The effect of planting date on maize: silage yield, starch content, and leaf area

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Abstract

Four field experiments were established in the Waikato and Manawatu regions over two years to determine planting date (PD) influence on growth, silage yield (SY) and starch content of seven maize (*Zea mays*) hybrids. Silage yield response to PD was best described using quadratic regression models. The PD at which silage yield was maximised (optimum PD) was later in the cooler, high latitude environment of Manawatu (23 October) than the more northerly locations in Waikato (9-15 October). In both regions, planting 2 or 3 weeks either side of the optimum PD reduced SY by <5%. In Waikato, the optimum PD in a warmer than average spring (+1°C) was 1-2 weeks earlier. Under non-limiting moisture conditions later planting reduced yields in both Waikato (24.22 versus 21.06 t/ha) and Manawatu (30.09 versus 22.50 t/ha). This was attributed to decreased temperatures (<15°C) and radiation (<17 MJ/m^2/d) during grain filling. Due to more rapid reductions in autumn temperature and radiation in Manawatu, yield decline beyond the optimum PD was greater (-183 kg/ha/d (0.6%), R^2=0.81) than Waikato (-50 to -85 kg/ha/d (0.3%), $R^2 \geq 0.67$). Starch content was highest for plantings before 6 November, dropping thereafter with harvest index. Highest maximum leaf area index was observed at mean daily temperatures of 17-19°C.

Additional keywords: harvest index, leaf area index, starch, maize silage

Introduction

Maize silage is of major importance to the New Zealand dairy industry where 4.8 million cows are milked on 1.7 million ha producing about 18.9 billion litres of milk every year (DairyNZ, 2014). Global milk demand is expected to increase as a result of increases in population, protein demand, income levels and urbanisation in the developing world.

Even though dairy farming in New Zealand is primarily pasture-based, the intensive production system, the economic incentives to get greater production from a given land area, and the increased global demand for milk means that supplementary feeding from other sources such as maize silage plays a pivotal role in meeting seasonal feed deficits. Inclusion of maize silage in a grass-based system can increase feed intake, milk yield and milk protein levels (Phipps *et al*., 2000).

Maize silage is considered primarily as an energy source (Mahanna, 2014). Lactating cows fed maize silage require feed with 14-18% crude protein (Kolver, 2000) and hence high protein pasture or other supplements are required to fill the deficit. The energy in maize silage is largely due to its high grain content, so a decrease in harvest index associated with delayed plantings (Tsimba *et al*., 2013a) could significantly influence silage quality.

The common pasture rotation system in the North Island includes maize silage as a supplement (Densley *et al*., 2006). Maize growers are faced with the task of selecting hybrids that will maximise silage yield (SY) and quality. Their hybrid choices should fit within their farming systems such that harvesting is completed either in time for autumn grass planting or before the first killing frost in autumn. On the other hand, to maximise yield and quality (e.g., starch content) crop growth and development should coincide with the best environmental conditions for maize growth. Environmental factors such as temperature, radiation and soil water vary with season. However within these mean trends there is a degree of day-to-day and season-to-season variation resulting in uncertainties in crop production and optimal management. Environmental interactions with crop growth and development influence crop cycle duration, yield, grain content and quality. For instance, if intercepted photosynthetically active radiation (IPAR) levels around flowering are low, harvest index (HI) may be significantly reduced due to barrenness which reduces grain content and lowers starch and metabolisable energy (ME) content of the silage. Under favourable growing conditions, assimilate production rate, which determines maize yields, is driven by leaf area index (LAI), IPAR and leaf photosynthetic rate (Monteith, 1977).

The objective of this study was to quantify SY, starch content and LAI responses of maize hybrids differing in maturity when planted under a range of environmental factors (temperature, radiation, photoperiod and water) generated by a wide range of planting dates (PDs). A wider range of crop responses to PD in this same research but different study are described in Tsimba *et al*. (2013a; 2013b), and the relationship between crop response to planting date and environment is further explored by Tsimba (2011) using a crop simulation model.

Materials and Methods

Background

Site and planting details are described in detail in Tsimba *et al*. (2013a). In summary, four replicated experiments (hereafter considered environments or ENVs) were conducted over two seasons at Rukuhia Research Station (37° 52’ S, 175° 20’ E) in 2006-2007 (RUK07), and 2007-2008 (RUK08), Ngaroto Research Station (37° 58’ S, 175° 19’ E) in 2007-2008 (NGA08) and Massey University (40° 22’ S, 175° 34’ E) in 2007-2008 (MAS08).

