Productivity and quality of kale, swede, fodder beet and maize in Manawatu

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Abstract

Winter grazing of forage crops can result in large losses of nitrogen (N) from leaching and consequently, deterioration in water quality in affected catchments. A viable alternative cropping option which can potentially reduce N leaching may be useful for maintaining productivity while minimising environmental risks. Maize could be a possible alternative crop because of its yield and low N as well as convenience to cut and carry system. Thus, maize, kale, swede and fodder beet were compared in a factorial randomised complete block design with or without N application. Dry matter (DM) yield ranged from 12,450 to 30,417 kg DM/ha with the highest yield achieved by maize hybrids. Yield was increased by N application, but there was no interaction between forage entries and N rates. Forage entries differed significantly in all quality traits while N application only affected crude protein (CP), soluble sugars and starch (SSS) and acid detergent fibre (ADF). Metabolisable energy (ME) was significantly different for all forage entries. It ranged from 9.5–11.0 MJ/kg DM for swede, fodder beet and maize and was <9.5 MJ/kg DM for kale. Maize hybrids showed the lowest CP (5.4–5.9%DM) and highest SSS (42.7–48.0%DM). Dry matter yield was positively correlated with SSS (r = 0.58; P<0.001) and neutral detergent fibre (NDF) (r = 0.56; P<0.001). Similarly, ME was positively and strongly correlated with SSS (r = 0.79; P<0.001) while CP was negatively correlated with yield and all quality traits. The results highlight the advantages of maize having high DM yield and good feed quality under unlimited moisture conditions.

Additional keywords: beet, brassicas, dry matter yield, feed quality, maize silage, nitrogen, supplementary feed crops

Introduction

Maize, fodder beet and forage brassicas are commonly used as feed crops in New Zealand (NZ), especially in winter feeding or as a supplement during summer drought periods when pasture growth is low or poor quality (Cheng *et al.*, 2018; Fletcher *et al.*, 2012; Wilson *et al.*, 2006). As a supplementary feed crop, maize is particularly important in the North Island (Chakwizira *et al.*, 2017; Clark *et al.*, 2007; Densley *et al.*, 2006) while fodder beet, kale and swede are more important for winter grazing in the South Island (Gibbs, 2014; Malcolm *et al.*, 2016b).

High stocking density with high urinary N loading and high winter rainfall (Edwards *et al.*, 2017; Malcolm *et al.*, 2017) contributes to excessive N losses particularly if forage diets are high in protein. Nitrate leaching losses have been shown to occur in grazed wintering systems in NZ (Edwards *et al.*, 2014; Malcolm *et al.*, 2017; Malcolm *et al.*, 2016a). Nitrate leaching losses could be reduced using specific crop selections or using an integrated whole farm system approach (Edwards *et al.*, 2017; Malcolm *et al.*, 2016a). As urinary N excretion is directly related to N intake by animals (Kebreab *et al.*, 2001), a possible strategy is to utilise crops that are high yielding and have low N content. It has been further suggested that there is potential to minimise N loading in paddocks by managing the composition of supplementary feed crops in animal diets (Dalley *et al.*, 2020; de Ruiter *et al.*, 2019).

The best cropping options for winter feeding may comprise a balance of *in situ* grazed crops and supplements. Differing feed allocations are required to reduce the environmental concerns and yet provide an economic yield while delivering suitable feed quality for animals. Therefore, the objective of this study was to compare productivity and feed quality of maize and traditional winter forage crops under different N treatments in the lower North Island environment.

Materials and Methods

The trial was established at the Pasture and Crop Research Unit, Massey University, Palmerston North (40° 22′ 53″ S, 175° 36′ 22″ E) on a Manawatu sandy loam. A soil sample was taken on 11 October 2018 to assess soil fertility (Table 1). Soil nutrients were converted into mg/kg dry soil using the conversion factors: K × 20; Ca × 125; Mg, Na × 5 (Chapman & Bannister, 1994). The 150 kg/ha of Cropmaster 15 fertiliser (15% N, 10% P, 10% K, 7.7% S) was applied at planting (13 November 2018) to ensure adequate fertility for initial crop establishment.

Table 1: Soil characteristics before experiment (0–15 cm depth).

