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RESEARCH ARTICLE

Dry matter accumulation and nutritive value of winter forage crops sown in Canterbury on different dates

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Supplementary forage crops are used in New Zealand to overcome feed shortages during winter and early spring. The objective of this study was to maximize annual dry matter (DM) yield by optimizing sowing and harvest dates. Forage crop options include faba bean, oats and Italian ryegrass. These were sown on five dates in the autumn and winter of 2008 and on three sowing dates in the autumn of 2009. The maximum total DM ranged from 4420 to 26,310 kg ha⁻¹ across all species and sowing dates for both seasons. Oats yielded the highest maximum total DM in both years. The quality analysis showed oats sown in early March and harvested at the end of August attained herbage metabolisable energy (ME) of 11.5 MJ kg⁻¹ DM and high total ME per ha which was suitable for the lactation of dairy cows. Thus, oats was the beneficial alternative forage crop for farmers to choose. Faba bean had lowest maximum total DM yield compared with oats and Italian ryegrass in the first season; however, faba bean had higher maximum total DM compared with Italian ryegrass but lower than oats and faba bean-oat intercrop in the second season. Faba bean sown from early March to mid-April and harvested at the end of November attained a herbage nitrogen (N) content of more than 2.4% and had the highest total N uptake per ha compared with oats and Italian ryegrass at 2.4% of herbage N.

Keywords: *Avena sativa*; dry matter yield; harvest date; *Lolium multiflorum*; nutritive value; sowing date; *Vicia faba*

Introduction

Faba bean (*Vicia faba* L.), oats (*Avena sativa* L.) and Italian ryegrass (*Lolium multiflorum* L.) are annual crops grown in autumn in New Zealand to provide supplementary winter forage. Increasing the supply of supplementary feed on dairy farms is one of the stated objectives under the Strategic Framework for New Zealand's Future Dairy Industry (Caradus 2006; Dairy NZ 2010). Improved productivity of these crops could provide additional feed to meet livestock requirements at times of a deficit in pasture supply. This leads to more efficient use of land and more available feed for lactation and winter feeding. Together this may increase livestock numbers and make dairying

more competitive with other land use options and contribute to the increased profitability of this pastoral industry (Brown et al. 2007). However, the reduced sunlight hours and lower temperatures in winter limit the yield and quality of forage crops. Cool temperatures also reduce the conversion of intercepted radiation to dry matter (DM)—the radiation use efficiency—hence there is a decrease in biomass production (Watiki et al. 1993; Kooman et al. 1996; Loss & Siddique 1997). In addition, low temperatures delay leaf appearance and expansion, and thus canopy closure (Kirby et al. 1982; Firman et al. 1995). Defining optimal sowing and harvest dates is therefore crucial to maximizing total annual production from a given

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land area. Selection of optimum sowing and harvest dates must also consider the requirements of both the preceding and subsequent crop or pasture in a rotation. The time of autumn sowing should ensure canopy closure before leaf expansion is restricted by low temperature (Reddy et al. 2003). In addition to DM yield, forage quality is affected by the time of harvest, which affects the stage of maturity of individual crops. Thus, the time of mechanical harvest, or consumption of these crops must also factor in changes in forage quality. For maintenance feed, maximizing total ME and protein production per unit area may be the prime consideration. In contrast, for production animals, the absolute quality of the herbage may be more important. Thus, in the first year, all crops were harvested at an early stage of crop development, whereas an extended harvest window was considered in year 2. Overall, the study aimed to identify a range of suitable sowing and harvest dates, and to quantify the quality-quantity trade-offs of crops grown later into spring. Monocultures of these crops were also compared with an intercrop of faba bean and oats to determine if the differences in canopy architecture were advantageous to increase yields.

Materials and methods

Experimental site

Two separate field experiments were grown during the 2008 and 2009 seasons at Lincoln University, Canterbury, New Zealand (43° 38'S, 172° 28'E, 11 m asl). Experiment 1 was sown in autumn and winter with a final harvest in mid-spring of 2008. Experiment 2 was sown in autumn with a final harvest in early summer of 2009. For experiment 1, the site had previously been used for barley

(*Hordeum vulgare* L.) crops in 2007, whereas for experiment 2, the site had been in lucerne (*Medicago sativa*) from 1998 to 2007 and barley in 2008. The soil types were a Templeton silt loam interface in 2008 (US Soil Taxonomy: Udic Ustochrept fine silty, mixed, mesic) and a Wakanui deep silt loam (US Soil Taxonomy: Aquic Ustochrept fine silty, mixed, mesic) in 2009 (Watt & Burgham 1992) (Table 1).

Experimental design, treatments and crop management

Both experiments were a split plot design with sowing date as a main plot and species as a subplot with four replicates. For experiment 1, sowing dates in 2008 were 4 March, 28 March, 21 April, 12 May and 3 June, and in 2009 (experiment 2) the three sowing dates were 16 March, 16 April and 15 May. The same crop cultivars of 'Old New Zealand' faba bean, 'Milton' oats and 'Feast II' Italian ryegrass were used for both years. In 2009, there was an additional treatment of an intercrop of faba bean and oats. In 2008, there were 60 sub-plots of 2.1×14 m, sown in 150 mm rows. In 2009, there were 48 sub-plots of 6.3×10 m in 150 mm rows. In both years, faba beans and oats were sown to meet target populations of 60 and 240 plants m^{-2} , respectively. Italian ryegrass was sown at 25 $kg\ ha^{-1}$. Plots were sown with an Øyjord cone seeder at a target depth of 40 mm for faba bean and oats and 10 mm for Italian ryegrass. In 2008, sulphur superphosphate was applied on 2 March at 200 $kg\ ha^{-1}$ over the experimental area. All plots except those with faba bean received 500 $kg\ N\ ha^{-1}$ in 10 split applications of 50 $kg\ N\ ha^{-1}$, as urea from 4 March to 31 October. In 2009, a single application of 150 $kg\ ha^{-1}$ of superphosphate

Table 1 Soil test results of two sites used for forage crop experiments at Lincoln University, Canterbury, New Zealand, in 2008 and 2009.

