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Ranking maize hybrids for silage quality and milk production in pasture-based dairying

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ABSTRACT

A large database (n=1611) of maize hybrid nutritive characteristics was developed by sampling 42 maize hybrids from three replicate plots at 100 Pioneer Research sites during 2000, 2001, and 2002. Compared to changes from year to year, differences in nutritive quality across hybrids of different maturity were small. Differences in maize hybrid quality accounted for $34 extra milk income per tonne of maize silage DM, whereas the differences in hybrid yield had a much larger impact on milk income ($8672/ha maize grown). Maize hybrids were ranked similarly for milk production potential, although the rankings were much closer, and sometimes equal for hybrids when fed in a New Zealand pasture system compared to a US total-mixed-ration system. Being able to select maize silage hybrids in New Zealand based on the extra milk they are likely to produce will be of benefit to dairy farmers, especially as inclusion rates of maize silage increase.

Keywords: Maize silage; quality; dairy cow; model.

INTRODUCTION

An increasing number of New Zealand dairy farmers are using maize silage, and the quantity used per farm is rising (Kolver *et al*., 2001). However, the variation in nutrient content of maize silage hybrids in New Zealand and the influence of silage quality on dairy cow performance is not well documented.

Currently in New Zealand, hybrids are ranked according to silage and grain yield, ability to stay green, drought tolerance, early growth, readily available energy, and whole-plant digestibility (Genetic Technologies Ltd., 2002). In confined dairying systems, where cows are fed a total mixed ration (TMR), the maize industry uses a model that can rank the milk production potential of maize silage hybrids using quality characteristics (MILK2000 - University of Wisconsin Corn Silage Evaluation System; Schwab *et al*., 2001).

This paper reports the nutrient content of maize silage hybrids based on a large multi-year database, and ranks the milk production capability of hybrids in pasture-based dairy systems using the Cornell Net Carbohydrate and Protein System model (CNCPS; Fox *et al*., 1992). A comparison is made with rankings from the industry-standard MILK2000 model.

MATERIALS AND METHODS

Maize sampling

Fresh plant samples were collected during 2000, 2001, and 2002 from 100 Pioneer Research sites in the North and South Island. A total of 1611 samples were collected in triplicate from 42 hybrids. Hybrid plots were randomly allocated in three replicates at each site. Not all hybrids were represented at each site, and not all hybrids were represented in each year. Of the 42 hybrids, 35 were commercially available and seven were experimental hybrids tested in 2002. The research sites were chosen to represent environmental conditions that ranged from challenging to ideal. In some cases, the most suitable hybrids were not planted in each site.

A 2-kg sample of fresh harvested plant material was collected from each plot directly from the harvester. The sample was mixed, subsampled (1 kg), and then air freighted to Des Moines, Iowa in a frozen state for analysis by near-infrared spectroscopy at the Pioneer Forage Laboratory.

Yield (kg DM/ha) was determined for each replicate plot. Each sample from each replicate plot was analysed for dry matter (DM), crude protein (CP), soluble sugars (SS), starch, acid detergent fibre (ADF), neutral detergent fibre (NDF), ash content, and *in vitro* DM (IVD) and NDF digestibility (NDFD).

Modelling

Mean quality characteristics were used to rank each of 42 hybrids on their ability to produce milk using MILK2000 and the CNCPS model. The MILK2000 model is an empirical, spreadsheet-based model that was developed to evaluate maize silage hybrids in a TMR feeding system. Maize silage constitutes the entire forage intake, 75% of total dietary NDF is assumed to be supplied by maize silage, and the total ration contains 30% NDF, which equates to a maize silage NDF intake of 0.86% of live weight. Intake of maize silage is then adjusted based on the NDFD. For the maize hybrids evaluated in this study, average maize silage intake was 12 kg DM/cow/d and average inclusion rate was 48% (Schwab & Shaver, 2001). Key inputs include DM, CP, NDF, NDFD, starch, CP associated with NDF (NDFCP), ash, and ether extract content (%DM), and yield (kg DM/ha). The concentration of ether extract and NDFCP was not measured in the maize samples, so maize silage ether extract and NDFCP values in the CNCPS feeds library were used (16.4 NDFCP, %CP; and 2.85% fat). Milk production due to the maize silage component of the ration is calculated based on net energy for lactation (NE_L), which is calculated from total digestible nutrients (TDN). Quality of maize (NDF and NDFD) is also used to adjust DM intake. A standard cow for the US TMR system (613 kg live weight) and base level of production were used by the model.