Massey University is located in the Manawatu region and is characterised by a shorter growing season. The hybrids used, planting details, weather data collection and experimental design has been previously described (Tsimba *et al*., 2013a).

In short, five or six single cross hybrids representing three maturities (early, mid- and late) were planted in Manawatu and Waikato ENVs over four or five PDs (PD1-PD5) that spanned mid-September to mid-December.

In Waikato, six single cross hybrids representing three maturities, early (38H20 and 38P05), mid- (36B08, 36M28) and late (34D71 and 34P88) were planted across 5 PD’s, PD1 to PD5, each three weeks apart. The respective comparative relative maturities (CRM) were 91 (38H20), 94 (38P05), 102 (36B08), 103 (36M28), 107 (34D71) and 109 (34P88). Planting dates were 18 September, 11 October, 2 November, 24 November, and 15 December 2006 (RUK07), 20 September, 13 October, 1 November, 22 November, and 13 December 2007 (RUK08) and 21 September, 11 October, 1 November, 22 November, 13 December 2007 (NGA08). For MAS08 five hybrids classified as early (39G12, CRM 78), mid- (38H20 and

38P05) and late season (36M28 and 36B08) were planted on 16 October, 6 November, 23 November, and 10 December 2007. All hybrids were planted at 130,000 plants/ha and thinned around the V4 leaf stage to either 110,000 (39G12, 38P05, 38H20) or 105,000 (for all other hybrids). These planting densities were derived from optimum agronomic planting densities required to maximise silage yield under unstressed conditions (Genetic Technologies Limited, 2013).

Leaf number and leaf area index

Before the first leaf had senesced, ten plants in the centre two rows (five consecutive plants per row) were tagged by cutting the tip of leaf five. Leaf 10 was also tagged as soon as it appeared. Tagged leaves were used as reference points for convenient and accurate counting of leaf number after the lower leaves had senesced.

At anthesis, four consecutive plants were selected for green LA measurements in each plot. The length (from ligule to leaf tip) and width (the widest portion of the leaf blade) of each green leaf were measured *in situ*. Individual green LA was estimated as the product of leaf length and maximum breadth, adjusted by a constant coefficient as follows:

$$LA = \text{length} \times \text{maximum width} \times 0.75$$

(Elings, 2000)

Maximum LA per plant was calculated by summing the individual LA's. Leaf area index for each plot was calculated as the average plant maximum LA divided by the average land area occupied by a single plant.

Silage DM Yield

A bordered area of 7.6 m^2 (2.5 m x 0.76 m x 4 rows) at RUK07 was hand-harvested for total aboveground biomass, at approximately 35% DM content hereafter referred to as silage. Harvested areas for the other sites were 9.8 m^2 (3.5 m x 0.7 m x 4 rows), 5.9 m^2 (3.9 m x 0.76 x 2 rows) and 11.9 m^2 (3.9 m x 0.76 m x 4 rows) for MAS08, NGA08 and RUK08 respectively. To accurately determine harvest maturity, plants from the border rows were periodically sampled and oven dried to determine DM content, starting when kernels from the centre of the ear had reached about 50% milk line (Wiersma *et al*., 1993).

Plants were cut at ground level and weighed immediately. Six plants were randomly selected as a subsample for DM and quality analysis. The six plants were mulched into a homogenous sample using a modified chipper shredder. A 1 kg representative subsample from the mulched biomass was oven dried to constant weight at 75°C to estimate silage DM. A further 1 kg subsample was collected for starch content determination and sent to a commercial laboratory for quality assessment by near-infrared spectroscopy (NIRS) using the Pioneer® World Forage NIRS calibration (Welle *et al*., 2003).

Data analysis

Proc GLM in SAS was used to estimate the relationships between silage yields, starch content and LAI and associated components by least squares regression on PD or on thermal time (Tsimba *et al*., 2013b). The notation *, ** and *** is used to illustrate significance at $P<0.05$, $P<0.01$ and $P<0.001$ respectively, while NS refers to $P\geq0.05$.

Results

Weather Summary

Mean monthly weather data are described by Tsimba *et al*. (2013a). The ENVs of RUK07 and MAS07 experienced no obvious water stress, but NGA08 was somewhat affected by drought occurring sporadically from December through April, while RUK08 on shallow lighter soil was severely affected by drought over the same period. The total rainfall (including irrigation) for RUK07, MAS08, NGA08 and RUK08 was 650 mm, 498 mm, 562 mm and 545 mm respectively (Tsimba, 2011). Both RUK08 and NGA08 experienced higher than normal spring and summer temperatures. A general steady increase in mean temperature from PD1 to PD5 characterised all ENVs.

