Optimising maize planting date and hybrid selection using simulation modeling

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Abstract

A simulation study was conducted to establish how maize hybrid maturity interacts with planting time to determine maize (*Zea mays*) grain yields. Using 31 years of weather data from three locations, a modified version of the CERES Maize model was used to establish the best maize hybrid maturity x planting date (PD) combinations required to minimise risk and maximise grain yields. Maximised yields generally resulted from early to mid October plantings. These dates meant that high total irradiance during grain filling coincided with moderate temperatures (19-25°C) required to maximise yields. When planted outside the optimum PD range, maize grain yields were reduced at rates depending on location and/or hybrid maturity. Warmer locations and earlier maturing hybrids had wider planting windows than later hybrids grown in cooler locations. Due to less variability in performance, earlier hybrids could also be considered a better option to plant in stressful or low yielding situations.

Additional keywords: CERES-Maize, planting window, maize grain yields, switch date

Introduction

In New Zealand different environmental and agronomic conditions exist between and within the main maize growing regions, requiring variable management options for individual situations. Hybrid maturity duration and planting date (PD) need to be appropriately balanced with other agronomic and environmental factors. Yields are usually maximised when growth coincides with optimum growing conditions such as maximum radiation levels (Sorensen *et al*., 2000). Bruns and Abbas (2006) observed that long duration hybrids generally yielded more than early maturing hybrids under non-limiting season lengths. Research conducted in New Zealand also showed a yield penalty from planting short duration hybrids if season length was sufficient for later maturing hybrids (Sorensen *et al*., 2000). It is hence critical to select an appropriate maize hybrid that fits within a specified location and planting window, particularly in situations where planting has been delayed, or in replant situations.

Even though agronomic studies are usually used to establish PD effects on maize development and yield (Capristo *et al*., 2007), seasonal variations across years and locations reduce their utility. The complexity of crop x location interactions on crop production may be simplified if a user-friendly decision support system could be developed that more accurately predicts their effects in real time using long term weather information to determine a realistic estimate of risk.

The objective of this study was to predict the interaction between maize hybrid maturity and PD in different environments for grain yield magnitude and stability over time using a New Zealand modified version of the CERES-Maize model (Jones and Kiniry, 1986).

Materials and Methods

Five or six hybrids of varying maturities were sown in three Waikato and one Manawatu environment over four or five PDs between 2006 and 2007 planting seasons. Full details of the field experimental procedures are described in Tsimba *et al*. (2013a; 2013b). Maize growth and development data from these field experiments were used to calibrate and evaluate perfomance of the CERES-Maize model under New Zealand conditions. To improve confidence in the model performance, independent data sets were used for model calibration and evaluations. Full details of model limitations, modifications and evaluation procedure are described in Tsimba (2011). In summary, the modified model was considered adequate to use under New Zealand conditions and extended to simulate the interaction between planting time and maize hybrid maturity on maize grain yield in three locations in Waikato (Hamilton), Poverty Bay (Gisborne) and Bay of Plenty (BOP, Whakatane) using 31 years of historical weather data (1978-2009). In general, Poverty Bay can be considered the warmest climate and Waikato the coolest (Table 1). In all locations, weather data were obtained from the NIWA automated weather station closest to the largest concentration of maize production. These were, respectively, Hamilton (37° 52' 12" S, 175° 20' 24" E, 50 m above sea level), Gisborne (38° 39' 36" S; 177° 58' 48" E, 5 m above sea level) and Whakatane (37° 55' 48 "S; 176° 55' 12 "E, 6 m above sea level). The Horotiu sandy loam (vitric orthic allophanic soil), Makarori silt loam (weathered orthic recent soil) and Whakatane loamy sand (allophanic orthic pumice soil) were used for model runs for the three areas, respectively.

Long term model simulations were conducted for six maize hybrids, representing three maturity classes (early, mid and late), and nine PDs (1 and 15 September, 1 and 15 October, 1 and 15 November, 1, 15 and 31 December). The six hybrids were 34P88 and 34D71 (late), 36M28 and 36B08 (mid), and 38P05 and 38H20 (early).

