Optimising sweet corn plant population by planting date combinations across New Zealand

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Abstract

Planting date and population are key agronomic factors that affect the yield of sweet corn. Early planting dates in October typically maximise radiation interception when solar radiation peaks in late December and higher populations increase net crop radiation interception during early growth. However, early planting increases the risk of frost damage in some regions and greater plant population densities result in higher seed costs. Currently the New Zealand sweet corn processing industry uses the same population throughout the entire season. To evaluate if plant populations could be optimised based on seasonal radiation patterns to improve profitability a sweet corn model was run for a range of planting dates, populations and cultivars for the Hastings, Gisborne and Blenheim regions using 20-30 years of historical weather data. The influence of frost and irrigation were also included. Positive associations between populations, early planting and late maturing cultivars with yield appear consistent among regions with the exception of frost affected crops in Hastings. Reducing costs by lowering populations is likely to decrease yield and total revenue by more than the cost savings, but this may change depending on differences in prices paid per tonne of product and seed costs.

Additional keywords: radiation interception, crop maturity, processing capacity, frost, irrigation, *Zea mays* L.

Introduction

Producers of sweet corn (Zea mays L.) need to balance a range of factors including planting date, population, irrigation and soil fertility in order to remain profitable and environmentally sustainable. Planting date affects net crop radiation interception of sweet corn, and early planting dates, typically in October, achieve the greatest net radiation interception (Stone *et al*., 1998; Rogers *et al*., 2000). Though early planting dates using long season cultivars may achieve the highest radiation interception and therefore yield, processors require a spread of maturity times over which processing capacity is available. Processors therefore routinely sacrifice some potential yield by using a range of planting times and a mix of cultivars to align crop maturity with processing capacity.There is a positive relationship between population and net crop radiation interception; crops established at higher populations will often mature at the same time as lower populations densities but they will achieve critical leaf area sooner and therefore intercept more radiation, potentially yielding more (Stone *et al*., 1998). However, higher populations come at the expense of additional seed, fertiliser and water. Therefore the gain in yield from increases in population needs to be considered in light of the additional expense incurred. The yield benefit achieved by increasing plant population will also be affected by factors which determine the overall crop performance such as planting date and cultivar. Additionally, populations beyond an optimum can have a negative effect on yield and quality by reducing the percentage of kernel fill (Rogers and Lomman, 1988). Plant population can also have indirect effects on crop performance. For instance Limpus *et al*. (2010) highlighted a positive relationship between population and both water use and water use efficiency in fresh market sweet corn.

Frost during crop growth can reduce the yield of sweet corn by damaging plant tissues. This places constraints on the planting time of sweet corn as planting too early or too late can risk frost damage. Wilson and Salinger (1994) and later Fletcher and Moot (2006) used the threshold of an air temperature < -1°C or grass minimum < -3°C and assumed that under these conditions the crop would no longer produce a marketable yield. Despite its simplicity and lack of direct experimental testing, the most widely used threshold for frost damage in New Zealand remains those used by Wilson and Salinger (1994).

The purpose of this paper is to test the hypothesis that optimum plant populations differ with planting date. The additional abiotic effects of frost and irrigation were also considered.

Materials and Methods

A simple model was used to estimate the yield of sweet corn ears (72% moisture) under optimal nutrient supply (Reid, 2016). This model simulates the time course of total and green leaf area index, and from these calculates cumulative light interception and biomass yield. Leaf growth and senescence, and radiation conversion efficiency vary with soil water deficit. Finally ear dry mass is calculated assuming a linear relationship between harvest index and thermal time from silking. The model was parameterised using experimental datasets for the response of sweet corn to water deficit, sowing time and plant population (Reid, 2016).