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To predict milk production in a New Zealand pasture-based system from hybrids differing in quality, the CNCPS model (version 4.0.31) was used. The CNCPS is the basis for the model released with the current NRC (2001) and has been evaluated for pasture-based diets (Kolver *et al*., 1998). The model uses mechanistic and empirical relationships to predict metabolisable energy, metabolisable protein, amino acid, and macro mineral requirements of dairy cattle and the supply of these components from the diet. In particular, the model can simulate interactions between feeds being digested in the rumen.

The base pasture diet and milk production used for the pasture-based maize silage evaluation was from observed data for a New Zealand Friesian cow (470 kg live weight) producing 2 kg milksolids/d (24.2 kg milk/d) in early lactation (57 days in milk), consuming 16.6 kg DM/d of pasture, and gaining 0.1 kg live weight/d (Kolver *et al*., 2002). Pasture was of high quality (12.4 MJME/kg DM, 15% DM, 41.9% NDF, 29% CP, 5.4% fat, 10.6% ash). For the other parameters required by the model, data from a high-quality pasture in the CNCPS library was used, which included a carbohydrate B2 rate of 16%/h, a protein B2 rate of 22%/h and an effective fibre content of 41 (% of NDF that was effective). The model correctly predicted the milk production and liveweight change on the base pasture diet.

The simulation fed maize silage at 4 kg DM/cow/d and pasture at 12.6 kg DM/cow/d. Maize silage represented 24% of the cows diet which is a level commonly used in New Zealand (Kolver *et al*., 2001). A base diet of pasture fed at 12.6 kg DM/cow/d was also simulated, and the difference in milk production between this diet and the pasture/maize silage diets was considered to be the milk production attributable to the maize silage portion of the diet. This would represent a farm scenario in which stocking rate was high, and substitution rate low. The simulation used a 50% grain maize silage with medium particle size (CNCPS library number 311) for the base maize silage. This silage contained 35% DM, 8% CP, 41% NDF, 3.5% fat, and 43% non-fibre carbohydrate, which was very similar to the mean of the 42 hybrids (Table 3). In addition, there was small variation across hybrids around these values. The value of effective fibre was increased from 71% of NDF to 87% of NDF to better reflect the level of maize silage processing that occurs in New Zealand (Kolver *et al*., 2001). Ruminal degradation rate of carbohydrate (A = 10%/h; B1 = 35%/h; B2 = 6%/h) and protein (B1 = 300%/h; B2 = 15%/h; B3 = 0.25%/h) degradation were not altered between hybrids.

The evaluation of maize hybrids in a TMR scenario used the quality data from fresh maize plants as the MILK2000 model was designed to use fresh maize plant data (Table 1, 2, 3). The evaluation within a pasture-based system used quality data for ensiled maize silage that had been calculated from the fresh plant data. This calculation was made using regression equations derived from a dataset of 44 maize samples that had subsequently been sampled 30-45 days after ensiling (personal communication, Dr Don Sapienza, Pioneer Hi-Bred International, Iowa). Equations for the quality inputs required by the CNCPS were: %DM ensiled = 0.7212x + 9.3689, R^2 = 0.39; %CP ensiled = 0.2381 + 6.9784, R^2 = 0.07; %NDF ensiled = 0.575x + 18.501, R^2 = 0.39; %Ash = 0.8558x + 0.9526, R^2 = 0.56, where x = nutrient content in fresh maize. The values used for DM, CP, NDF, and ash content were derived in this way and differed from the fresh plant values by –0.9, 1.3, 0.9, and 0.3 percentage units, respectively.