In each location, the planting date and hybrid maturity treatments in the simulation experiment were arranged as a factorial design. The simulated grain yield scenarios from the PD and maturity treatments were compared by ANOVA using the Mixed Procedure (Proc Mixed) in SAS (Littell *et al*., 2006). Years (31) were treated as replications.

Table 1: Mean monthly minimum (T_{min}) and maximum (T_{max}) temperatures across three New Zealand environments (Waikato, Hamilton; BOP, Whakatane; Poverty Bay, Gisborne) over a 31 year period (1978-2009). Data from www.cliflo.niwa.co.nz - 26 April 2010.

	Waikato		BOP		Poverty Bay	
Month	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}
			°C			
September	16.3	6.3	16.5	6.4	17.0	7.1
October	17.8	8.0	18.2	8.4	19.0	8.8
November	19.8	9.5	20.2	10.3	21.0	10.7
December	22.0	11.5	22.1	12.6	23.2	13.0
January	24.1	12.4	23.9	13.8	24.7	13.9
February	24.6	12.7	24.2	14.1	24.2	14.0
March	22.8	11.0	22.7	12.0	22.6	12.4
April	19.9	8.5	20.0	8.9	19.9	9.8
May	16.8	6.2	17.3	6.3	17.4	7.5
Mean	20.5	9.6	20.6	10.3	21.0	10.8

To determine yield response to PD, simulations were conducted across the nine PD treatments, holding all other variables constant. Nitrogen was assumed to be non-limiting in all simulations since maize fertiliser applications are usually based on soil test results. The seeding rates used for simulations using mid- and late- hybrids were 10.7 plants/m^2 while the performance of early maturing hybrids was simulated using 11.4 plants/m^2.

Quadratic regression analysis was applied to the average simulated yield data across the nine PD treatments to estimate the PD that would on average result in the highest simulated yield for each location. The best PD was considered as one resulting in the highest simulated yields with the least risk of crop failure, defined here as either frost damage or inability to reach harvest maturity within a specified time-frame.

For practical purposes and to allow for planting flexibility, the range of optimum PDs, hereafter referred to as the "planting window" were determined. Planting dates with ≤5% yield reduction were considered to be within the planting window required to maximise yields. Estimation of the optimum planting window also took into account the risk probability and the chance of attaining threshold grain yield levels of 10 t/ha (Tsimba, 2011).

Grain was considered ready for harvest when it reached 24% moisture, and crops failing to reach 24% grain moisture by 30 June were considered to have failed and awarded a 0 t/ha yield. Using the 31 yr of weather data, probability tables for risk were constructed and "switch" dates when yields from a later hybrid equalled an earlier hybrid were determined.

Results

Across locations and PDs, average simulated grain yield was ranged from 0 - 15.6 t/ha (Table 2). Provided they were planted in the right environment, later maturing hybrids usually outyielded earlier hybrids when planted early. Poverty Bay had the highest average simulated yields (11.8 t/ha), compared to 9.3 and 7.6 t/ha for

BOP and Waikato, respectively. In Poverty Bay, highest yields (>15.0 t/ha) were observed with mid October plantings. In BOP, the highest yields (≥13.0 t/ha) were obtained with early to mid October PDs. In Waikato, maximum yields were obtained with late September to early October plantings.

Very early planting (1 September) resulted in 20-24% yield reduction in BOP and Poverty Bay, with an even greater loss in the Waikato (Table 2). Late hybrids generally had an earlier optimum planting date than mid or early hybrids (Table 3).