For the calculations reported here, we tested a factorial combination of 13 plant populations (in steps of 5,000 from 40,000 to 100,000 plants/ha), seven planting dates (from 1 October to 28 December) and two irrigation scenarios (unirrigated, or irrigated to minimise stress by returning the soil to within 5 mm of field capacity whenever the soil water deficit reached 30% of the available water capacity). Each of those factorial combinations was tested for further factorial combination of three locations and three cultivars. The regions were Gisborne, Hastings and Blenheim; for each of these the calculations were repeated with at least 20 seasons of weather data sourced from NIWA weather stations Whakatu EWS, Gisborne Aero/AWS and Blenheim AWS. The cultivars were distinguished by their duration: short (‘Sheba’), medium (‘Challenger’) and long (‘XP1029’). Cultivar specific parameters for the model (notably maximum number of leaves, maximum leaf area per stem, and thermal times from sowing to silking and harvestable maturity) were gathered by examination of the data of Rogers *et al*. (1999; 2000) and Stone *et al*. (1998; 2001a; 2001b). Economic comparisons were made on the basis of paid yield at a price of $200 per tonne with an 8% discount for quality across all sowing dates and regions and a fixed seed price of $724 per 100,000 seeds. Fixed costs and variable costs of irrigation and fertiliser were not included.

One potential consequence of early or late sowing is damage from frost. Unfortunately, we are aware of no experiments that included direct and relevant measurements of the consequences of frost on sweet corn. So, best and worst case scenarios we examined. For the potential worst-case scenario it was assumed that if an air temperature < -1°C or grass minimum < -3°C temperature was reached, the crop would no longer produce any yield (Wilson and Salinger, 1994). The best case scenario assumed frost had no effect on yield.

The total number of combinations of population density, planting date, cultivar, location, season, irrigation and frost scenario was 82,057. Comparisons between scenarios were made on the basis of mean predicted yield, and paid yield minus the seed cost. Though the variability of predicted yields were initially explored and trends found to be consistent within any one planting date, mean yields are reported, as number and range of predicted yields within the mix of scenarios evaluated would have obscured the underlying trends.

Results

First the effect of plant population on simulated yield was considered for early (1 October), mid (15 November) and late (30 December) season planting dates for each year, and frost effects assumed. For this situation there is a positive relationship between simulated mean yield and population in all regions (Figure 1). This was consistent both with and without irrigation, though the yield achieved and the magnitude of yield differences between populations were increased by irrigation. The early plantings achieved the highest mean yield in Blenheim and Gisborne but in Hastings yields were higher for mid-season plantings. Early plantings in the former regions intercept a greater proportion of the seasonal radiation than other planting times. This was not the case in Hastings due to the higher prevalence of frost early on in the season. Late plantings missed much of the seasonal peak in radiation and achieved the smallest simulated mean yields.

The highest populations were the most profitable when taking in to account the price paid for yield and cost of seed (Figure 2). This indicates that on average the additional revenue received from increasing the population was greater than the cost of additional seed. It should be noted that this analysis was undertaken using a fixed yield price and cost of seed. Changes in these variables or in deductions due to changes in quality are likely to affect the economic return growers receive. Fixed costs should also be considered if calculating the expected gross margin of production, but they vary greatly between individual growers and are outside of the scope of this paper.

The comparison among cultivars planted at 65,000 (commercially typical) and 100,000 plants/ha showed that longer duration cultivars were expected to produce the highest yields for any specific planting date within the season (Figure 3). The longer duration cultivars intercepted more radiation during growth and these benefits were not cancelled out by the risk of frost during late season growth. Irrigation had a positive effect on mean simulated yield, and the differences in yield among cultivars.