Site	pH	Olsen P	K	Ca	Mg	Na	Mineral N	OM[1]
		———	———	(mg/kg)	———	———	(kg/ha)	(%)
Massey	5.6	30	100	1125	115	30	93	3.9
Optimum[2]	5.8–6.2	20–30	120–200	500–1250	≥50	10–15	100–200	7–17

[1] Organic matter
[2] The optimum values are general recommendations for non-limited crop production (Nicholls *et al.*, 2012)

Experimental design

Twelve forage entries were selected based on their yield potential and suitability for winter '*in situ'* grazing or supplements. These were arranged in a factorial with two N treatments in a randomised complete block design (3 replicates) (Table 2). Nitrogen fertiliser was applied at 0 or 300 kg N/ha (urea) with split applications of 200 and 100 kg N/ha at 38 and 72 days after sowing (DAS).

Table 2: Treatment combinations (forage entries × N treatments), species type or maturity level, seed treatments and their effectiveness.

Treatment combinations	Type/maturity	Seed treatments	Pest controlled
Maize			
P8000	80 CRM	Mesurol®, Poncho® and Vitaflo®	bird repellent, Argentine stem weevil, Black beetle, Cut worm; *Pythium*, *Rhizoctonia* and *Fusarium* diseases
P8805	88 CRM		
P9400	94 CRM		
Kale			
Gruner	Giant	Superstrike®	Springtails; *Pythium*, *Rhizoctonia*, *Fusarium* diseases; Molybdenum nutrient
Regal	Intermediate		
Sovereign	Intermediate		
Swede			
Triumph	Early maturity	Ultrastrike®	Springtails, Argentine stem weevil, Aphids, *Nysius* (Wheat bug); *Pythium*, *Rhizoctonia* and *Fusarium* diseases; Molybdenum nutrient
Clutha Gold	Medium maturity	Superstrike®	Springtails; *Pythium*, *Rhizoctonia*, *Fusarium* diseases; Molybdenum nutrient
Invitation	Late maturity	Agricote	Springtails, Argentine stem weevil, Aphids, *Nysius* (Wheat bug); *Pythium*, *Rhizoctonia* and *Fusarium* diseases; Molybdenum nutrient
Fodder beet			
Cerise	Grazing/Lifting	Gaucho	insects, fungal diseases
Enermax	Lifting	Thiram, hymexazol, thiamethoxam, tefluthrin	insects, seed-borne fungal diseases
Monro	Grazing	Thiram, Iprodione	fungal diseases
N treatments			
Control	0 kg N/ha		
High-N	300 kg N/ha		

CRM: comparative relative maturity

Trial details

Maize plots were drilled in four rows with 70 cm spacing and hand thinned twice (2 and 4 weeks after sowing) to achieve the target population of 130,000 plants/ha. Fodder beet plots comprised five rows at 30 cm spacing with a target plant density of 110,000 plants/ha. The sowing rate was 220,000 seeds/ha with thinning required to achieve the target plant density. However, emergence was very close to the target density with even distribution across the plot. Consequently, thinning was not required. Kale and swede plots were drilled in ten rows with 15 cm spacing at 4 kg and 1.5 kg seeds/ha respectively. All plots were 5 m long and 1.5 m wide, except for maize which were 2.8 m wide. A minimum of 2 m space was allowed between maize and other plots to avoid shading effects.

Hand weeding was carried out twice at 24 and 50 DAS on maize and fodder beet. Versatill herbicide (Clopyralid 598 g/l ai) was applied at 1 l/ha on kale and swede plots at 50 DAS with supplemental hand weeding.

Weather data

Meteorological data were obtained from AgResearch Grasslands, Palmerston North, less than 1 km from the trial site (Table 3). The growing season was quite dry except for the month of December. The trial was irrigated between mid-January and the end of March (305 mm in total) ensuring minimal risk of moisture stress.

Table 3: Mean monthly temperature (°C) and rainfall (mm) over the 2018–19 cropping season compared to the long-term mean. Long-term means: NIWA, Palmerston North, 1981–2010.

	Month								
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
2018–19 Season									
Temperature (°C)	15.1	17.9	19.4	17.9	18.3	13.5	12.4	8.8	
Rain (mm)	90.8	173.0	30.8	30	51.6	81	59.5	124.6	641.3
Irrigation (mm)	-	-	105	120	80	-	-	-	305.0
Long-term									
Temperature (°C)	14.1	16.4	17.8	18.2	16.4	13.6	11.3	9.1	
Rain (mm)	75.1	95.6	55.1	71.1	54.7	60.1	73.5	91.9	577.2