Table 2: Simulated maize grain yields (kg/ha) for nine planting dates and three hybrid maturities planted in three New Zealand environments over 31 year (1978-2009)

	BOP			Waikato			Poverty Bay		
Planting Date	Late	Mid-	Early	Late	Mid-	Early	Late	Mid-	Early
01 Sep	9,852	10,470	9,426	7,731	8,697	8,904	11,561	11,525	11,564
15 Sep	12,612	12,479	12,327	10,217	11,364	11,115	13,654	13,199	14,258
01 Oct	12,931	13,200	12,967	11,577	12,058	11,788	15,287	15,563	15,012
15 Oct	12,940	13,196	12,746	11,521	11,805	11,585	14,741	15,620	15,443
01 Nov	12,208	13,223	12,781	9,518	11,355	11,174	15,076	15,511	15,109
15 Nov	10,065	12,689	12,936	6,494	9,794	10,236	14,253	14,951	15,007
01 Dec	4,460	8,330	11,686	1,007	5,601	7,878	10,317	14,108	14,033
15 Dec	425	1,175	5,911	0	587	2,397	1,620	7,042	11,564
31 Dec	0	0	181	0	0	145	436	436	1,286
SE		555.6			481.5			540.9	

Table 3: Estimated planting windows required to achieve ≥95% of the highest possible grain yields and maintain crop failure risks to P≥0.1 for three hybrid maturity classes across three environments of New Zealand. Date in parenthesis refers to the planting date resulting in the maximum grain yields.

Environment	Hybrid Maturity	Optimum PD
BOP	Early	29 September - 2 November (16 October)
BOP	Mid	23 September - 27 October (9 October)
BOP	Late	19 September - 20 October (2 October)
Poverty Bay	Early	1 October - 5 November (18 October)
Poverty Bay	Mid	30 September - 3 November (17 October)
Poverty Bay	Late	25 September - 28 October (11 October)
Waikato	Early	23 September - 27 October (9 October)
Waikato	Mid	20 September - 24 October (6 October)
Waikato	Late	17 September - 15 October (26 September)

Unlike Poverty Bay, a 15 November PD (or later) in Waikato and BOP significantly increased risk of crop failure for late hybrids (Table 4). Even though mid hybrids could be considered adequate in BOP for this PD, only early hybrids could be planted with minimal risks in Waikato. With early hybrids, a 1 December planting resulted in yield reductions of ≤10% for BOP and Poverty Bay compared to 33% in Waikato.

In Waikato, the lowest yield variability was observed with 1 to 15 October plantings. This date was consistent for late hybrids in BOP though 1 October to 15

November applied to early and mid hybrids. In contrast, a wider window existed for Poverty Bay where early and mid hybrids achieved CV's of <10% between 1 October and 1 December compared to 1 October to 15 November for the late group.

The planting windows required to achieve break-even yields by 30 June, with a risk level (crop failure) of P<0.1, varied across ENVs, crop or hybrid maturity (Table 5). Under Waikato conditions (relatively poor soil structure), late hybrids could only be planted up to 21 October for grain, after which potential yields were significantly reduced. Earlier hybrids were a less risky choice for grain production. Across locations, the lowest yields were obtained under water stress, very early or late planting conditions, whereas highest yields came from simulations of early to mid October plantings.

Table 4: Probability of grain crop failure / risk for nine planting dates and three maize hybrid maturities simulated over 31 year in three New Zealand environments.

Planting Date		01 Sep	15 Sep	01 Oct	15 Oct	01 Nov	15 Nov	01 Dec	15 Dec	31 Dec
Site	Maturity	Probability								
	Late	0.24	0.08	0.00	0.00	0.03	0.19	0.61	0.97	1.00
BOP	Mid	0.24	0.08	0.00	0.00	0.00	0.02	0.32	0.90	1.00
	Early	0.24	0.08	0.00	0.00	0.03	0.19	0.61	0.97	1.00
	Late	0.34	0.11	0.03	0.03	0.19	0.42	0.87	1.00	1.00
Waikato	Mid	0.34	0.11	0.00	0.00	0.05	0.15	0.48	0.94	1.00
	Early	0.34	0.11	0.00	0.00	0.02	0.06	0.29	0.73	0.98
Poverty Bay	Late	0.20	0.09	0.00	0.00	0.00	0.00	0.27	0.87	1.00
Poverty Bay	Mid	0.20	0.09	0.00	0.00	0.00	0.00	0.03	0.47	0.97
Poverty Bay	Early	0.20	0.09	0.00	0.00	0.00	0.00	0.02	0.13	0.90

Table 5: The latest planting dates to maintain crop failure risk at P<0.1 and achieve a high probability (P≥0.7) of attaining break-even grain yields for three hybrid maturities in three New Zealand environments.