Leaf area index

Across hybrid maturity classes, ENV had a significant effect on the average total leaf number, with highest values obtained at NGA08 (18.7) and RUK08 (18.6). RUK07 averaged 18.4 leaves across treatments while MAS08, which had an earlier set of hybrids, had the lowest total leaf number (17.9).

At NGA08, PD had a significant effect on leaf number, with the highest numbers obtained under PD1 (19.1) and PD2 (18.9) conditions. The fourth and fifth plantings had significantly less leaves (18.4 and 18.5).

There were significant differences in maximum LAI among all four ENVs, with mean values varying from 6.9 (NGA08), 6.7 (RUK08), 6.5 (RUK07) and 6.4 (MAS08) (Table 1). PD had a significant impact on LAI in all ENVs except MAS08. In general, LAI showed a quadratic response to PD, resulting in the lowest values obtained with either early or late planting (Table 1). As expected, over all sites and hybrids, plants with more leaves generally had higher LAI (R=0.59***).

A significant quadratic response of LAI to PD was observed at NGA08 (R^2=0.30**) and RUK08 (R^2=0.33**) where LAI was maximised by planting between 28 and 31 October (i.e., around PD3). In both ENVs, PD5 had the smallest LAI, followed by PD1. Despite RUK08 experiencing significant drought stress, the effects of water stress, particularly for PD1 to PD4, were not evident during the leaf expansion phase.

Table 1: Maximum leaf area index at NGA08, RUK08, RUK07 and MAS08 environments, for 4 or 5 planting dates (PDs), averaged for 6 hybrids differing in maturity; SE is standard error across all hybrids or maturities. Figures in parenthesis refer to mean temperatures (°C) during leaf expansion for the respective treatment.

PD	NGA08		RUK08		RUK07		MAS08	
1	6.7	(16.9)	6.1	(16.9)	6.1	(15.8)	-	-
2	7.1	(18.1)	7.0	(18.2)	6.5	(16.1)	6.2	(17.2)
3	7.5	(18.8)	7.4	(18.8)	6.5	(16.9)	6.4	(17.9)
4	7.1	(19.4)	6.9	(19.5)	7.1	(17.7)	6.6	(18.3)
5	6.0	(19.9)	5.9	(19.9)	6.5	(18.8)	6.3	(18.7)
SE	0.27		0.29		0.20		0.22	
Significance	***		***		***		NS	

Silage DM yield

Highest silage yields (SYs) were obtained at MAS08 (Table 2), while the lowest yields were recorded at RUK08, under severe drought. RUK07, a typical Waikato season, was the only ENV that exhibited a significant PD x hybrid maturity interaction for SY. While early hybrids yielded similarly across PDs, a quadratic response to PD was obtained for mid- (R^2=0.74**) and late hybrids (R^2=0.79**).

Maximum silage yields were obtained by planting around the 9 to 15 October for RUK07. Yields were generally higher for later hybrids under early planting but as planting was delayed, the yield gap between the hybrid maturities narrowed. Linear yield reductions from the maximum attained of 47 kg/ha/d (0.2%/d; mid-) and 77 kg/ha/d (0.3%/d; late) ($R^2 \geq 0.80$**) were observed.

Quadratic regression also explained the SY response to PD of all hybrid maturities at MAS08 (R^2=0.91***) and NGA08 (R^2=0.64***). Maximum production was estimated by regression to result from 2 and 23 October plantings at NGA08 and MAS08, respectively. Planting past the estimated optimum PD resulted in linear yield losses of 85 kg/ha/d (0.3%/d; R^2=0.67***) and 183 kg/ha/d (0.6%/d; R^2=0.81***) for NGA08 and MAS08. At RUK08, planting delay resulted in a linear silage yield decrease of 56 kg/ha/d (0.3%/d); R^2=0.76***) and the response was compounded by drought stress.

Table 2: Silage dry matter yields for NGA08, RUK08, RUK07 and MAS08 environments by planting date (PD) for 6 maize hybrids differing in maturity; SE is standard error over PD treatments for all hybrid maturities.

