Productivity of rotationally grazed simple and diverse pasture mixtures under irrigation in Canterbury

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Abstract
Herbage dry matter (DM) production, botanical composition and nutritive value were compared over 2 years under irrigation and dairy cow grazing for simple two-species grass (perennial ryegrass or tall fescue)-white clover pastures and diverse pastures where herbs (chicory and plantain), legumes (red clover and lucerne) and prairie grass were added to the simple mixtures. Averaged over 2 years, annual herbage DM production was 1.62 t DM/ha greater in diverse (16.77 t DM/ha) than simple (15.15 t DM/ha) pastures, primarily reflecting greater DM production in summer. Diverse pastures had lower metabolisable energy (ME) (12.0 vs 12.2 MJ ME/kg DM) and neutral detergent fibre (301 vs 368 g/kg DM) content than simple pastures, although the total ME produced per year was greater in diverse than simple pastures (202 vs 185 GJ ME/ha). Ryegrass-based pastures had higher annual DM production than tall fescue-based pastures in the first but not second year. The results indicate that including additional legumes and herbs with simple grass-white clover pastures may increase total DM and ME production of dairy pastures under irrigation.

Keywords: *Lolium perenne* L., *Festuca arundinacea,* herbs, legumes, pasture mixtures, diversity, nutritive value

Introduction
The focus of dairy farming on simple and productive forage systems has led to a limited range of plants being used, predominantly perennial ryegrass-white clover pastures, with some brassica and maize. There has been relatively low adoption of more diverse mixtures containing alternative legumes such as red clover and lucerne, or forage herbs such as chicory and plantain. With a growing awareness of the role that plant species may play in reducing the environmental impacts of dairy farming (Moir *et al.* 2012), concerns about the poor persistence of perennial ryegrass (Parsons *et al.* 2011), and the need for improved herbage quality in spring and both quality and quantity in dry summers (Clark *et al.* 1997), there has been increased interest in the use of alternative plant species in more diverse mixtures.

In studies in extensive low input grasslands, increased plant diversity has been linked to greater herbage dry matter (DM) production, more efficient use of available water, reduced nitrate leaching and greater resistance to weed invasion (Lee *et al.* 2013; Sanderson *et al.* 2004). However, there is limited data on the performance of intensively managed diverse pastures under grazing. Dryland pasture studies in New Zealand (Daly *et al.* 1996; Goh & Bruce 2005) show that diverse pastures containing more than 10 species had greater herbage DM production than simple ryegrass-white clover mixtures, and sustained a higher legume content. Under full irrigation, Goh & Bruce (2005) showed multi-species pastures had greater total DM production and higher legume content than simple ryegrass-white clover pastures.

This experiment was carried out to determine the herbage DM production, botanical composition and nutritive value under irrigation of two-species mixtures of perennial ryegrass (standard and high sugar) and tall fescue sown with white clover compared with more diverse mixtures where additional herbs (chicory and plantain), legumes (lucerne or red clover) and grasses (prairie grass) were added to two-species mixtures.

Materials and methods
Site
This experiment was conducted between June 2010 and May 2012 at the Lincoln University Research Dairy Farm in Canterbury, New Zealand. The experiment was a randomised block design consisting of three base pasture types and two levels of diversity. A 9 ha area was divided into three blocks each of 3 ha using permanent double wire fencing, and each block was sown into six treatment paddocks each of 0.5 ha. The treatment paddocks were randomly allocated to six pasture treatments (Table 1). The treatments were based on three simple two-species mixtures of perennial ryegrass-white clover (RG), high sugar ryegrass-white clover (HS), and tall fescue-white clover (TF) pastures, and three diverse pasture mixtures of more than four species where herbs (chicory and plantain), legumes (red clover or lucerne) and prairie grass were added to the simple pasture mixtures (RGD, HSD, TFD) (Table 1.).