Dry matter yield

Maize

Maize yield was measured on 14 March 2019 for 'P8000' and 'P8805', and 19 March 2019 for 'P9400' when the plant reached approximately 34% whole crop DM (Tsimba *et al.*, 2014; Williams, 2012). Harvest samples were taken from two center rows (0.7 m × 2 rows × 2 m length = 2.8 m^2) by cutting at 10 cm above ground level. Fresh weight was recorded in the field and three representative plants from each plot were mulched using an Alko dynamic 2200 S mulcher. Approximately 200 g of mulched material was dried at 70°C to a constant weight over a period exceeding 2 days for DM determination and nutrient analysis. Immediately after maize was harvested, Italian ryegrass 'Lush' (30 kg/ha) was sown in the maize plots and harvested at the same time as the fodder beet and brassicas.

Fodder beet, kale and swede

Dry matter yields of winter forage crops were measured on 28 June 2019. Plants were taken from 1 m row lengths, four samples per plot excluding guard rows and borders. After field weighing, three representative plants were taken, and oven dried at 70°C to a constant weight for DM and quality analysis.

Feed quality test

Following DM measurement, samples were ground with a Cyclone mill (1.0 mm screen) and approximately 40 g of samples were sent to the Nutrition Laboratory, School of Food and Advanced Technology, Massey University. Samples were analysed for metabolisable energy (ME), crude protein (CP), soluble sugars and starch (SSS), acid detergent fibre (ADF) and neutral detergent fibre (NDF) using near infrared reflectance spectroscopy (NIRS).

Statistical analysis

Data were analysed using standard general linear regression (GLM) model and correlation procedures in SAS software version 9.4 (SAS Institute Inc., Cary NC). Significant interactions and treatment means were separated using Fisher's protected least significant difference (LSD) tests when the ANOVA *F* value was significant (P≤0.05). Before running the ANOVA model, the homogeneity of variances was tested for yield to ensure comparing across all forage entries. There was no significance of variances for yield in Bartlett's (Pr>ChiSq = 0.6351) and the Brown-Forsythe (Pr>F = 0.9863) tests while Levene's test showed significance (Pr>F =0.0144). Therefore, we assumed variances are equal since no large deviations occurred. Orthogonal contrasts were used to test the significance of difference in means between crop groups.

Results

Dry matter yield

Dry matter yields among the forage entries and N treatments differed significantly (Table 4). The yield ranged from 12,450 kg DM/ha for 'Invitation' swede to 30,417 kg DM/ha for 'P9400' maize hybrid. The maize hybrids produced significantly higher yields than the brassicas or fodder beet. Maize yield averaged 29,505 kg DM/ha with an additional to 2,600 kg DM/ha from the Italian ryegrass in the combined winter and summer production season. 'P9400' maize hybrid produced the maximum yield but was not different from the other hybrids (P8000 and P8805) despite the differences in maize hybrid maturities (80 CRM – 94 CRM) (Table 4). Differences in yield between kale (19,290 kg DM/ha) and fodder beet (20,055 kg DM/ha) groups were not significant (P>0.05; Table 5) however, differences between other group means were significant.

High N (300 kg N/ha) application increased DM yield by 2,700 kg DM/ha compared to control (0 kg N/ha) (Table 4). No interaction between forage entry and N application was observed for yield.

Forage quality

Differences between forage entries were highly significant in all quality traits assessed (P<0.0001; Table 4). Nitrogen application affected CP, SSS and ADF but did not influence ME and NDF. Forage entries × N interactions were observed for ME, CP and ADF contents.

Table 4: The effect of forage entries and nitrogen fertiliser application on dry matter yield and forage quality (whole plant basis) at final harvest