The ranking of maize hybrids in a TMR-feeding system compared to a pasture-based feeding system were made on the basis of milk produced from the maize silage component of the ration per tonne of maize silage DM fed, and per ha of maize silage grown.

Statistical analysis

Mean values for yield and nutrient content from the three replicates for each hybrid were analysed (n=537) using the residual maximum likelihood (REML) procedure of Genstat (Version 3.2). Hybrids were classed by maturity into Ultrashort- (<90 d), Short- (90-97 d), Medium- (98-105 d), and Long- (>105 d) Comparative Relative Maturity (CRM). To test hybrid maturity and year effects, the model included year and maturity as fixed effects, and location and hybrid as random effects. For analysis of individual hybrids, hybrid was included as a fixed effect and maturity was not included in the model. Predicted means are presented to account for unequal observations across year, location, and hybrid. Significant effects were declared at P<0.05 and trends at P<0.10. A subsequent analysis included DM% and crop yield as

TABLE 1: Predicted mean yield (kg DM/ha) and nutrient composition (%DM) of maize silage hybrids with Ultrashort (<90 d), Short (90-97 d), Medium (98-105 d), and Long (>105 d) Comparative Relative Maturity (CRM).

	Maturity					
	Ultrashort	Short	Medium	Long	SED	P=
No. observations	75	115	154	193		
Yield	16018	18895	21391	22260	831	0.000
Dry matter	39.9	36.6	36.4	35.2	1.24	0.005
Crude protein	7.9	7.4	7.5	7.4	0.16	0.011
Soluble sugar	2.6	4.0	4.4	4.6	0.43	0.001
Starch	31.6	32.1	31.5	30.0	0.94	0.093
Acid detergent fibre	23.3	22.7	23.0	24.1	0.49	0.015
Neutral detergent fibre	41.2	40.5	41.1	42.5	0.73	0.035
Ash	4.5	4.2	4.3	4.4	0.12	0.132
DM[1] digestibility	70.0	71.0	70.8	69.2	0.62	0.011
NDF[1] digestibility	41.5	42.4	42.8	41.5	0.46	0.008

[1]DM=Dry matter; NDF=Neutral detergent fibre.

TABLE 2: Predicted mean yield (kg DM/ha) and nutrient composition (%DM) of maize silage hybrids in 2000, 2001, 2002.

	Year				
	2000	**2001**	**2002**	**SED**	**P=**
No. observations	72	136	329		
Yield	20801	18474	19647	929	0.084
Dry matter	39.2	34.5	37.4	1.31	0.005
Crude protein	6.8	7.2	8.7	0.14	0.000
Soluble sugar	3.0	4.4	4.4	0.60	0.061
Starch	34.6	33.8	25.5	0.91	0.000
Acid detergent fibre	24.0	21.4	24.5	0.51	0.000
Neutral detergent fibre	41.4	40.8	41.8	0.71	0.035
Ash	4.5	3.3	5.3	0.15	0.000
DM[1] digestibility	69.6	72.8	68.3	0.63	0.011
NDF[1] digestibility	41.1	43.2	41.9	0.52	0.001

[1]DM=Dry matter; NDF=Neutral detergent fibre.

TABLE 3. Predicted mean yield (kg DM/ha) and nutrient composition (%DM) of 42 maize silage hybrids of differing Comparative Relative Maturity (CRM).