	MAS08	NGA08	RUK08	RUK07		
	Hybrid maturity					
	All	All	All	Early	Mid-	Late
PD	kg/ha					
1	-	24639	18498	22928	23508	25107
2	30092	24400	17440	22176	24268	26214
3	29025	24596	16219	21951	23444	24500
4	27838	21237	15086	22026	23116	23758
5	22496	19537	13808	21345	20977	20862
SE	658	329	382	684	684	684
	Significance					
PD	***	***	***	***	***	***
Maturity	NS	NS	NS	NS	NS	NS
PD x Maturity	NS	NS	NS	**	**	**

Silage starch content

Starch content was predicted using NIRS at RUK07, NGA08 and MAS08. In general, high starch contents were recorded under early planting treatments while late planting resulted in the lowest values (Table 3). The highest average starch levels (29%) were observed at RUK07 and MAS08, both of which experienced no water stress, compared to 26% at NGA08. MAS08 resulted in mid-hybrids maximising starch content under PD2 with the lowest values reserved for the last two PD treatments (Table 3). Conversely, for late hybrids, starch content responded in a quadratic manner with PD, resulting in the highest values (>31%) when planted on 3 November (MAS08). For early hybrids, with the exception of PD2 at RUK07, the lowest starch contents were observed at PD5 and the highest from early plantings.

Delayed planting at MAS08 resulted in linear decreases in starch content of 0.12%/d (R^2=0.99) and 0.18%/d (R^2=0.70***) for early and mid-hybrids, respectively. At NGA08, which experienced moderate drought stress, the highest levels of starch were obtained with

31 October planting (around PD2) (>28%) while 22 and 24% starch were recorded under PD1 and PD5, respectively (Table 3).

Table 3: Predicted silage starch content as affected by 4 or 5 planting dates (PDs) at NGA08, RUK07 and MAS08 in six maize hybrids differing in maturity; SE is standard error across PDs for all hybrid maturities.

	RUK07			MAS08			NGA08
	Hybrid maturity						
	Early	Mid-	Late	Early	Mid-	Late	All
PD					%		
1	31.8	31.3	27.6	-	-	-	22.2
2	25.8	30.4	30.4	32.4	35.0	29.7	28.8
3	32.8	28.5	31.9	-	34.7	30.9	28.1
4	30.1	27.4	27.0	28.2	26.2	30.0	25.5
5	27.8	27.4	25.5	25.8	26.7	22.5	23.7
SE	1.33	1.33	1.33	1.63	1.15	1.15	0.95
	Significance						
PD	**			***	***	***	***
Maturity	NS			*	*	*	NS
PD x Maturity	**			**	**	**	NS

Discussion

Silage DM yield

The observed quadratic response of SY to PD under non-water stress conditions was consistent with the recorded grain yield response, suggesting that silage yield response to PD was driven more by the grain component (R=0.87***) rather than stover *per se* (R=0.72***) (Tsimba *et al*., 2013a). Yields were maximised by planting earlier in ENVs characterised by warmer (Waikato) than cooler (Manawatu) springs. Low spring temperatures, consistent with early planting particularly in cooler regions, delay leaf area development and biomass accumulation (Muchow and Carberry, 1989), consequently decreasing yields. This also explains seasonal differences in optimum PD for SY within similar regions, e.g., NGA08 versus RUK07 where average temperatures for the two sites were 17°C versus 14°C during the period from tassel initiation (TI) to flowering for the first planting (Tsimba, 2011). RUK07 generally experienced a cooler spring than NGA08.

Low SYs (<21 t/ha) observed under late planting situations in the absence of drought were largely due to low temperature (<15°C) and radiation levels (<17 MJ/m^2/d) during grain filling. Photosynthetic activity in tropical C4 grasses is negatively affected by temperatures <15°C (Long, 1983). The greater silage yield decline with PD in plantings after the optimum date in Manawatu compared with the three Waikato sites could be attributed to the more significant rate of decline in temperature and radiation level at the higher latitude ENV which likely accentuated source limitations during grain filling (Andrade *et al*., 1993).

The ENV with the lowest spring temperatures (RUK07) was also the only one to show maturity x PD interactions for SY, where both mid- and late hybrids showed a quadratic yield response while the SY response of early hybrids was flat across

PD treatments. This could have been due to the smaller sink size of early hybrids (Capristo *et al*., 2007) and a well balanced source-sink ratio (Tsimba *et al*., 2013a) as well as their shorter duration. For instance, when planted late, long season hybrids had a greater proportion of their lifecycle in the period of diminishing radiation and temperature versus early hybrids planted at the same time. This is consistent with findings of Sorensen *et al.* (2000). Conversely, early hybrids became sink-limited and were less able to respond to optimum conditions (e.g., early PDs). The planting densities used for early hybrids (11 plants/m^2), although 5% greater than those for mid- and later hybrids (Tsimba *et al*., 2013a), may have been too low for the early plantings, since their LAI was about 20% lower than that of longer duration hybrids. To maximise yields under these conditions, long maturing hybrids should therefore be planted instead (Bruns and Abbas, 2006). Alternatively, densities for early hybrids should be increased by a further 10%.