Experimental site	pH (water)	Olsen-P ($\mu g\ ml^{-1}$)	Ca	Mg	K	Na	Sulphate ($\mu g\ g^{-1}$)	Available N (kg/ha)
			me 100 g^{-1}					
Experiment 1	5.9	23	6.20	0.85	0.33	0.15	2	42
Experiment 2	6.2	14	6.97	0.90	0.72	0.15	9	105

was applied on 10 March to all plots. Subsequent fertilizer applications of 150 kg of diammonium phosphate (DAP) ha⁻¹ and 33 kg N ha⁻¹ in the form of urea were applied to oats and Italian ryegrass. The higher rate of N for 2008 was applied to ensure N stress did not limit yield and in 2009 the soil had much higher levels of N than in 2008. Faba bean plots did not receive any N fertilizer applications. The application of N fertilizer to Italian ryegrass and oats promoted tillering and increased the rate of leaf appearance and leaf expansion for vigorous vegetative growth (Hay & Porter 2006). However, the N supply for faba beans is derived from the plant's capacity to fix N from air using a symbiotic relationship with bacteria within root nodules. Soil moisture content (SMC) was monitored every 7 to 10 days. Irrigation from hand-shift sprinklers was applied when the SMC was 20% below field capacity as measured by a Hydrosense probe (Campbell Scientific, USA) to a depth of 0.3 m in both years. Climatic data during the two growing seasons of the experiments are shown in Table 2.

Measurements

Dry matter yield

Dry matter accumulation was measured from two random samples taken from each plot using a

0.1 m² quadrat. Sampling commenced 3 weeks after crops were sown and followed at 2–3 week intervals. Crops were cut to ground level from each of the three rows across the plot. For the final harvest, 2 × 0.5 m² quadrats were used for sampling. Samples were weighed and oven-dried at 60 °C to constant weight. For Italian ryegrass, the whole plot was mown when it lodged and then allowed to regrow. In 2008, the crops were harvested at different times for each particular sowing date but with an aim of harvesting, at the latest, by the end of October to fit in with summer cropping operations. In 2009, the crops were harvested sequentially for all sowing dates until a final harvest when crops were more mature than in 2008. As a consequence, the final harvests for the first season crops were at different times and different stages of crop development for each sowing date. Specifically for 2008, harvests were on 13 October for the 4 March sowing date, 11 October for the 28 March sowing date and 25 October for the 21 April sowing date. For the 12 May and 3 June sowing dates, the final harvest was taken on 30 October 2008. In 2009, crops were sequentially harvested through October and November before a final harvest was taken on 4 December for all three sowing dates.

Table 2 Monthly solar radiation, minimum and maximum air temperature and long-term mean (LTM) (1975–2007) recorded in 2008 and 2009 at Broadfields Meteorological Station, Lincoln University, Canterbury New Zealand.

Month	Solar radiation (MJ m ⁻²)			Minimum temperature (°C)			Maximum temperature (°C)		
	2008	2009	LTM	2008	2009	LTM	2008	2009	LTM
Jan	725	723	727	12.0	12.0	11.4	22.7	24.4	22.1
Feb	539	444	625	12.3	11.0	11.3	21.0	20.2	21.7
Mar	448	478	469	10.0	9.1	9.7	20.4	20.0	20.0
Apr	271	285	316	5.6	7.1	6.8	18.7	18.2	17.2
May	196	186	191	1.1	3.2	4.2	13.9	12.7	14.3
Jun	126	137	135	0.2	3.9	1.7	12.7	14.5	11.4
Jul	134	180	165	1.6	1.4	1.4	11.1	11.6	10.9
Aug	227	254	251	0.8	1.0	2.7	12.6	11.3	12.2
Sept	341	414	394	3.8	4.4	4.4	17.7	15.0	14.4
Oct	560	570	557	3.8	4.1	6.2	22.0	16.1	16.6
Nov	683	616	697	8.3	6.2	7.9	19.7	20.7	18.4
Dec	699	701	739	10.4	9.2	10.0	19.8	19.9	20.4

Nutritive value

Analyses of forage quality were performed on oats, intercrop (oats) and Italian ryegrass from DM yield samples. These were ground by a centrifugal grinder (Retsh ZM 200) to pass through a 1 mm stainless steel sieve for chemical analysis. The ground samples were then analysed by near-infrared spectroscopy (NIR) using a NIRS-Foss system 5000 Rapid Content at the Analytical Service Laboratory, Lincoln University. Samples were analysed for nitrogen (N) content (%), and digestible organic matter in dry matter (DOMD%). Calibration equations developed from NIR spectra explained 90%–99% of sample variation in analysing nutritive value of crops (Collins & Fritz 2003). Crude protein (CP) and metabolisable energy (ME) were calculated based on Equations (1) and (2) (Agricultural Research Council [ARC] 1980).

$$\text{CP} = \text{N}\% \times 6.25 \quad (1)$$

$$\text{ME} = \text{DOMD} \times 0.16 \quad (2)$$

The ME was presented as herbage ME (MJ kg⁻¹ DM) and calculated as total ME in gigajoules ha⁻¹ (GJ ha⁻¹), herbage N (%) and total N were also calculated on a per hectare basis. Faba bean was unable to be analysed by NIR since there was no calibration in the current NIR software. These samples were analysed by wet chemistry for N and DM digestibility (DMD) at the Lincoln University Analytical Service. For ME analyses, a value above 11.5 MJ kg⁻¹ DM was considered adequate to support production stock while 8–10 MJ kg⁻¹ DM was adequate for growth of sheep and cattle (Fulkerson et al. 2007). For N, values above 2.4% were considered adequate for lactating dairy cows, while the lower value of 1.6% was satisfactory for live weight gain of sheep and cattle (Ulyatt et al. 1980).