Hybrid	**CRM**	**No. obs.**	**Yield**	**DM[1]**	**CP[1]**	**SS[1]**	**Starch**	**ADF[1]**	**NDF[1]**	**Ash**	**IVD[1]**	**NDFD[1]**
1	78	6	15220	41.6	8.2	2.4	31.3	22.9	40.9	4.4	70.6	41.6
2	75	9	14426	43.1	8.1	1.2	32.6	23.4	41.4	4.5	69.5	39.5
3	79	4	17151	41.1	7.5	3.4	31.2	23.4	41.0	4.4	69.9	41.2
4	83	12	15606	37.7	8.3	2.6	30.8	23.7	41.3	5.1	69.4	41.5
5	73	4	12636	47.0	8.1	1.9	31.0	24.1	42.5	4.5	68.9	41.1
6	87	27	17474	37.8	7.6	4.1	31.0	23.1	40.8	4.4	70.5	41.9
7	85	3	17512	36.0	7.3	2.3	33.6	22.2	40.5	3.9	71.8	43.0
8	90	10	18913	37.2	7.3	4.1	33.3	21.6	39.3	3.9	72.2	43.2
9	93	37	19164	37.8	7.3	4.6	32.3	22.8	40.0	4.3	70.7	41.6
10	94	21	18812	37.7	7.6	3.0	33.2	22.2	39.9	4.3	71.5	42.7
11	112	11	18228	37.4	8.1	5.1	28.4	23.8	41.8	4.6	69.7	41.9
12	92	7	19480	32.8	7.8	4.5	28.4	24.3	42.9	4.5	68.9	41.8
13	96	9	18251	33.5	7.1	5.6	32.1	22.1	39.6	4.1	71.9	42.9
14	97	21	18314	40.7	7.1	3.1	33.3	22.9	41.1	4.0	70.7	42.0
15	100	45	20761	36.1	7.7	4.6	31.1	22.8	40.9	4.2	70.9	42.9
16	98	22	20232	36.1	7.5	3.8	32.2	22.9	41.1	4.3	70.6	42.4
17	104	22	22763	38.0	7.1	4.4	31.4	23.7	42.0	4.1	70.0	41.9
18	103	22	24518	34.9	7.2	5.7	31.2	22.5	40.4	3.9	71.4	42.7
19	107	11	21102	34.9	7.6	5.0	31.1	22.7	40.5	4.3	70.9	42.6
20	105	8	21035	37.3	7.5	4.1	31.9	23.1	41.1	4.5	70.6	42.7
21	110	31	23621	33.8	7.2	5.0	29.4	24.6	43.3	4.2	68.5	41.0
22	112	21	21877	34.6	7.1	5.3	29.3	24.3	42.4	4.2	68.6	40.4
23	106	14	21962	37.9	7.2	3.1	34.6	22.4	39.7	4.2	71.1	41.3
24	109	32	22175	38.6	7.3	4.0	31.4	23.9	42.2	4.1	69.5	41.9
25	108	8	20612	37.5	7.1	3.9	34.2	22.3	39.5	4.2	71.1	41.9
26	107	7	22463	36.5	7.2	4.0	32.3	23.0	41.1	4.2	71.1	43.5
27	112	25	26108	33.6	7.2	4.5	28.6	25.7	44.6	4.3	67.2	40.3
28	113	6	23823	31.4	7.9	4.8	30.4	23.0	41.0	4.5	70.5	43.0
29	113	7	26044	31.9	7.7	5.0	30.3	23.4	41.1	4.5	69.8	41.3
30	83	9	15400	39.3	8.2	2.0	30.9	23.4	41.6	4.8	69.7	41.8
31	108	6	21544	34.5	7.4	5.0	30.9	23.5	41.1	4.4	69.8	41.7
32	101	10	18671	36.1	7.4	4.1	29.3	24.4	43.1	4.6	69.6	43.5
33	100	9	21387	36.3	7.8	4.1	31.8	23.0	41.1	4.4	70.7	43.0
34	100	14	20183	36.4	7.7	4.2	32.3	22.2	39.8	4.4	71.6	43.1
35	90	3	18222	39	7.3	3.6	32.6	23.0	40.7	4.4	70.7	42.1
36	94	7	18375	33.7	7.8	4.4	30.5	22.4	40.2	4.5	71.4	43.6
37	112	2	23343	35.5	7.3	4.3	29.3	24.6	43.6	4.6	69.0	42.3
38	113	5	21312	29.3	7.9	5.7	22.7	27.2	47.6	4.8	64.4	39.2
39	104	2	22329	38.2	7.4	4.8	35.0	20.9	37.5	4.0	74.1	45.3
40	108	4	22883	38.3	7.1	4.6	27.7	26.0	45.6	4.3	67.8	41.5
41	111	3	23266	36.1	6.7	3.9	28.9	26.4	46.1	4.4	67.4	40.6
42	86	1	17489	39.8	7.8	2.5	36.2	20.7	37.3	4.1	72.8	43.1
SED			1244	1.64	0.21	0.76	1.77	1.08	1.52	0.25	1.32	0.85
P=			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[1]DM=Dry matter; CP=Crude protein; SS=Soluble sugars; ADF=Acid detergent fibre; NDF=Neutral detergent fibre; IVD=in vitro digestibility; NDFD=In vitro neutral detergent digestibility.[1]DM=Dry matter; CP=Crude protein; SS=Soluble sugars; ADF=Acid detergent fibre; NDF=Neutral detergent fibre; IVD=in vitro digestibility; NDFD=In vitro neutral detergent digestibility.