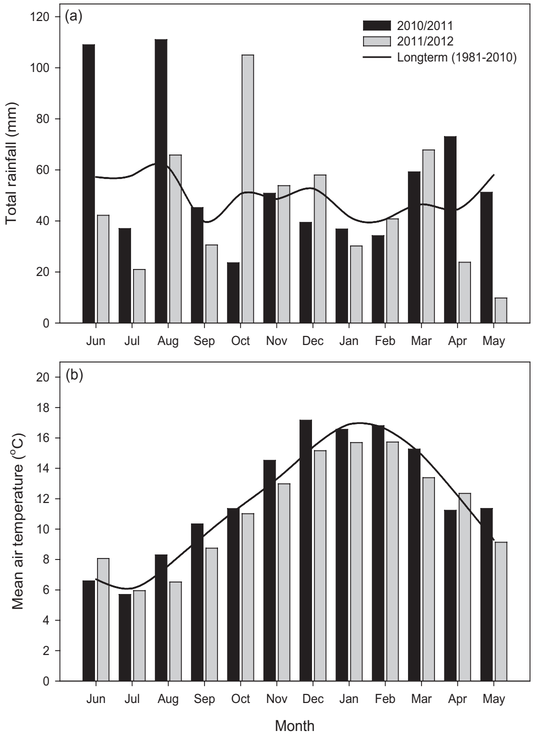

Figure 1 Mean monthly rainfall (a) and mean monthly air temperature (b) from 2010 to 2012 at Lincoln, Canterbury, New Zealand. Data collected from Broadfields Meteorological Station, 1 km from research site.

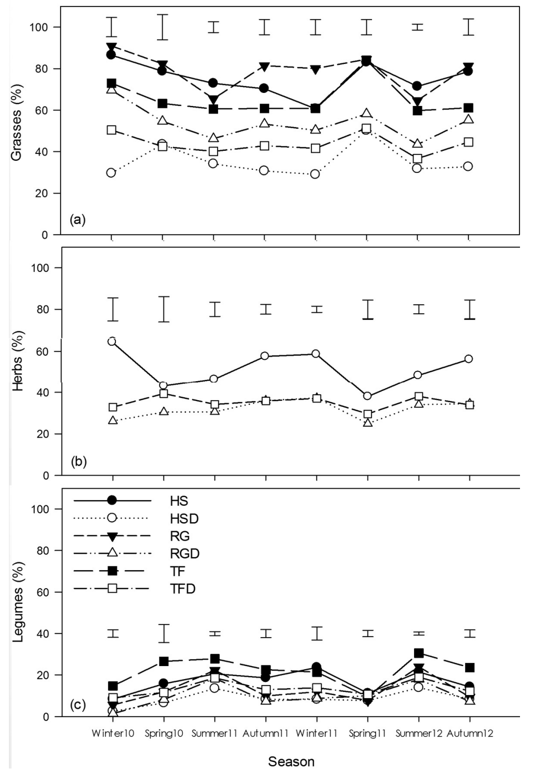

Figure 2 Seasonal botanical composition (% of DM in pre-grazing mass) of (a) grasses, (b) herbs and (c) legumes for six pasture mixtures (Table 1) between June 2010 and May 2012. Error bar equals LSD (α=0.05) for interaction at each time point.

Grazing management

From late August to mid May each year, all paddocks were rotationally grazed by Friesian-Jersey dairy cows. Grazing usually occurred when the grass had reached approximately the 2.5- to 3-leaf stage. Cows were removed from the paddocks when the pasture height was approximately 3–4 cm. Paddocks were grazed nine times between June 2010 and May 2011 and 10 times between June 2011 and May 2012. All pasture mixtures were cut for silage in November 2011 and January 2012. The mixtures were fertilised with 200 kg N/ha/yr which was applied in four applications of 50 kg N/ha as urea each in early spring, mid spring, mid summer and mid autumn. The area was irrigated by travelling lateral irrigator between October and March

Table 1 Plant species, cultivar names and sowing rates (kg seed/ha) of simple and diverse pasture mixtures.

Species	Common name	Cultivar	Simple			Diverse		
			RG	HS	TF	RGD	HSD	TFD
Lolium perenne L.	Perennial ryegrass	One50-AR1	20			10		
Lolium perenne L.	High sugar ryegrass	Abermagic		20			10	
Festuca arundinacea	Tall fescue	Advance			20			10
Bromus wildenowii	Prairie grass	Atom				15		15
Medicago sativa	Lucerne	Torlesse						8
Trifolium pratense	Red clover	Colenso				4		
Trifolium repens	White clover	Kopu 2	5	5	5	2	2	2
Plantago lanceolata	Plantain	Tonic				1	1	1
Chicorium intybus	Chicory	Choice				2	2	2
Total number of species			**2**	**2**	**2**	**6**	**4**	**6**

2010/11 (499 mm) and between November and March 2011/12 (368 mm) with approximately 20–30 mm of water applied per week.