Data analysis

Analyses of variance (ANOVA) using Genstat 12.2 determined main effects and significant

interactions. Means were separated by least significant difference tests at the 5% significance level. Both the experiments, in 2008 and 2009, were analysed as split plot designs with sowing dates as main plots and species as sub-plots with four replicates. The maximum total DM (TDM) production for individual plots was identified and analysed by ANOVA. The ‘maximum TDM’ refers to the highest yield from the whole growing season for each sowing date for both seasons of the experiments, and may have occurred at or before the final harvest. For the nutritive value analysis, the herbage ME, total ME per ha, herbage N and total N per ha data were fully replicated. These data were subjected to analyses of variance (ANOVA) using Genstat 12.2 and the standard error of mean (SEM) for sowing date effect, species effect and the interaction of sowing date and species effect are presented.

Results***Total dry matter accumulation****Experiment 1 (2008)*

Oats had a maximum TDM yield from the 4 March sowing of 15,016 kg ha⁻¹ (203 days after sowing [DAS]) compared with Italian ryegrass (12,730 kg DM ha⁻¹) (223 DAS) and faba bean (11,410 kg DM ha⁻¹) from the same sowing date (Fig. 1). The last two sowing dates gave the lowest maximum TDM yield which ranged from 4420 kg DM ha⁻¹ for faba bean to 9996 kg DM ha⁻¹ for oats.

Experiment 2 (2009)

In 2009, oats sown on 16 March produced the highest maximum TDM of 26,310 kg DM ha⁻¹ when harvested 239 DAS (Fig. 2). This was followed by intercrop faba bean-oats sown at the same time with 24,840 kg DM ha⁻¹ (66.6% oats, 33.4% faba bean). Faba bean sown on 16 April and Italian ryegrass sown on 16 March produced maximum TDM of 21,340 kg DM ha⁻¹ (218 DAS) and 17,890 kg DM ha⁻¹ (263 DAS), respectively, as monocultures.

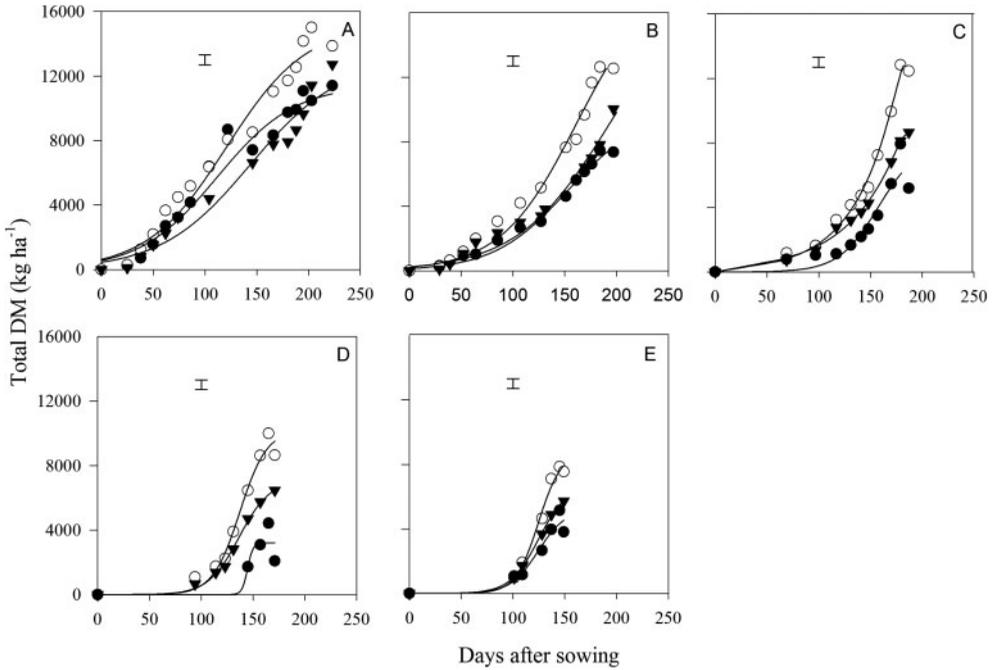


Figure 1 Total dry matter (TDM) yield of faba bean (●), oats (○) and Italian ryegrass (▼) over time when sown at Lincoln University, Canterbury, New Zealand on: **A**, 4 March; **B**, 28 March; **C**, 21 April; **D**, 12 May; **E**, 3 June 2008. Error bars are standard error of mean (SEM) of maximum TDM. Lines are the fitted generalized logistic curves.

Nutritive value of winter forages

Experiment 1 (2008)

Herbage metabolisable energy. Italian ryegrass had a higher ($P < 0.001$) maximum herbage ME than faba bean and oats for all sowing dates except

for 28 March (Fig. 3). All species produced DM with ≥ 11.5 MJ kg⁻¹ DM but at different times. Faba bean DM was ≥ 11.5 MJ kg⁻¹ from 106–186 DAS. For oats this occurred from 145–178 DAS and for Italian ryegrass from 150–203 DAS.

