36H36: □ 50 cm row spacing; ■ 75 cm row spacing. b) hyb. Raissa: ○ 50 cm row spacing; ● 75 cm row spacing. Bars are RMS errors for each linear fit. Hatched lines indicate data without clear or significant relationship with population.

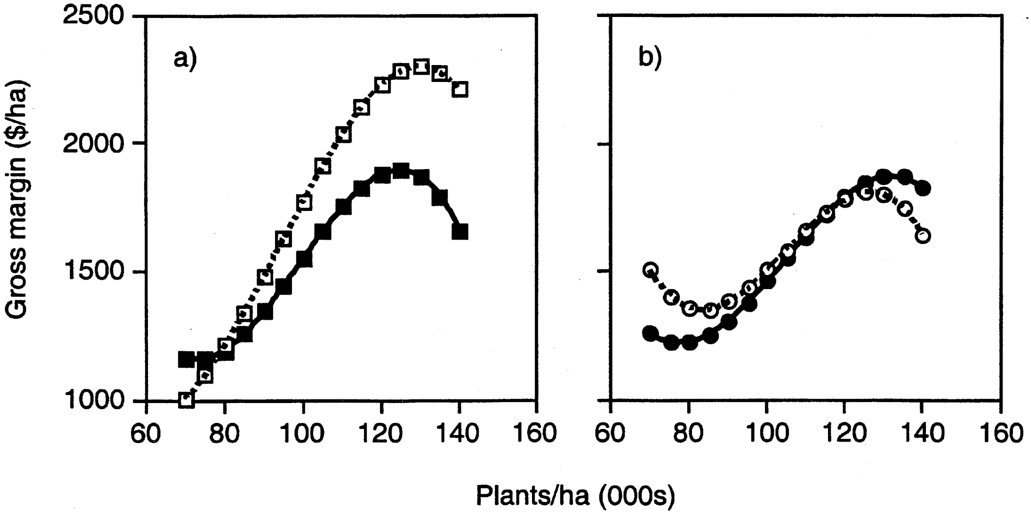

Figure 11. The effect of row spacing and plant population on gross margin from maize grown in Manawatu, 1999/00. a) hyb. 36H36: □ 50 cm row spacing; ■ 75 cm row spacing. b) hyb. Raissa: ○ 50 cm row spacing; ● 75 cm row spacing.

Discussion

In general, the influence of row spacing on maize yield was minimal (average 2%) and inconsistent (0-6%). By contrast, the effects of population on yield were substantial (average 7% per additional 10,000 plants/ha) and generally predictable (highly linear to a plateau). Consequently, row spacing had little impact on profitability, whereas an additional $100-1000/ha was available from crops sown at higher than standard populations.

Given previous evidence, the responses to row spacing and population should not be surprising. A range of studies from the USA report variable responses of grain yield and quality to changes in row spacing from 76 down to 56 or 38 cm (Nielsen, 1988; Paszkiewicz *et al.*, 1994; Lauer, 1996; Johnson *et al.*, 1998). In these reports yield varied in the range ±10%, with an average 3% yield increase when narrower (usually 56 cm) rows were used. Consequently, few authors recommend a change to narrower row spacing, despite the apparent logical appeal of the practice.

So what is the logic of narrow rows, and why don't the results follow the theory? The basic theory underlying the anticipated response to narrow rows can be described thus: 1) sunshine makes crops grow; 2) sunshine that hits leaves contributes to growth whereas sunshine hitting the ground is wasted; 3) by placing rows closer to each other, leaves will cover the ground more rapidly, so 4) more sunshine hits leaves and 5) the crop grows more. Seems simple enough. Unfortunately the theory does not always translate into practice, and part of this is probably because the leaves on a maize plant are longer than they are wide. At a given population, as the row spacing narrows, the space between plants within the row increases. The general rectangularity of maize leaves dictates that they more readily grow in length (into the row) than in width (within the row). Consequently, the advantages of rapid between-row canopy closure are likely to be offset to some extent by the disadvantages of slow or incomplete within-row closure.

The response of grain yield to population, by contrast, is one where the evidence tends to support the theory. The response of yield to plant population is probably more predictable because the mechanism is simpler: as more plants are added they become closer within the row, but the within- and between-row geometry does not change to the extent that it does with row spacing. Consequently, as population increases interception of sunshine increases, until the point where adding more plants does not significantly increase interception (Stone *et al.*, 1998b). It is at this point that the yield plateau is reached (caused by sunshine saturation, of a sort). In some cases, increasing population past the plateau leads to a yield decrease. This typically occurs where the crop exhausts the supply of an essential requirement, such as water or nitrogen. This occurred in most of the treatments in the Waikato, which had below average rainfall during the growing season. There was no such decrease in Hawke's Bay or Manawatu because the former was irrigated and the latter received sufficient rainfall.

The effect of plant population on grain quality varied with the component under consideration. Thousand kernel mass clearly and predictably decreased as population increased, in 13 out of 14 treatments. The response of bulk density to population was less predictable, which is probably not surprising given that it is an empirical physical quality that is, in itself, not mechanistically related to crop growth. It is a measure of the mass of grain that will fit into a container. Consequently, its links with crop growth and yield are, at best, uncertain.

The gross margins indicate that significant increases in profit may be available by growing crops at higher than standard populations. Gross margin appears to be maximised at a population of around 130,000 plants/ha on fertile sites free from moisture stress (as found in earlier work: Stone 1998) but is maximised at lower populations as moisture stress becomes pronounced. In most cases, there was only a minor effect of row spacing on gross margin, and scarcely enough to justify a potentially costly change in equipment configuration.

Conclusions

Row spacing had little influence on yield, quality or profitability of maize, whereas plant population had a major effect on all three. As a result of these (and other) experiments, it would appear that the cheapest and simplest route to improved profitability from maize is through increased plant populations rather than reduced row spacing.

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