Forage crop		DM yield (kg DM/ha)	Forage quality[1]				
			ME (MJ/kg DM)	CP (% DM)	SSS (%DM)	ADF (% DM)	NDF (% DM)
Maize	P8000	29,440 (2,640)[2]	10.8	5.9	42.7	23.2	45.2
	P8805	28,657 (2,437)	10.7	5.6	42.9	24.4	44.8
	P9400	30,417 (2,753)	10.6	5.4	48.0	25.3	42.2
Kale	Gruner	21,103	9.4	7.5	26.4	29.1	36.2
	Regal	16,185	9.1	10.7	23.0	26.2	33.4
	Sovereign	20,583	8.9	9.8	23.1	28.5	36.2
Swede	Triumph	17,877	10.3	15.0	29.3	18.9	21.4
	Clutha Gold	14,035	10.1	14.5	27.9	19.6	22.2
	Invitation	12,450	10.2	15.3	25.3	19.7	21.8
Fodder beet	Cerise	20,464	10.8	9.3	37.1	10.7	16.7
	Enermax	21,518	10.9	9.4	38.0	9.7	15.2
	Monro	18,182	10.9	11.0	37.4	11.4	17.9
	$LSD_{(0.05)}$	5,401	0.7	1.4	5.1	2.9	3.9
Nitrogen							
Control (0 kg N/ha)		19,558	10.4	8.8	34.6	19.8	28.7
High-N (300 kg N/ha)		22,261	10.1	11.1	32.3	21.3	30.1
	$LSD_{(0.05)}$	2,205	NS[3]	0.6	2.1	1.2	NS
Pr>F	Entry (En)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Nitrogen (N)	0.0174	0.0591	<0.0001	0.0282	0.0129	0.0773
	En x N	0.8131	0.0167	<0.0001	0.1249	0.0146	0.2068

[1] ME = metabolisable energy, CP = crude protein, SSS = soluble sugars and starch, ADF = acid detergent fibre, NDF = neutral detergent fibre

[2] Values in brackets are the additional dry matter yield of Italian ryegrass but excluded from data analysis

[3] NS, not significant

Metabolisable energy

Metabolisable energy (ME) content ranged from 8.9 to 10.9 MJ/kg DM and differed significantly among the forage entries (Table 4). Maximum ME values (10.9 MJ/kg DM) were observed in 'Enermax' and 'Monro' fodder beets but were not different from 'Cerise', maize hybrids or 'Triumph' swede. The kale cultivars had low ME values (8.9–9.4 MJ/kg DM) especially 'Sovereign'. Crop group means for ME were generally significantly different, the exception being maize (10.7 MJ/kg DM) versus fodder beet (10.8 MJ/kg DM) (Table 5).

Crude protein

Crude protein content of most trial entries was lower than the maintenance level required by dairy cows during wintering (less than 12%) (National Research Council (NRC), 2001), except swedes which had CP ranging from 14.5–15.3%DM (Table 4). The lowest CP occurred in the maize hybrids (5.4–5.9%DM). The CP content was likely to vary within the kale and fodder beet cultivars (Table 4), but the average CP content between kale (9.4%DM) and fodder beet (9.9%DM) were not significant (Table 5). The high N treatment also increased the CP content (11.1%DM) compared with the control (8.8%DM) (P<0.0001; Table 4).

Soluble sugars and starch

The highest SSS value was observed in maize 'P9400' (48.0%DM) (Table 4). Fodder beet entries had intermediate SSS levels while the brassicas were generally low. In comparing the means over all entries, N application caused a slight decrease in SSS (32.3%DM) when compared with the control (34.6%DM) (P<0.0282; Table 4).

Table 5: Orthogonal contrast between forage crop group means.

	DM Yield[1] (kg DM/ha)	ME[2] (MJ/kg DM)	CP[3] (%DM)
Group mean			
Maize	29,505	10.7	5.6
Kale	19,290	9.1	9.4
Swede	14,787	10.2	14.9
Fodder beet	20,055	10.8	9.9
Contrast analysis			
Maize vs kale	***	***	***
Maize vs swede	***	*	***
Maize vs fodder beet	***	NS	***
Kale vs swede	**	***	***
Kale vs fodder beet	NS	***	NS
Swede vs fodder beet	**	**	***

*P<0.05, **P<0.01, ***P<0.001, NS not significant

[1]DM yield = dry matter yield, [2]ME = metabolisable energy, [3]CP = crude protein

Fibre content

Fibre content was lowest (ADF 9.7–11.4%DM and NDF 15.2–17.9%DM) in fodder beet. Conversely, ADF content was highest in the kale (26.2–29.1%DM) while NDF was highest for maize (42.2–45.2%DM) (Table 4).

Correlation analysis

Dry matter yield was positively correlated with SSS (r = 0.58) and NDF (r = 0.56) but negatively correlated with CP (r = -0.61, P<0.001; Table 6). Similarly, ME was positively and strongly correlated with SSS (r = 0.79, P<0.001) while negatively correlated with CP (r = -0.25, P<0.05), ADF (r = -0.63, P<0.001) and NDF (r = -0.25, P<0.05). Crude protein had negative correlation with SSS (r = -0.61, P<0.001) and NDF (r = -0.57, P<0.001). Acid detergent fibre (ADF) and NDF were positively correlated (r = 0.83, P<0.001).