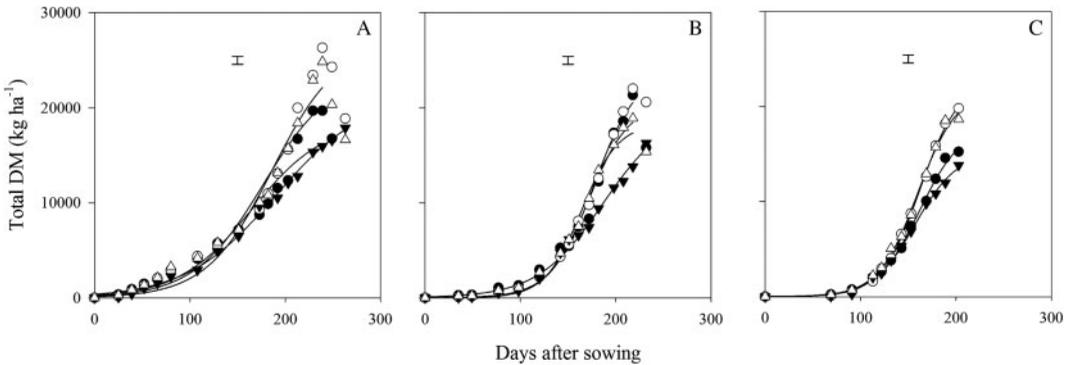


Figure 2 Total dry matter (TDM) yield of faba bean (●), oats (○), Italian ryegrass (▼) and faba bean-oat intercrop (△) over days when sown at Lincoln University, Canterbury, New Zealand on: **A**, 16 March; **B**, 16 April; **C**, 15 May 2009. Error bar represents standard error of mean (SEM) of maximum TDM. Lines are fitted generalized logistic curves.

Total metabolisable energy. Oats tended to produce a more total ME ha⁻¹ than Italian ryegrass or faba bean for all sowing dates (Fig. 4). The highest total ME was 163 GJ ha⁻¹ for oats sown on 4 March. This was greater ($P < 0.001$) than the total ME from Italian ryegrass (130 GJ ha⁻¹) or faba bean (54 GJ ha⁻¹), when crops were harvested in late September (203 DAS).

Herbage N (%). Faba bean always had an N content of at least 2.4% (15% CP) at all sowing dates (Fig. 5). Herbage N content for the first four sowing dates ranged from 3.2%–3.8% (20%–24% CP) from crops harvested from the end of September (184 DAS) to end of October (171 DAS). Italian ryegrass attained 2.4% in early (192 DAS) to late October (150 DAS) except when sown on 4 March and 12 May. For oats, a herbage N content of 2.4% was measured from

early September (166 DAS) to early October (123 DAS) across all sowing dates, except for 4 March.

Total N. Faba bean sown on 4 March produced the highest total N uptake of 368 kg ha⁻¹ when harvested in late September (203 DAS) (Fig. 6). Similarly, Italian ryegrass sown at the same time produced the highest total N uptake of 390 kg ha⁻¹ when harvested in the middle of October (223 DAS). For oats, crop N uptake remained below 280 kg ha⁻¹ across all sowing dates.

Experiment 2 (2009)

Herbage metabolisable energy. Italian ryegrass had a herbage ME of at least 11.5 MJ kg⁻¹ DM from sowing until when it was harvested from early October to the end of November (163–259 DAS) (Fig. 7). For faba bean and oats, an ME ≥ 11.5 MJ kg⁻¹ DM was obtained from early

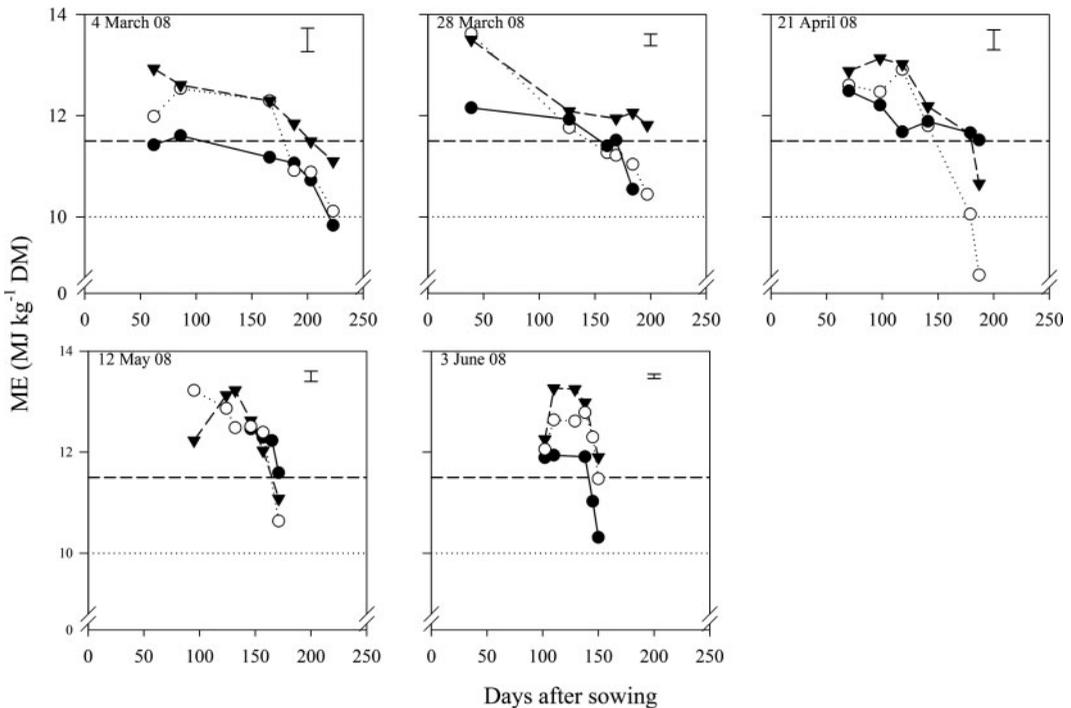


Figure 3 Herbage metabolisable energy (ME) of faba bean (●), oats (○) and Italian ryegrass (▼) sown on five sowing dates in 2008 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for species effect. Sowing dates of crops are given in the top left corner. Dotted line (···) for herbage ME at 10 MJ kg⁻¹ DM and dashed line (---) for herbage ME at 11.5 MJ kg⁻¹ DM.