Measurement

Herbage mass was measured weekly with a calibrated rising plate meter (RPM; Jenquip, Filip's EC-09 Electronic Folding Plate Meter, 50 readings per paddock). Calibration measurements for each pasture mixture, pre- (n = 18) and post-grazing (n = 18) were collected each season. Immediately prior to cutting two RPM measurements were recorded in the area to be harvested (quadrat = 0.2 m^2). All live material was removed to ground level (0.5–1.0 cm stubble heights). Any soil contaminants in the samples were removed by hand and samples were oven-dried at 65°C for at least 48 hours, weighed, and DM determined. Calibration equations for each pasture mixture were determined by linear regression. Calibrated equations for each pasture mixture were:

HS (kg DM/ha) = 34.9 + 136.6 RPM, R^2=0.84, S.E.= 4.16
RG (kg DM/ha) = 150.4 + 132.5 RPM, R^2=0.76, S.E.= 5.23
TF (kg DM/ha) = 139.4 + 118.5 RPM, R^2=0.81, S.E.= 3.95
HSD (kg DM/ha)=450.5+105.3 RPM, R^2=0.86, S.E.=2.90
RGD (kg DM/ha) = 381.4 + 99.1 RPM, R^2=0.80, S.E.= 3.41
HSD (kg DM/ha) = 610.6 + 83.5 RPM, R^2=0.80, S.E.= 2.90

Grazing records of each paddock were kept so herbage growth rate (kg DM/ha/day) could be estimated by comparing the previous RPM reading and the date of grazing. A new regrowth period was considered to commence following each grazing. Herbage DM production was then calculated on annual and seasonal bases (winter: June–August, spring: September–November, summer: December–February and autumn: March–May).

Botanical composition was measured prior to each grazing by cutting four quadrats, each 0.2 m^2, in each paddock to 1cm above ground level at four random locations throughout each paddock using electric hand shears. Fresh sub-samples of around 200 g were dissected into sown grass, herbs, legumes, weeds and dead material before dry weight of each component was determined. The oven dried sub-samples were bulked for nutritive analysis following grinding to pass through a 1 mm stainless steel sieve. Samples were analysed using near infrared spectroscopy for nitrogen content, digestible organic matter (DOMD), water-soluble carbohydrate (WSC) and neutral detergent fibre (NDF) by Lincoln University Analytical Laboratory. Calculation of metabolisable energy (ME) was derived from formula provided by McDonald *et al.* (2002), where ME (MJ/kg DM) = 0.016 DOMD. ME for all pasture mixtures were calculated based from this equation.

Meteorological data

Rainfall and temperatures for the measurement period are presented in Figure 1. Total rainfall during the first year of experiment (670 mm) was slightly higher than the average long-term rainfall of the last 20 years (579 mm). However, rainfall in the second year (564 mm) was slightly lower than the average long-term rainfall as depicted in Figure 1(b). The monthly air temperatures showed a similar trend to the long-term average air temperature.

Statistical analysis

Herbage DM production, botanical composition, and nutritive value were analysed by two-way factorial ANOVA (3 base pastures × 2 level of diversity) using the statistical package GenStat (Release version 12.2, 2010). Botanical composition data collected at each

Table 2 Effect of base pasture and diversity on annual and seasonal DM production (t DM/ha). P-values from ANOVA for main effects of base pasture and diversity are shown. Means followed by different letters within a row are significantly different (P<0.05), according to least significant difference test (LSD, α=0.05) following a significant ANOVA.