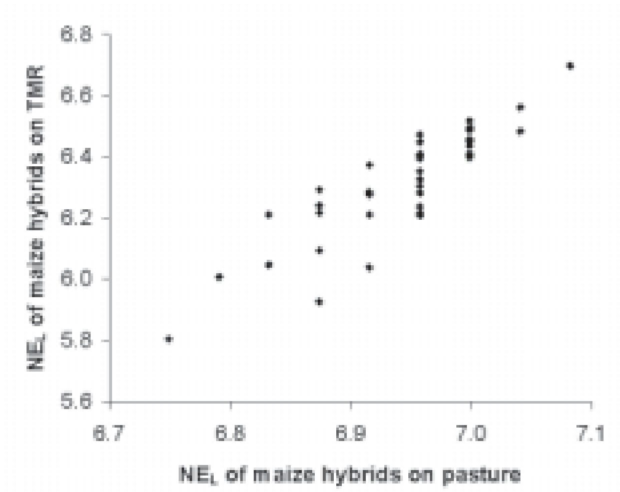
explanatory variables, but results were not changed significantly and these results are not reported.

RESULTS

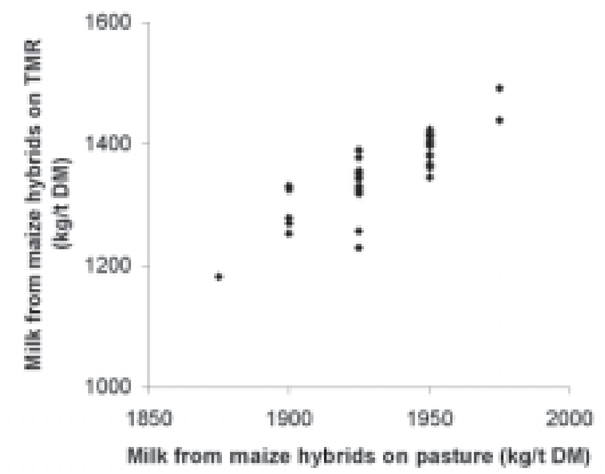
Increased hybrid CRM resulted in increased yields,

FIGURE 1. Ranking of maize silage hybrids when fed to dairy cows in a US total mixed ration or a New Zealand pasture-based system: a) Predicted net energy for lactation (MJ NE_L/kg DM); b) Predicted milk production (kg) from the maize silage component of the ration per tonne of maize silage DM fed; c) Predicted milk production (t) from the maize silage component of the ration per hectare of maize silage grown.