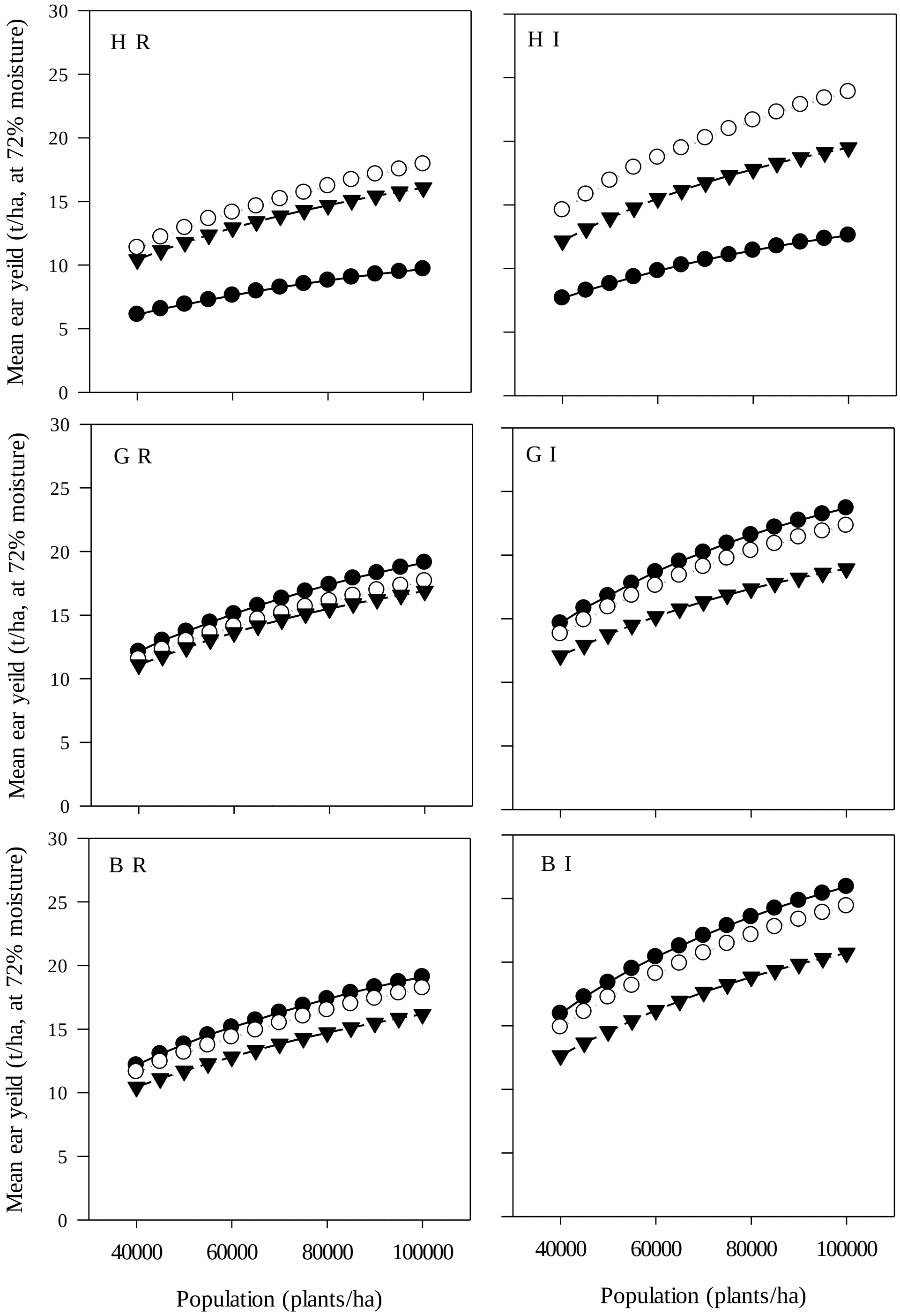

Figure 1: Effect of sweet corn population on fresh mean ear yield (t/ha, at 72% moisture content) for early, mid and late planting dates (1 October ●, 15 November ○, and 30 December ▼ planting day of year) for rain fed (R) and irrigated (I) long maturity cultivar crops with frost sensitivity in Hastings (H), Gisborne (G) and Blenheim (B).