	Base Pasture					Diverse Pasture			
	HS	RG	TF	P-value	LSD	Simple	Diverse	P-value	LSD
Winter 2010	2.03^b	2.92^a	1.99^b	<0.001	0.35	2.19	2.44	0.08	0.29
Spring 2010	5.30^a	5.48^a	4.22^b	<0.05	1.05	4.97	5.03	0.87	0.86
Summer 2011	6.26	6.11	5.89	0.74	1.06	5.65^b	6.52^a	<0.05	0.86
Autumn 2011	2.52	3.03	2.43	0.26	0.83	2.60	2.72	0.70	0.68
Winter 2011	0.91	1.04	1.25	0.13	0.35	1.09	1.04	0.66	0.28
Spring 2011	6.43	5.42	5.36	0.38	1.83	5.32	6.15	0.25	1.50
Summer 2012	6.77	6.70	6.80	0.99	2.03	6.26	7.25	0.21	1.66
Autumn 2012	2.48	2.35	2.06	0.65	1.00	2.22	2.38	0.66	0.82
Year 1	16.10^{ab}	17.55^a	14.53^b	<0.05	2.33	15.41	16.71	0.16	1.90
Year 2	16.58	15.52	15.47	0.77	3.89	14.89	16.82	0.21	3.17
Mean	16.34	16.53	15.00	0.31	2.27	15.15	16.77	0.08	1.86

grazing were averaged across season prior to analysis. Means were separated using Fisher's protected least significant difference test whenever the ANOVA indicated a significant treatment effect.

Results

Annual and seasonal dry matter production

Annual DM herbage production ranged from 14.53 to 17.55 t DM/ha, and averaged over two years, was 1.62 t DM/ha higher in diverse (16.77 t DM/ha) than simple (15.15 t DM/ha) pastures (Significant at P=0.08) (Table 2). In the first year, annual DM herbage production was similar in RG-based (17.55 t DM/ha) and HS-based (16.10 t DM/ha) pastures, and RG-based pastures had greater herbage DM production than TF-based pastures (14.53 t DM/ha) (Table 2). In the second year, total DM herbage production was unaffected by base pasture type. In the first year, winter and spring herbage DM production was lower (P<0.05) in TF-based pastures than RG-based and HS-based pastures (Table 2). Diverse pastures produced 0.87 t DM/ha more (P<0.05) herbage DM than simple pasture mixtures in summer of the first year (Table 2). Annual and seasonal herbage DM production were unaffected by the interaction on base pasture type and diversity.

Botanical composition

The percentage of grass was higher (P<0.001), and percentage of legume was lower (P<0.001), in simple than diverse pastures throughout the trial (Figure 2). Averaged over the 2 years of trial, the respective average percentage of grass and legume was 70.1% and 20.1% for simple and 41.3% and 13.2% for diverse pastures. The percentage of legume was greater in TF-based than