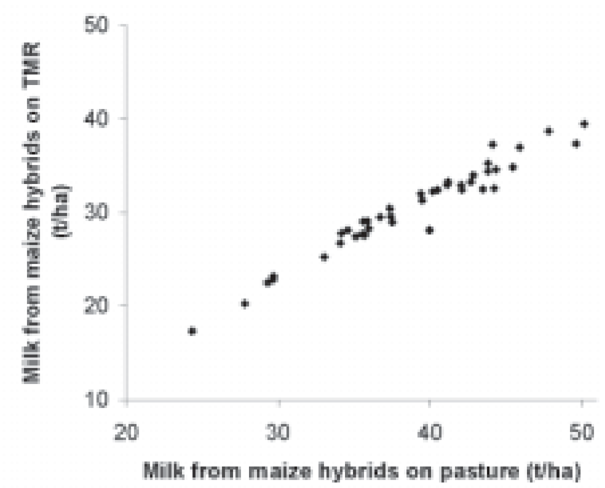
(a)



(b)



(c)



and an increased content of ADF and NDF (Table 1). The Ultrashort maturity had a higher DM and CP content, and a lower content of soluble sugars than Short-, Medium-, or Long-maturity hybrids. The Short- and Medium-maturity hybrids had higher DM and NDF digestibility compared to Ultrashort- or Long-maturity hybrids. There was a trend for lower starch content in the Long-maturity maize compared to Short-maturity maize. Ash content was not different between hybrids of varying maturity.

Over three years, there was a trend for differences in yield (2327 kg DM/ha), with differences between years for all quality components measured (Table 2). The content of DM, CP, soluble sugar, starch, ADF, NDF, ash, DMD, and NDFD varied by 4.7%, 1.9%, 1.4%, 9.1%, 3.1%, 1%, 2%, 4.5%, and 2.1%, respectively, over the three years.

There was significant variation between maize hybrids for all characteristics measured (Table 3). Across the 42 hybrids yield varied by 13472 kg DM/ha, and the content of DM, CP, soluble sugar, starch, ADF, NDF, ash, DMD, and NDFD varied by 17.7%, 1.6%, 4.5%, 13.5%, 6.5%, 10.3%, 1.2%, 9.7%, and 6.1%, respectively.

Figure 1 illustrates the comparative ranking of maize hybrids when fed to cows consuming a TMR in the US (simulated using MILK2000) or grazing pasture in New Zealand (simulated using the CNCPS model). Maize hybrids that were predicted to have the highest and lowest NE_L content in a US system were also predicted to have the highest and lowest NE_L content when fed within a New Zealand pasture system ($R^2 = 0.78$; Figure 1a). However, a narrower range of NE_L was predicted for maize hybrids used in a pasture system. This meant that some individual hybrids were given an equal ranking when used in a New Zealand pasture system, but were predicted to have a different NE_L ranking in a US TMR system.

A similar result was apparent when hybrids were ranked according to the amount of milk produced from the maize silage component of the ration (kg milk/t DM; Figure 1b). Although the regression coefficient was high ($R^2 = 0.71$), a number of hybrids were given an equal ranking in the New Zealand pasture scenario.

When potential milk production was expressed per ha of maize grown (Figure 1c), there was greater agreement in the ranking of hybrids in the US versus NZ systems ($R^2 = 0.95$).

DISCUSSION

Being able to select maize hybrids in New Zealand based on the extra milk they are likely to produce would be of significant benefit to dairy farmers. This study shows that there are large differences in hybrids when milk production is calculated from hybrid differences in quality and yield characteristics.

At a $4/kg milksolids payout, a difference in milk income of $34/t maize silage DM fed might be expected when the highest and lowest ranked hybrids are compared on differences in nutritional value only. In 2000, the average Waikato farmer bought in an average of 100 t maize silage DM from off the farm (Kolver *et al.*, 2001). If the same price was paid for the maize silage irrespective of hybrid, difference in hybrid quality characteristics would result in an additional $3400 in profit.

When crop yield is included in the calculation, the difference in expected milk income between the highest and lowest ranking hybrid is $8672/ha of maize grown. Waikato dairy farmers that grew maize on farm in 2000 grew an average of 4 ha/year (Kolver *et al.*, 2001). Assuming similar planting costs between hybrids, these farms would make an additional $34688 in farm profit if the hybrid with the best milk-producing qualities was used instead of the hybrid with the worst milk-producing qualities.