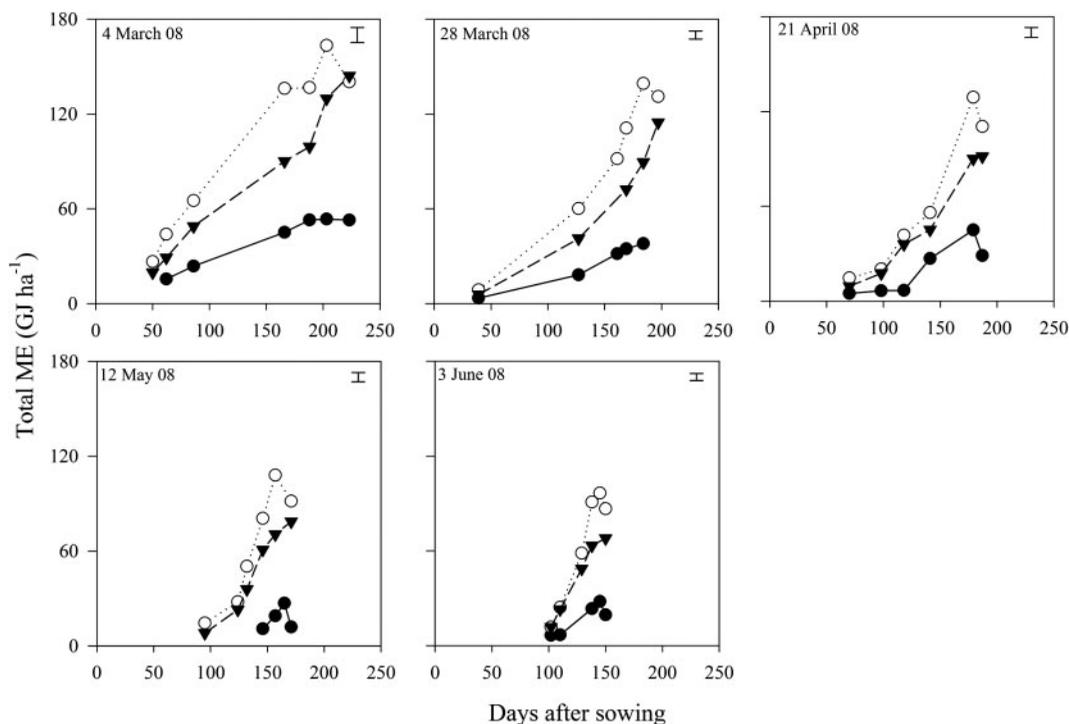


Figure 4 Total metabolisable energy (ME) of faba bean (●), oats (○) and Italian ryegrass (▼) sown on five sowing dates in 2008 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for species effect. Sowing dates of crops are given in the top left corner.

August to late September (113–128 DAS for faba bean and 137–148 DAS for oats).

Total metabolisable energy. Oats showed a consistently higher total ME than the other forage crops for the 16 March and 15 May sowing dates, while it was higher than in faba beans and the intercrop from the 16 April sowing (Fig. 8). The maximum total ME from the three sowing dates was 220 GJ ha⁻¹ for oats when crops were harvested in the middle of November. While, it was 176 GJ ha⁻¹ for Italian ryegrass (263 DAS), 81 GJ ha⁻¹ for faba bean (218 DAS) and 166 GJ ha⁻¹ (80.3% oats, 19.7% faba bean) for the faba bean-oat intercrop (239 DAS).

Herbage N (%). Herbage N content of faba bean stayed above 2.4% throughout the growing season at all sowing dates (Fig. 9). The herbage N content was still above 2.6% at harvests in late November and early December, 250 DAS on the 16 March

sowing, 218 DAS on the 16 April sowing and 202 DAS on the 15 May sowing. Oats maintained $\geq 2.4\%$ N when harvested from early September (170 DAS) to late October (160 DAS). While for Italian ryegrass, a suitable time to harvest and achieve an N content of at least 2.4% N was from the middle of October (213 DAS) to the end of November (196 DAS). The intercrop had a herbage N content of $>2.4\%$ for most of the growing at all three sowing dates, only dropping below this critical value about 200 DAS.

Total N. The faba bean had greater N uptake than the oats, the Italian ryegrass and the faba bean-oat intercrop from the 16 March and 16 April sowing dates (Fig. 10). The total N uptake in faba bean reached a maximum of 539 kg ha⁻¹ (208 DAS) for all evaluated sowing dates. Maximum total N uptake was 401 kg ha⁻¹ (239 DAS) for oats, 412 kg ha⁻¹ (218 DAS) for Italian ryegrass and 445 kg