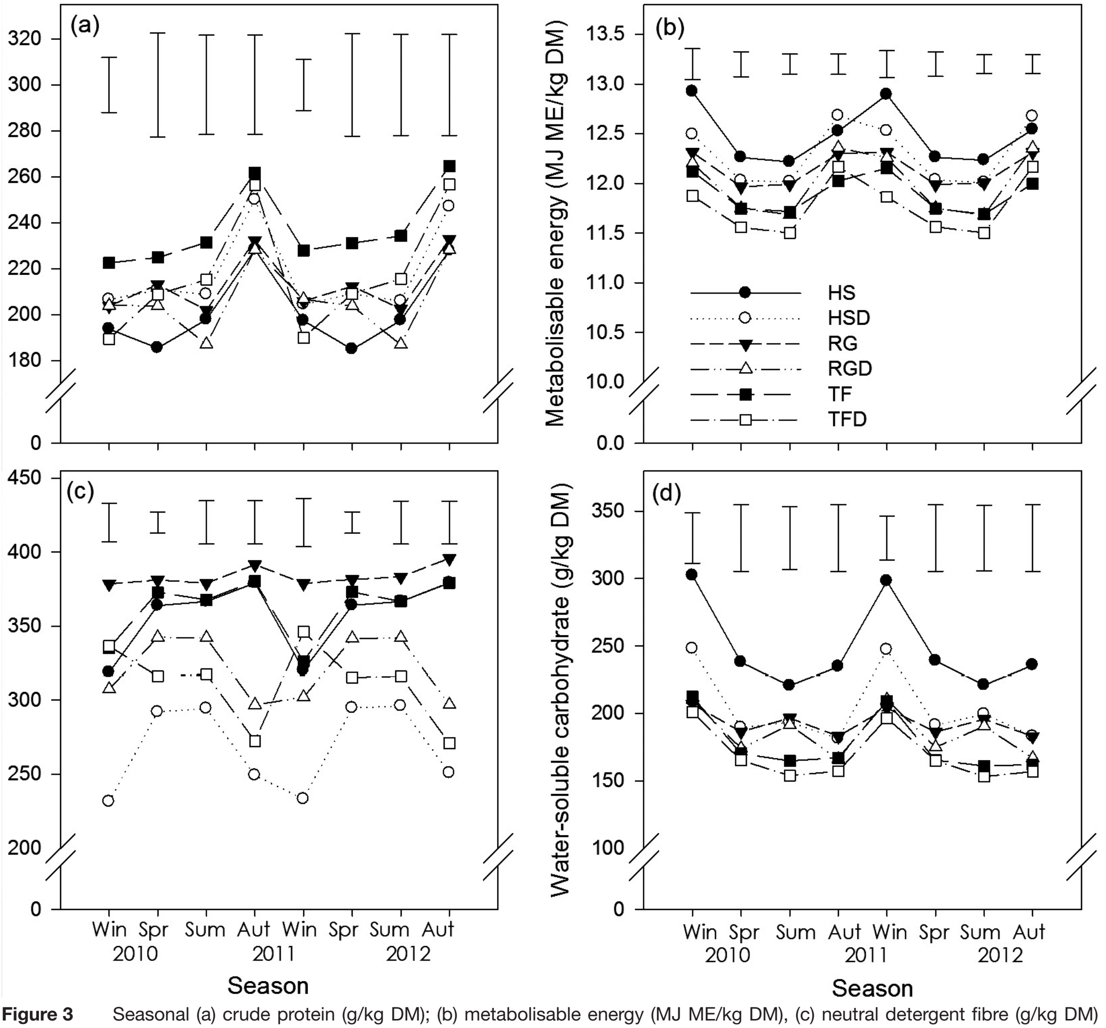

Figure 3 Seasonal (a) crude protein (g/kg DM); (b) metabolisable energy (MJ ME/kg DM), (c) neutral detergent fibre (g/kg DM) and (d) water-soluble carbohydrate (g/kg DM) for all pasture mixtures from June 2010 to May 2012 in Lincoln. Error bar equals LSD (α=0.05) for interaction at each time point.

RG-based and HS-based pastures throughout the trial. The percentage of herb (chicory plus plantain) in the diverse pastures was high, ranging from 25.4 to 64.8%, with little change between first ($\bar{x}$ = 39.9%) and second ($\bar{x}$ = 40.0%) years (Figure 2b). The mean percentage of herb was greater (P<0.05) in HSD ($\bar{x}$ =50.6%) than RGD ($\bar{x}$ =33.3%) and TFD ($\bar{x}$ =36.0%) in all seasons except spring 2010.

Nutritive value

Crude protein ranged from 196 g/kg DM to 261 g/kg DM throughout the year, and was highest in autumn of each year ($\bar{x}$ = 259 g/kg DM and 261 g/kg DM in autumn 2011 and 2012, respectively) (Figure 3a). Crude protein was unaffected by base pasture or diversity (Figure 3a). Metabolisable energy ranged from 11.6 to 12.7 MJ ME/kg DM with little seasonal variation (Figure 3b). ME was higher (P<0.001) in HS-based pastures ($\bar{x}$ = 12.4 MJ ME/kg DM) than RG-based pastures ($\bar{x}$ = 12.1 MJ ME/kg DM) and TF-based pastures ($\bar{x}$ = 11.8 MJ ME/kg DM) in each season (Figure 3b). In all seasons except autumn 2011 and autumn 2012, ME was higher (P<0.01) in simple pastures ($\bar{x}$ = 12.2 ME MJ/kg DM) than diverse pastures ($\bar{x}$ = 12.0 ME MJ/kg DM). Neutral detergent fibre ranged from to 275 g/kg DM to 363 g/kg DM and averaged over the trial was greater (P<0.001) in simple ($\bar{x}$ = 368 g/kg DM) than diverse pastures ($\bar{x}$ = 301 g/kg DM). In most seasons, NDF was lower (P<0.001) in HS-based pastures ($\bar{x}$ = 313 g/kg DM) than TF-based pastures ($\bar{x}$ = 337 g/kg DM) and RG-based pastures ($\bar{x}$ = 353 g/kg DM) (Figure 3c). The water soluble carbohydrate (WSC) concentration ranged from 157 g/kg DM to 275 g/kg DM, and at all dates was higher (P<0.01) in HS-based ($\bar{x}$ = 226 g/kg DM) than RG-based ($\bar{x}$ = 189 g/kg DM) or TF-based pastures ($\bar{x}$ = 172 g/kg DM) (Figure 3d). There was a trend for WSC to be lower in diverse ($\bar{x}$ = 186 g/kg DM) than simple ($\bar{x}$ = 206 g/kg DM) pastures, with this effect was significant (P<0.001) in winter 2011.