Despite PD playing a part, the observed linear decline in SY with PD at RUK08 was confounded by the growing impact of drought stress on late planted crops as the soil water reservoir was depleted by evapotranspiration. Water stress reduced LAI and possibly radiation use efficiency (RUE), thereby decreasing photosynthetic capacity and therefore lowering yields. Due to these confounding effects of water stress at RUK08, it was impossible to quantify the direct effects of PD on SY in this ENV.

Starch content

Although some quadratic responses to PD were observed, starch content was generally higher under early than late planting conditions following the grain yield trend as reported in Tsimba *et al*. (2013a). The starch levels observed in the present study also fell within the range of 26-37% reported in the literature (Weiss and Wyatt, 2000). These findings confirm the view that maize silage is an energy rather than protein source for livestock.

The lower starch contents at the drought stressed ENVs were consistent with reduced grain fill caused by water stress. All hybrids generally had significantly less DM yield and low starch when planted late and this could be attributed to reduced HI values, averaging 0.39 (Tsimba *et al*., 2013a). High starch and low NDF contents in maize silage also significantly improve food intake and milk yield (Phipps *et al*., 2000).

In general, NGA08 which received <60 mm total rainfall during grain filling across all PD treatments resulted in lower starch content than MAS08 and RUK07 ENVs that received >220 mm during the same period (Tsimba *et al*., 2013a). This concurs with Deinum and Bakker (1981) who suggested that silage quality was largely determined by the prevailing environmental conditions (e.g., temperature, moisture and irradiance). The differences in the responses of hybrid maturity groups in some ENVs to PD imply that starch content varied with season. Since hybrids varying in maturity attain developmental milestones at different times, variation in weather will also differentially affect their growth and quality, so it is not unexpected that quality responses to PD were more apparent in late hybrids, particularly where grain filling occurred under declining environmental conditions.

The metabolisable energy (ME) of maize silage is directly proportional to starch content (Bal *et al.*, 1997), so a decrease in starch content due to delayed planting will result in lower ME silage. Late planting was also found to be more detrimental in cooler than warmer areas.

Leaf area index

Leaf area index for late hybrids in Waikato was, on average, about 20% higher than that of early and mid-hybrids. The larger LA per plant for later maturing hybrids can be expected to result in more

IPAR per plant. Even though yield differences between early and late hybrids are largely attributed to the longer period of radiation interception for the latter, at the individual plant level, more LA could also provide an advantage to later hybrids. Differences in LAI observed here confirm the need to increase planting density for early maturing hybrids in order to intercept a similar amount of PAR as the later maturing hybrids.

Leaf area expansion and stem elongation are among processes most sensitive to drought (Kiziloglu *et al*., 2009). The observed differences in LAI among ENVs were largely due to temperature variations since water stressed versus unstressed ENVs generally showed no significant difference in LAI (Table 1), implying that water stress affected plots after leaf area expansion was complete. Wilson *et al*. (1973) showed that temperatures <18°C and >25°C lowered LAI. Lower temperature regimes of about 15-17°C under early planting conditions in the current study therefore reduced LAI. While reduced LAI with early and late plantings was largely due to temperature, lower leaf numbers and increased moisture stress in some ENVs could also have contributed to lower LAI under very late planting conditions. The inclusion of earlier hybrids in the Manawatu was largely responsible for the lower LAI values in those ENVs.

Conclusions

Planting date recommendations will always carry a degree of uncertainty since optimum PDs usually vary from season to season, and data based on a single season's experimentation could be misleading. In Waikato, the PD that maximised SY in a normal season was about 2 weeks later than when early season mean temperatures exceeded the 16°C average. In Manawatu, the PD to achieve maximum biomass yields when temperatures were 1-2°C warmer than a normal season was 23 October. For Manawatu and Waikato, the variation in SY in response to PDs two to three weeks either side of the optimum PD, was relatively small (<5%), but the decline in SY occurred at a greater rate with later plantings.

Late planting reduced starch content due to lower HI. This will typically result in lower ME silage, a prerequisite to achieve more milk in dairy cows. It was apparent that the best planting date to maximise yield and starch content was region and season specific varying from early October to late October. To compensate for source and sink limitations and physical plant size, higher densities (>10%) are required for short season hybrids when planted early.

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