These calculations show that relative to crop yield, the variation in nutritional characteristics of maize silage produced under best practice conditions can be small, and will have a smaller effect on potential milk production. If the Ultrashort-maturity maize crops are ignored, nutritional characteristics varied by less than two percentage units between Short-, Medium- and Long-maturity hybrids.

The modelling showed that the supply of energy from maize silage was the key nutritional component affecting milk production. When 4 kg maize silage DM (24% of the diet) was fed to dairy cows grazing high-quality pasture, milk production was first limited by supply of metabolisable energy, with metabolisable protein, methionine, and lysine being supplied in excess of requirements. This indicates that ME (or NE_L) content of maize silage can be used to rank hybrids. It would be expected that the ME value of maize silage would change depending on associative effects of other feeds in the cows diet. This may account for some of the variation in hybrid ranking between the US TMR and the New Zealand pasture scenarios that were modelled. Of significance in this comparison however, was the relatively tight ranking of hybrids in the pasture scenario in terms of NE_L content of maize and in terms of milk produced per tonne of maize silage DM fed. This may partly be due to the relatively small variation in quality characteristics, and the smaller amount of maize silage that was fed to grazing cows (4 kg DM) compared to the US cows fed TMR (10 kg DM). Small differences in maize silage quality, when making up only 24% of the diet of a grazing cow, will have a relatively small impact on total energy supply, especially if pasture quality is high. It would be expected that ranking of hybrids for quality will become more important as dairy farmers include higher amounts of maize silage in the cows' diets. A growing proportion of farmers are using up to 1250 kg maize silage DM/cow (Densley *et al.*, 2001). For a 500-cow herd fed at this level, differences between the highest and lowest ranking hybrid based on quality characteristics alone (milk produced/t maize silage DM fed) would result in difference in profit of $21,000. If a lease block were used to grow the maize crop, and yield became part of the calculation, milk income from highest and lowest ranking hybrids would differ by $312,192. It must be noted, however, that the range between the highest and lowest ranking hybrid observed on the research sites may be wider than experienced if the most suitable hybrid is selected for a particular farm environment.

The close agreement in ranking of hybrids in a US TMR system and a NZ pasture system when ranked on tonnes of milk/ha of maize grown occurs because crop yield, rather than differences in quality, is the key driver of milk produced per ha of maize grown. Given the small differences between hybrids of different CRM, this suggests that longer-maturing hybrids should be grown to maximise milk production.

The close ranking of hybrids in the New Zealand pasture system in comparison to the US TMR system may have been influenced by the assumptions used in the simulation models. An additional source of variation may have occurred when quality characteristics of fresh maize was converted to ensiled maize for use in the CNCPS. However, differences between fresh and ensiled values were relatively small (average of 0.8 percentage units). In the MILK2000 model, maize quality characteristics (NDF content and NDFD) influence intake of maize silage, and, hence increases the impact of quality on final milk production. In the NZ grazing scenario, generally a smaller, set, amount of maize silage is fed (in the modelling scenario this was 4 kg DM/cow), so smaller differences between hybrids due to quality characteristics could have been expected.

The nutritive differences that existed between hybrids of different CRM were generally expected. Longer maturity hybrids tend to have a lower cob:stover ratio than shorter maturity hybrids, which was reflected in the higher NDF, and lower starch content observed in the current study. The differences in maize quality between years likely reflects management and climatic factors. The higher DM content of hybrids in 2000 probably reflected a faster dry-down time and a harvest that was marginally later than in 2001 and 2002.

A large database of maize hybrid nutritive characteristics is reported. This shows comparatively small differences in quality across hybrids of different CRM, with larger differences occurring from year to year. Differences in maize hybrid quality accounted for $34/t maize silage DM fed in extra milk income, whereas the differences in hybrid yield had a much larger impact on milk income ($8672/ha maize grown). Maize hybrids were ranked similarly for milk production potential, although the rankings were much closer, and sometimes equal, for hybrids when fed in a New Zealand pasture system compared to a US TMR system. Ranking hybrids on quality will be of benefit to dairy farmers, especially as the amount of maize silage use increases.

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