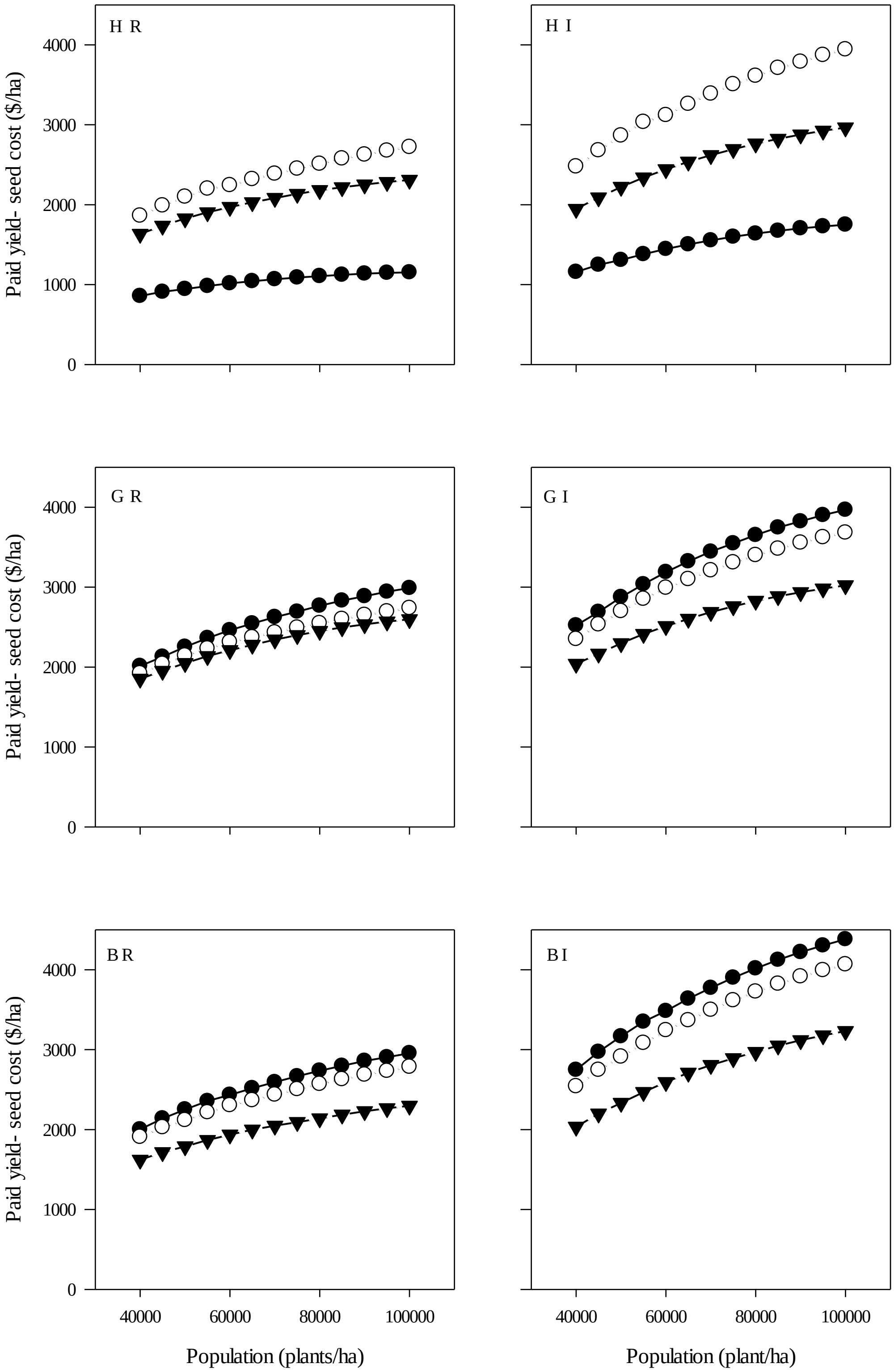

Figure 2: Mean paid yield less seed cost for populations from 40,000 to 100,000 plantings (1 October ●, 15 November ○, and 30 December ▼ planting day of year) for rain fed (R) and irrigated (I) long maturity cultivar crops with frost sensitivity in Hastings (H), Gisborne (G) and Blenheim (B).