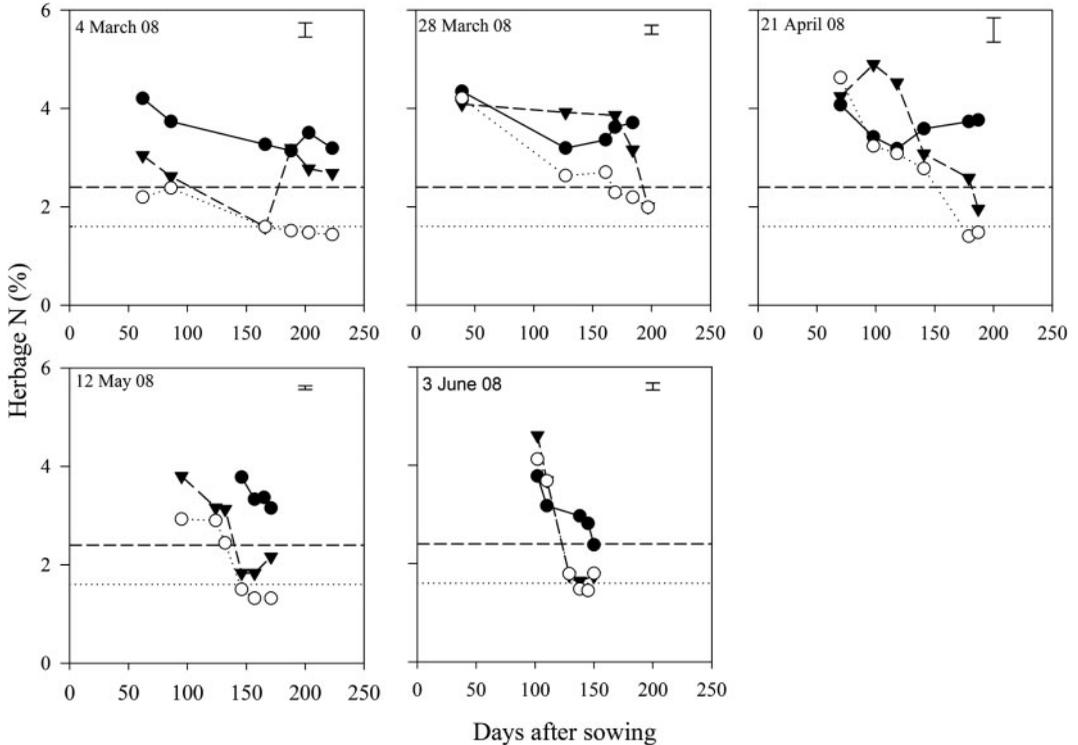


Figure 5 Herbage nitrogen (N) content of faba bean (●), oats (○) and Italian ryegrass (▼) sown on five sowing dates in 2008 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for maximum herbage N for species effect in 2008 season. Sowing dates of crops given in the top left corner. Dotted line (···) for herbage N at 1.6% (10% CP) and dashed line (---) for herbage N at 2.4% (15% CP).

ha⁻¹ (59.5% oats, 40.5% faba bean) (213 DAS) for the faba bean-oat intercrop.

Discussion

Maximum total dry matter

Oats consistently gave the highest maximum TDM in both growing seasons of 2008 (15,016 kg ha⁻¹) and 2009 (26,310 kg ha⁻¹) across species sown (Figs. 1–2). Similarly, McDondald & Stephen (1979) reported that oats gave the most consistent and highest DM yields, in Mosgiel, New Zealand, ranging from 3000–17,000 kg ha⁻¹. Overall, maximum TDM in 2009 (Fig. 2) was greater than in 2008 (Fig. 1). This could be attributed to the later final harvest in 2009. The decline in yield at the last harvest in 2009 was expected since senescence had commenced and,

because forage species differ in their growth behaviour, delaying the harvest date of certain species would maintain the feed supply over a longer feeding period. Another forage option that could be sown other than oats is turnip (*Brassica rapa*). Turnip sown in the middle of March and harvested in early August yielded 8427 kg ha⁻¹ in Canterbury, New Zealand (Collie & McKenzie 1998). This offers alternative crop combinations from different sowing and harvest dates. The quality of the feed can also be altered by manipulating harvest dates.

Based on yield comparisons for two growing seasons, there was a window of sowing dates available to produce similar yields. For instance, oats sown on 4 March 2008 produced 15,016 kg ha⁻¹ by the end of September (203 DAS) (Fig. 1) compared with a 16 March 2009 sowing at

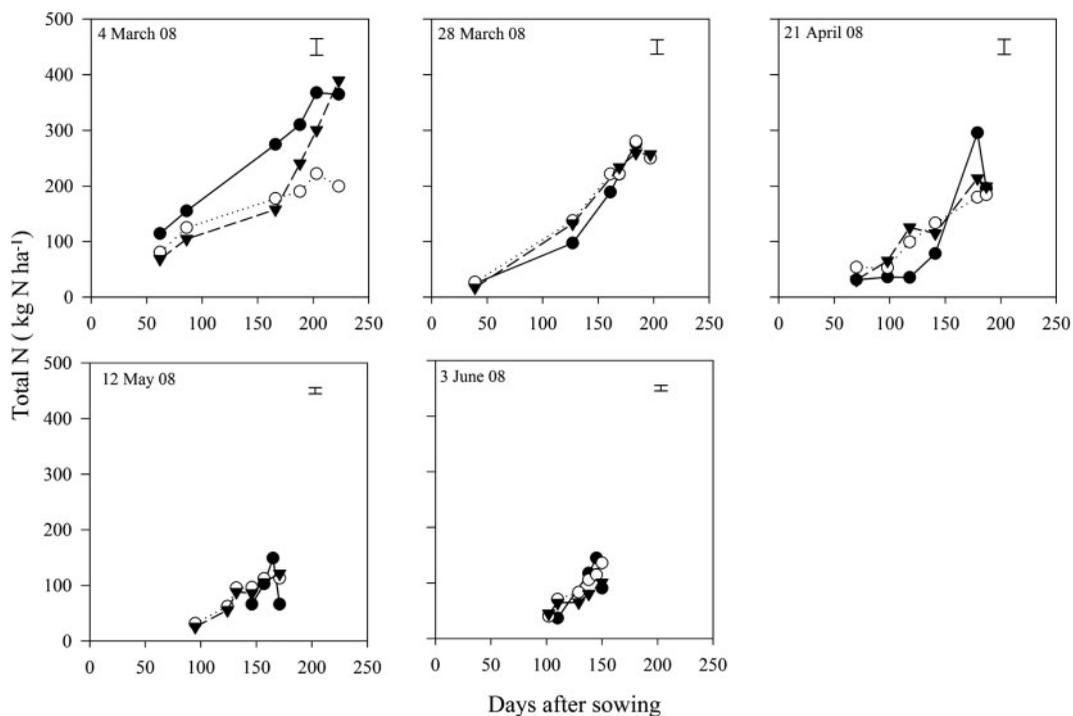


Figure 6 Total nitrogen (N) uptake of faba bean (●), oats (○) and Italian ryegrass (▼) sown on five sowing dates in 2008 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for species effects. Sowing dates of crops given in the top left corner.