Environment	Hybrid maturity	Latest PD
BOP	Early	27 November
BOP	Mid	19 November
BOP	Late	09 November
Poverty Bay	Early	09 December
Poverty Bay	Mid	06 December
Poverty Bay	Late	20 November
Waikato	Early	24 November
Waikato	Mid	06 November
Waikato	Late	21 October

Discussion

Overall, across the three locations, simulated yields were consistent with other New Zealand trial results (Genetic Technologies, 2009; Tsimba *et al*., 2013a). Simulated optimum PDs for the three locations were around early and mid October, in general agreement with optimum PDs from field studies in Waikato and Manawatu (Tsimba *et al*., 2013a). The simulated optimum PDs required to maximise yields are also in agreement with the general recommendation that planting should be considered when soil temperatures are ≥10°C (Shaw, 1988).

Within a location, optimum PDs required to achieve the highest yields were generally similar, irrespective of hybrid maturity. Field studies conducted in Waikato and Manawatu (Tsimba *et al*., 2013b) revealed that the main difference between hybrids of dissimilar maturities was in the grain filling duration rather than emergence-anthesis duration. Consequently, onset of grain filling is generally similar for hybrids planted on the same date irrespective of maturity. Maize crops planted around early to mid October normally flower in January so grain filling occurs under high irradiance and moderate temperature conditions of between 19 and 25°C, resulting in maximum yields (Muchow et al., 1990).

Planting outside the optimum PD range resulted in yield reductions, varying in magnitude in a way that depended on location or hybrid maturity. Effect of late planting on yield was greater in cooler locations (e.g., Waikato). In cooler locations, temperature may hence be considered as the most limiting factor to maize production. Compared with their later maturing counterparts, lower yields in early hybrids, particularly when sown early in the season, are usually due to source limitation caused by smaller leaf area, lower radiation interception and cooler temperatures (Stone *et al*., 1999). The smaller ear size also means that under optimum conditions, early hybrids are also sink-limited, failing to achieve maximum yields for the environmental conditions (Sorensen et al., 2000).

The study showed that in low potential situations (e.g., low water holding capacity soils) with a high chance of a mid season drought, late hybrids have a lower probability of producing adequate yields than earlier hybrids. This is probably because early hybrids have shorter growth duration, smaller sink size, a better source-sink balance and hence a lower probability of encountering adverse growing conditions. Since earlier hybrids' performance was less variable (vs. late hybrids) across all environments, they will be a better option to plant in stressful conditions (e.g., the selected Waikato location) or when planting is delayed. Similarly, due to their larger sink and source sizes, late hybrids should be planted under the best and most reliable growing conditions to take full advantage of the environment capability (Sorensen *et al*., 2000; Capristo *et al*., 2007).

The longer growth durations of later hybrids subjected grain crops to a greater risk of failing to mature in a timely manner when planted late. Higher risks due to late planting of late hybrids have also been reported widely in the literature (e.g., Fletcher *et al*., 2008). Earlier hybrids and warmer environments have wider planting windows. The date for switching hybrids in order to minimise risk and maintain reasonable yields was dependent on the location, being later in warmer environments.

Conclusions

Planting between early and mid October maximised yields in all three regions. Risks due to early planting were higher in cooler than warmer locations whereas crop failures due to late planting were greatest for late hybrids, particularly in cooler areas. Though late hybrids generally outyielded early hybrids when planted early, the reverse occurred when planting was delayed, particularly in cooler areas.

Based on historical independent yield data, CERES-Maize was able to model the effect of planting date on hybrid choice. A "switch" date, when an early hybrid should replace a late hybrid, can hence be estimated. The date for switching hybrids in order to minimise risk and maintain reasonable yields was dependent on the location, being later in warmer areas.

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