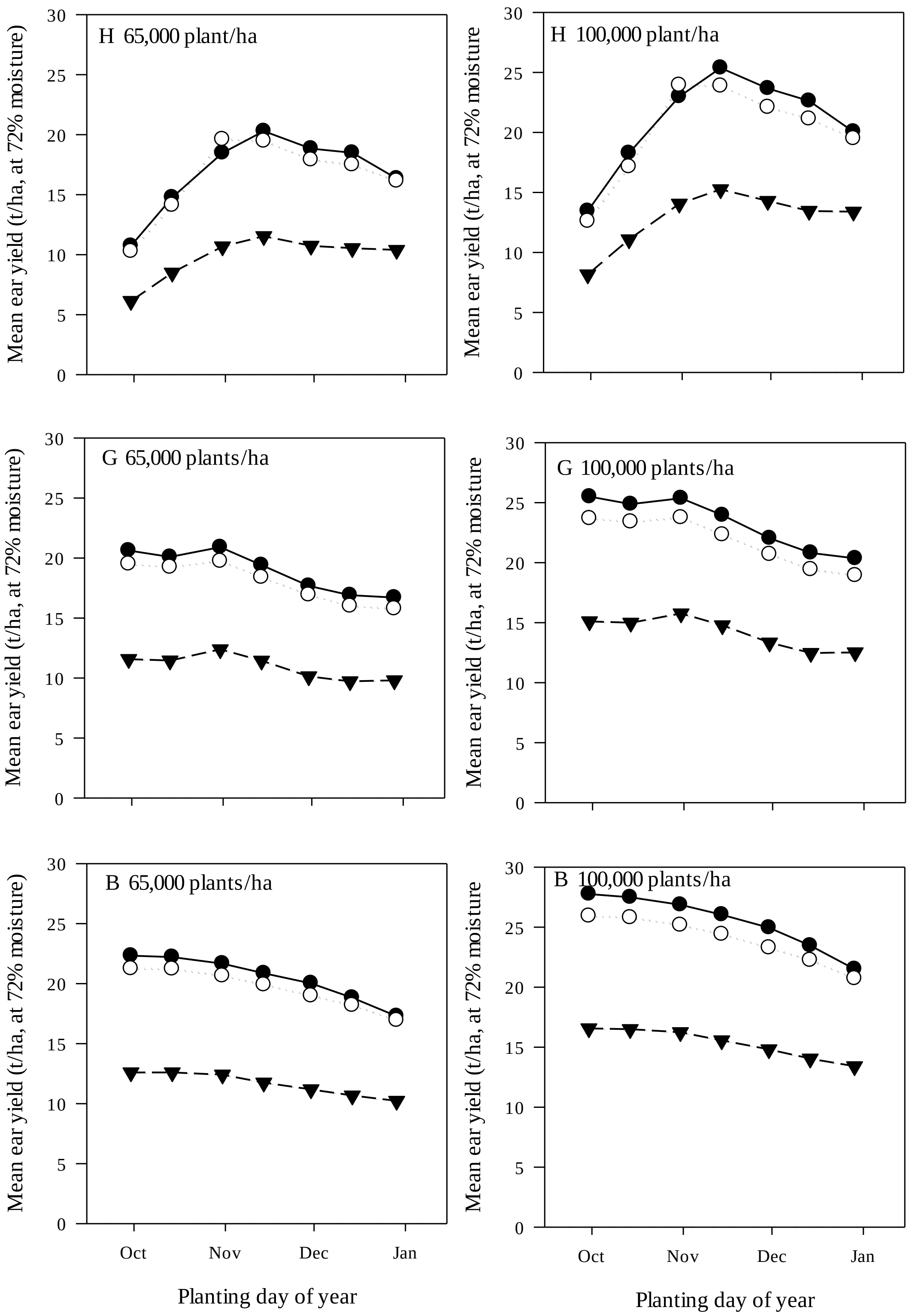

Figure 3: A comparison mean ear yield among short (▼), medium (○) and long (●) maturity cultivars over a range of planting dates for the Hastings (H), Gisborne (G) and Blenheim (B) regions at 65,000 and 100,000 plants/ha with scheduled irrigation and with frost effects.

Frost incidence had a profound effect on the mean yield of early planting in Hastings, reducing the simulated mean yield by approximately 50% (Figure 4). This was a consequence of frost killing crops for 1 October plantings in Hastings for 11 of the 21 years simulated. Frost made little difference in the other regions where sweetcorn yield was simulated due to the infrequency within the weather data used for this simulation.