Discussion

DM herbage production

Annual DM herbage production calculated from weekly rising plate meter and averaged across both years for the three base pastures was 1.62 t DM/ha greater in the diverse than simple pastures. The high DM yield of the diverse pasture supports previous results that diverse pastures are at least as good as conventional two-species pastures (Daly *et al.* 1996; Goh & Bruce 2005; Ruz-Jerez *et al.* 1991; Sanderson *et al.* 2005). In the current study, the higher DM production primarily reflected increased growth during summer, with approximately 1 t DM/ha more grown over summer in diverse than simple pastures. In turn, the higher herbage growth is probably due to a high abundance of herbs (chicory and plantain) in diverse pastures in summer, which grow rapidly at this time of year given adequate water (Sanderson *et al.* 2005). Increased legume growth is unlikely to be an explanation as in most seasons the proportion of legume in pasture was lower in diverse than simple pastures.

Ryegrass and white clover are particular suitable in summer moist or irrigated pastures, where under the appropriate fertiliser and grazing management regime, they form a productive pasture of a high quality. In this experiment, annual herbage DM production was greater in the perennial ryegrass-based pastures (RG and HS) than TF-based pastures in the first but not second year, supporting similar results by Minneé *et al.* (2010). Compared to perennial ryegrass, tall fescue pastures are more suitable and tolerant to hot, dry summer environments and may have higher growth rates (McCallum *et al.* 1992). The difference between Year 1 and Year 2 may be explained by the slower establishment of tall fescue relative to perennial ryegrass (Milne *et al.* 1997), although the tall fescue was sown in summer, five months before measurements began.

Nutritive value

The metabolisable energy content of all pasture mixtures was high (>11.5 MJ ME/kg DM). Averaged over 2 years, ME was greater in simple than diverse pastures, although the difference was small (12.2 versus 12.0 MJ ME/kg DM). The greater ME in simple pastures most likely reflects the higher legume proportion in the simple than diverse pastures, with legumes often noted to have high ME (Waghorn 2007). Furthermore, pastures were consistently grazed to low pasture residuals preventing build-up of stem and dead material, meaning grass ME is likely to have been maintained at a high level in simple pastures. Despite the lower ME in diverse pastures, total ME produced per ha was greater in diverse (202 GJ ME/ha/yr) than simple (185 GJ ME/ha/yr) pastures due to their higher DM production.

There was negligible effect of pasture mixture on crude protein content, with values ranging from 195 to 261 g/kg DM. Similar CP content in simple and diverse pastures was also observed in related work using a subset of pastures from this study (Totty *et al.* 2013). These authors showed greater milksolids production per cow but reduced urine N concentration and urine N excretion per cow from the HSD than RG and HS pastures when offered at the same allowance, demonstrating potential environmental benefits. These findings may also be attributed to lower NDF in diverse (300 g/kg DM) than simple (368 g/kg DM) pastures, most likely due to high chicory and plantain content with lower NDF (Burke *et al.* 2002). Both CP and NDF values were within the range ranges suggested by Holmes *et al.* (2002) and Pacheco & Waghorn (2008) to be adequate for milk production in early lactation. The water soluble carbohydrate concentration was higher (+37 g/kg DM) in the high sugar perennial ryegrass than the standard ryegrass, supporting results obtained by Bryant *et al.* (2009) in Canterbury.

Conclusion

Rotationally grazed diverse pastures under irrigation in Canterbury were at least as productive as simple perennial ryegrass and tall fescue-white clover pastures. Increased summer growth of diverse pastures could be attributed to a high herb content. The herbage and ME production data indicate that diverse pastures may play an important role in promoting greater milksolids production per cow and per ha. Together, with data indicating lower N excretion from cows grazing diverse pastures, the results indicate that diverse pastures containing additional herbs and legumes may play an important role maintaining or increasing milksolids production while reducing the environmental impact of dairy farming.

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