When plant N content was plotted against the SSS:CP ratio, the relationship was negative curvilinear (Figure 1). The average SSS:CP ratio of maize and fodder beet was greater than 3 which is the threshold to suggest a feed for minimising urinary N excretion (Dalley *et al.*, 2017; de Ruiter *et al.*, 2019). All brassica treatments showed less than 3 in the average SSS:CP ratio.

Table 6: Simple correlation coefficient between dry matter yield and forage qualities at final harvest. *P<0.05, **P<0.01, ***P<0.001, [NS] not significant

	DM Yield[1] (kg DM/ha)	ME[2] (MJ/kg DM)	CP[3] (%DM)	SSS[4] (%DM)	ADF[5] (%DM)	NDF[6] (%DM)
DM Yield	1					
ME	0.22	1				
CP	-0.61***	-0.25*	1			
SSS	0.58***	0.79***	-0.61***	1		
ADF	0.21	-0.63***	-0.19	-0.32**	1	
NDF	0.56***	-0.25*	-0.57***	0.15	0.83***	1

[1]DM yield = dry matter yield, [2]ME = metabolisable energy, [3]CP = crude protein, [4]SSS = soluble sugars and starch, [5]ADF = acid detergent fibre, [6]NDF = neutral detergent fibre

Discussion

Dry matter yield

Although yield was increased by N application, there was no interaction between N application and forage entries for yield, indicating all crops responded in the same way. Maize yields of 28,657–30,417 kg DM/ha were generally consistent with the previous reports in NZ (Chakwizira *et al.*, 2017; Densley *et al.*, 2006; Johnstone *et al.*, 2010; Minnee *et al.*, 2009; Tsimba *et al.*, 2014). Despite being a shorter season crop than fodder beet or brassicas, maize (C4 species) was more productive because of its greater conversion efficiency of solar radiation to crop biomass (Minnee *et al.*, 2009). Maize also responded to irrigation, approximately 30% increase in yield in the literature with fully irrigation in a similar climate in Australia and NZ (Islam *et al.*, 2012; Teixeira *et al.*, 2014).

Kale and swede yields were within the range suggested by NZ companies (Anon., 2019) and slightly higher than yields reported by previous studies conducted in southern locations of the country (Chakwizira *et al.*, 2012; Chakwizira *et al.*, 2013; Westwood *et al.*, 2014). Total rainfall and average temperature during the growing season were higher in this study (641 mm: ~15.4°C) than the above studies (about 270-540 mm: ~12.5°C), which may account for the increased yields of kale and swede.

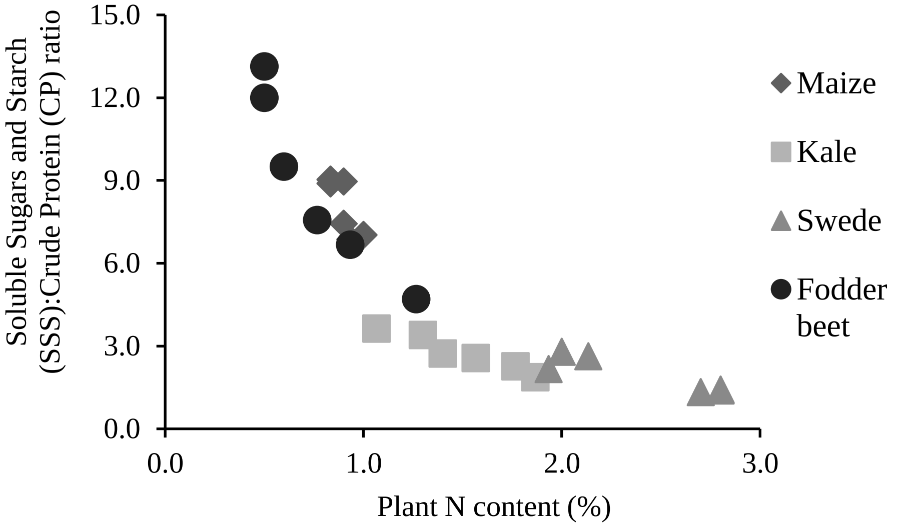

Figure 1: The relationship between plant N content and the soluble sugars + starch and crude protein ratio (SSS:CP).