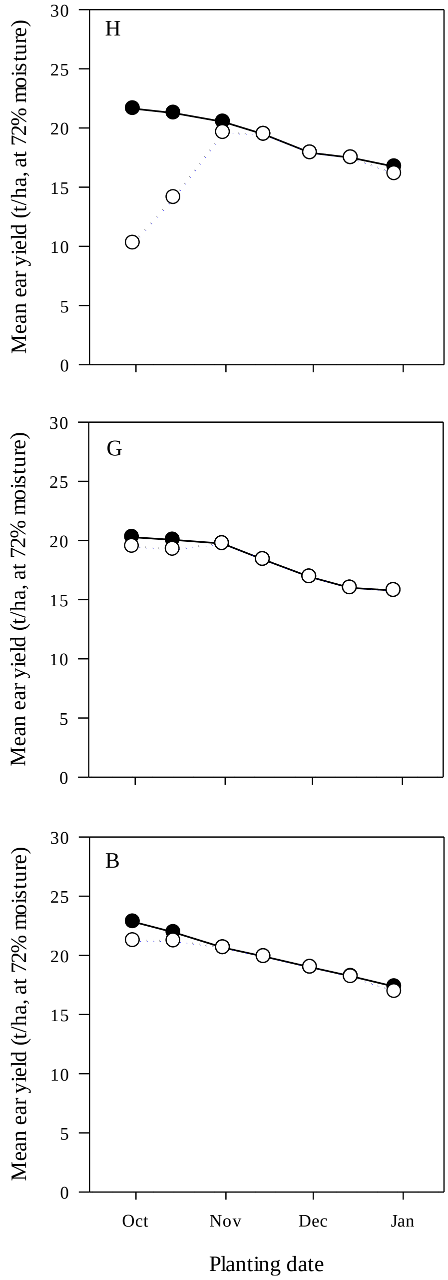

Figure 4: A comparison of mean ear yield for frost sensitive (○) and frost insensitive (●) medium maturity cultivars at a population of 65,000 plants/ha, over a range of planting dates for the Hastings (H), Gisborne (G) and Blenheim (B) regions with irrigation.

Discussion

The results indicated that increases in population up to 100,000 plants/ha would result in additional yield across the three maturity cultivars evaluated and the range of planting dates. Thus, unless growers face variable costs exceeding the expected returns from marginal yield increase they may continue to see benefits from increasing populations up to 100,000 plants/ha. It is important to acknowledge that the model does not include risk factors such as pests, diseases, pollination or extreme weather events. Additionally the model does not incorporate quality parameters such as kernel fill; these may also be reduced at high populations, but have previously been found to be minimal (Rogers and Lomman, 1988). The results also indicate there is still a yield benefit from increasing populations when irrigation is not available. However, the marginal yield gain from increasing population is greatest when irrigation is applied and for the earlier sown crops. There was no obvious yield peak in the population by planting time relationship that would indicate an optimum has been reached. The highest populations are predicted to intercept the greatest amount of solar radiation and the returns from the resulting additional yield are expected to outweigh the cost of additional seed. This would not be the case if there were substantial increase in the cost of seed or reduction in the price paid for yield.

The implications of planting date and population on the consistency of supply may be of particular interest to processors. While early planting produced the highest average yields without frost sensitivity, average yields declined markedly when frost sensitivity was included, especially in Hastings. Thus the scheduling of early planting crops for production in frost prone regions can lead to either high or no yields. It is worth noting that the algorithm for frost impact used here and previously by Wilson and Salinger (1994) and Fletcher and Moot (2006), constitutes an extreme potential frost effect. Actual effects of frost may not be as large as predicted in this work. Previous frost modelling within sweetcorn has assumed total crop death after assumed thresholds (Wilson and Salinger, 1994), but experimental measurements are lacking for the response of sweet corn to air temperatures around 0°C at either end of the growing season. Maize models have used a sliding scale of frost stress to reduce leaf area (APSIM, 2016), though again supporting evidence for this is scarce. Further experimental investigations of the sensitivity of sweet corn to frost including the stage of development and relative impact on crop performance are recommended.

Conclusions

Positive relationships between populations, early planting and late maturing cultivars with yield appear consistent among regions with the exception of frost affected crops in Hastings. Reducing costs by lowering populations is likely to decrease yield and total revenue by more than the cost savings, but this may change depending on differences in prices paid per tonne or product and seed costs.

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