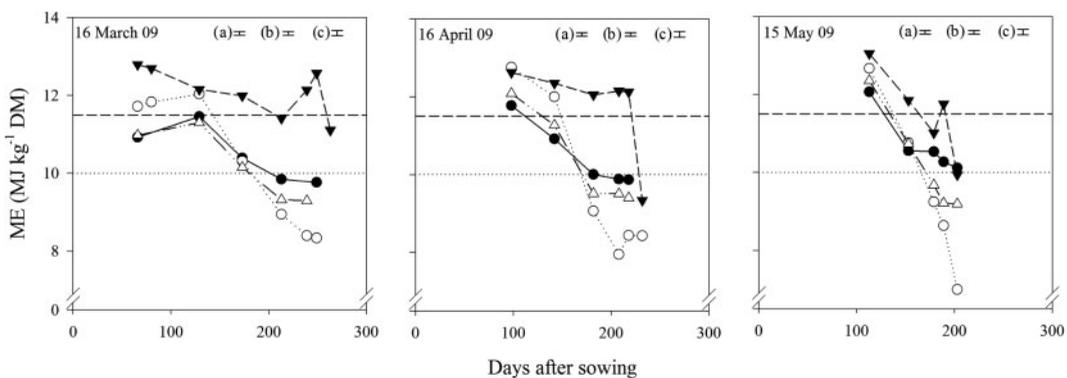


Figure 7 Herbage metabolisable energy (ME) of faba bean (●), oats (○), Italian ryegrass (▼) and faba bean-oat intercrop (Δ) sown on three sowing dates in 2009 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for herbage ME of: (a) sowing date effects (SD); (b) species effects (S); (c) SD*S interactions. Sowing dates of crops are given in the top left corner. Dotted line (···) for herbage ME at 10 MJ kg⁻¹ DM and dashed line (---) for herbage ME at 11.5 MJ kg⁻¹ DM.

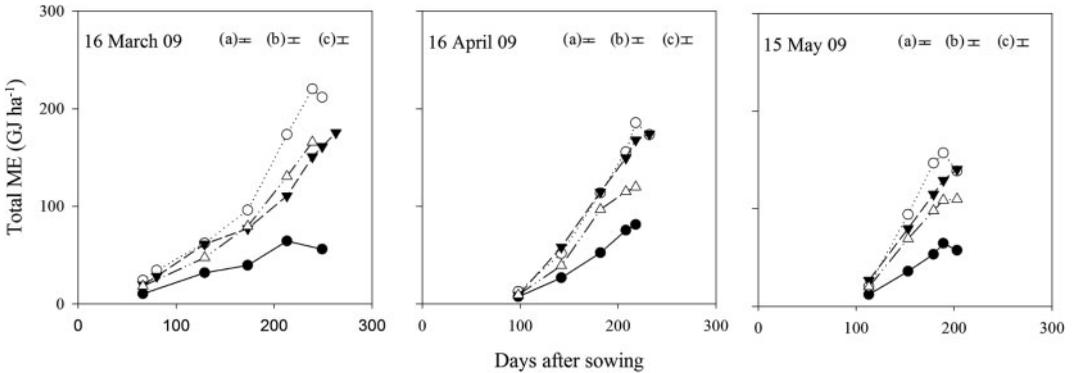


Figure 8 Total metabolisable energy (ME) of faba bean (●), oats (○), Italian ryegrass (▼) and faba bean-oat intercrop (Δ) sown on three sowing dates in 2009 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for total ME of: (a) sowing date effects (SD); (b) species effects (S); (c) SD*S interactions. Sowing dates of crops are given in the top left corner.

14,364 kg ha⁻¹ (191 DAS) (Fig. 2) at a similar harvest date. Oats sown later on 28 March in 2008, yielded 2690 kg ha⁻¹ less than oats sown on 16 March 2009 when harvested at the end of September. However, after the 28 March sowings, there was a consistent decrease in the DM yield compared with other sowings in March, specifically due to the shorter growing period. These results suggest oats can be sown in early or mid March to produce yields of at least 14 t ha⁻¹ by the end of September. The potential DM production

of 26.3 t ha⁻¹ of oats in 2009 could be obtained by harvesting the crop later, in the middle of November.

The maximum TDM of faba bean sown on 4 March 2008 was 11,410 kg ha⁻¹ (223 DAS) (Fig. 1) compared with 14,290 kg ha⁻¹ for crops sown on 16 March 2009 (211 DAS) (Fig. 2) when both crops were harvested in the middle of October. The yield difference was due to an infestation of chocolate spot (*Botrytis fabae*), Ascochyta blight (*Ascochyta fabae*) and a severe outbreak of rust (*Uromyces*

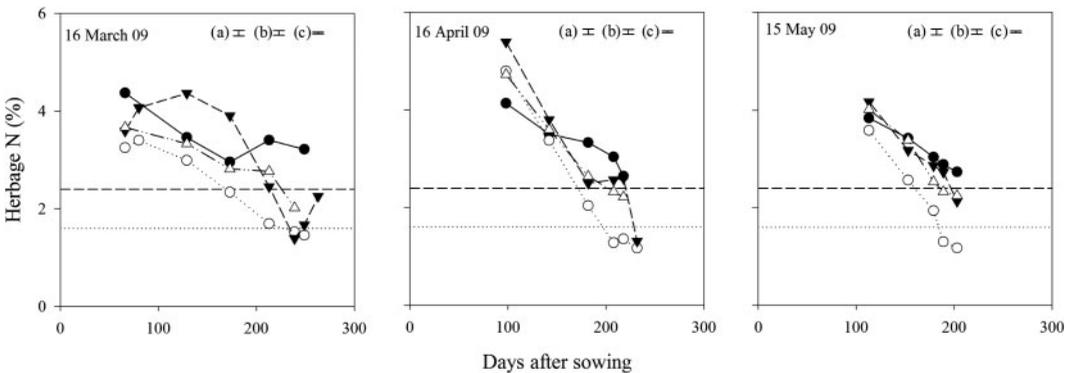


Figure 9 Herbage nitrogen (N) content of faba bean (●), oats (○), Italian ryegrass (▼) and faba bean-oat intercrop (Δ) sown on three sowing dates in 2009 at Lincoln University, Canterbury, New Zealand. Error bars represent standard error of mean (SEM) for maximum herbage N for: (a) sowing date effects (SD); (b) species effects (S); (c) SD*S interactions in 2009 season. Sowing dates of crops are given in the top left corner. Dotted line (···) for herbage N at 1.6% (10% CP) and dashed line (---) for herbage N at 2.4% (15% CP).