Fodder beet yields were generally low (20,055 kg DM/ha mean) compared with the potential yield of >30 t/ha (Matthew *et al.*, 2011). However, Matthew *et al.* (2011) found yield variation from 19-35 t/ha at two farm sites in Central Hawke's Bay. Fodder beet is slow to establish (30-60 DAS), so probably intercepted less light early in the season compared with other crops in the trial (Matthew *et al.*, 2011), reducing yield. Khaembah *et al.* (2019) reported 18% yield reduction due to limited radiation interception between October- and November-sown fodder beet crops. On the other hand, fodder beet yields in this study were similar to those obtained by Milne *et al.* (2014), who reported that both cultivar and sowing date influenced yield.

Feed quality

Among feed quality traits (Table 4), ME values were within the recommended ranges for all forage entries (9.5–11.0 MJ/kg DM) except kale. Maize ME contents were consistent with previous studies in Manawatu (Millner *et al.*, 2005). However, kale ME contents (8.9–9.4 MJ/kg DM) were surprisingly low in this study compared with previous reports; 11.4 MJ/kg DM (Westwood *et al.*, 2014) and ~12.1 MJ/kg DM (Cheng *et al.*, 2018). Poor ME content in kale treatments could be related to lower SSS and higher ADF contents (Table 4); ADF is negatively correlated and SSS is positively correlated with ME (Table 6).

There was a negative correlation between CP and ME content in this research, contrary to the results of Millner *et al.* (2011) who tested sorghum, sudan-grass and pearl millet in Manawatu. However, the relationship between CP and DM yield was consistent with the findings of the same authors. The low CP observed in the maize, kale and fodder beet entries would limit their ability to meet the protein requirements of non-lactating cows in winter (Chakwizira *et al.*, 2015; Dalley *et al.*, 2017; Kolver *et al.*, 2001). The low CP content is a result of the protein dilution effect caused by an increase in the rate of accumulation of dry mass other than the accumulation of protein (Fletcher and Chakwizira, 2012; Zhao *et al.*, 2020). It may also be a consequence of the lower concentrations of CP in the most important yield components, such as bulbs in fodder beet and stems in kale (contributed ~80% of total DM) (Chakwizira *et al.*, 2014, 2015; Chakwizira *et al.*, 2018).

The average SSS contents of maize and kale were similar to findings of previous studies (Dalley *et al.*, 2017; Westwood *et al.*, 2014) but that of swede and fodder beet entries were lower than the previous studies in NZ (Chakwizira *et al.*, 2014; Dalley *et al.*, 2020; Dalley *et al.*, 2017). The higher SSS contents were positively correlated with ME and DM yield, and can be used to balance nutrient requirements for dairy cows in early to mid-lactation (Kolver *et al.*, 2001).

Forage fibre content is important for rumen function and maintaining milkfat percentage at mid- and late-lactation (Kolver *et al.*, 2001). Average ADF and NDF values of kale and maize were within the range reported in previous research (Cheng *et al.*, 2018; Dalley *et al.*, 2017; Westwood *et al.*, 2014). The values of ADF (<20%) and NDF (<28%) in swede and fodder beet were within the range reported by Dalley *et al.* (2017) but seemed to be poor for rumen activity (Gibbs, 2014).

Feed versus environmental benefits

Crude protein content increased marginally with the application of N fertiliser. This is contrary to the result of Chakwizira *et al.* (2014). However, the same result was found in brassicas and summer forage crops at different N doses in Australia where annual rainfall was similar to this study (Jacobs and Ward, 2011). The CP values achieved in this study were generally low despite high rates of N fertiliser use (Table 4 and Figure 1). The SSS:CP ratio was high in maize (6.9–9.0) but was quite varied in fodder beet (4.7–13.1) (Figure 1) (Dalley *et al.*, 2020). Generally CP<12% and SSS>30% or SSS:CP ratio >3 are regarded as adequate for minimising the risk of nitrate leaching from deposited urine (Dalley *et al.*, 2017; de Ruiter *et al.*, 2019). Fodder beet and maize were likely to be the better forage options for reducing N leaching compared with the brassica crops. However, fodder beet is considered as a poor supplement for lactating dairy cows due to high acidosis risk and low milk response when intake exceeds 27% of daily dry matter intake (Fleming *et al.*, 2020).

Conclusion

Maize yields were higher than that of the traditional winter forage crops. Metabolisable energy content was good in all forage entries except kale. The crude protein content was quite low in maize and fodder beet, indicating potential for lower N leaching with high proportions of these feeds in animal diet. Nitrogen application affected some quality traits (CP, SSS and ADF). The results suggest maize as the best option on the basis of yield and overall nutritive value under non limiting soil moisture for growth.

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