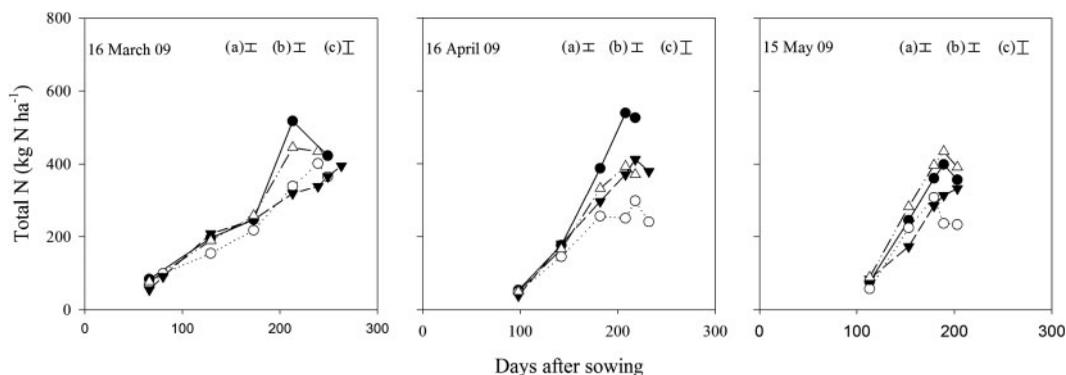


Figure 10 Total nitrogen (N) uptake of faba bean (●), oats (○), Italian ryegrass (▼) and faba bean-oat intercrop (△) sown on three sowing dates in 2009 at Lincoln University, Canterbury, New Zealand. Error bars represent maximum standard error of mean (SEM) for: (a) sowing date effects (SD); (b) species effects (S); (c) SD*S interactions. Sowing dates of crops are given in the top left corner.

viciae-fabae) on the 4 March sowing in 2008. For the 28 March sowing in 2008, the maximum TDM decreased to 7460 kg ha⁻¹ when harvested at the end of September (184 DAS) compared with 12,870 kg ha⁻¹ for the crop sown on 16 March in 2009 and harvested at 196 DAS (Fig. 2). Faba bean sown later on 21 April 2008 and harvested in the middle of October (179 DAS) produced a maximum TDM of 5280 kg ha⁻¹ (Fig. 1). This was less than when sown on 16 April 2009 and harvested at 184 DAS (Fig. 2). This was associated with the 21 April sowing being affected by a wilt caused by *Fusarium oxysporum*. The present results suggest faba bean could be sown in mid-March and harvested in the middle of October to get at least 14 t ha⁻¹. Sowing could be delayed until the middle of April and harvested in late November to produce the maximum TDM. However, sowing faba bean needs much attention due to significant yield losses associated with disease infestations as reported in the present study.

For Italian ryegrass, the crops sown on 4 March 2008 had a maximum TDM of 12,730 kg ha⁻¹ (223 DAS) (Fig. 1). This was 392 kg ha⁻¹ lower than that sown on 16 March 2009 (Fig. 2) when both crops were harvested in the middle of October. The crop sown later on 28 March 2008 produced 10,040 kg ha⁻¹ (Fig. 1) when harvested in the middle of October (197 DAS) compared

with 12,904 kg ha⁻¹ (209 DAS) when sown on 16 March in 2009 (Fig. 2). For crops sown later than mid-March, Italian ryegrass yields were significantly lower than for oats (Fig. 1). Thus, sowing Italian ryegrass either early or in the middle of March would be advisable to attain a higher DM yield.

For the faba bean-oat intercrop, the maximum TDM was 14,200 kg ha⁻¹ when it was harvested at the end of September (191 DAS) for the crops sown on 16 March 2009 (Fig. 2) (65.3% oats, 34.7% faba bean) compared with oats sown on 4 March. The crops yielded 6020 kg ha⁻¹ less when sowing was delayed to 16 April 2009 and harvested at the end of September (160 DAS). Thus, it is suggested this combination should be sown in the middle of March. Yield will be reduced if the sowing date is delayed later than this.

Nutritive value of winter forages

Herbage metabolisable energy (ME) and total ME Figures 3, 4, 7 and 8 indicate oats should be the choice of farmers who sow winter forage crops to provide high-quality feed for lactating dairy cows since it attained herbage ME of 11.5 MJ kg⁻¹ DM and at the same time gave the greatest total ME ha⁻¹. Oats sown in early March gave a higher total ME at 136 GJ ha⁻¹ when harvested at the end of

August, 178 DAS. Harvesting of oats sown in early March could also be delayed until late September to maximize total ME. However, the mean ME declined to 10 MJ kg⁻¹ DM which is unsuitable for lactating dairy cows but adequate for growth of sheep and cattle.

Italian ryegrass is the alternative crop to be sown from early March to mid-April and can be harvested anytime before the end of November to obtain maximum DM yield as well as high quality. Italian ryegrass maintained a herbage ME of ≥ 11.5 MJ kg⁻¹ DM longer than the other species (Fig. 7) and had a high total ME at 169 GJ ha⁻¹ (sown on 16 April 2009). Italian ryegrass has the potential to continuously provide high-quality feed when cut at regular intervals (140 and 182 DAS). Whereas oats and faba bean yield a single harvest of which the quality is determined by stage of harvest. Equally, from similar sowing dates, harvested Italian ryegrass could be delayed until the end of November (228 DAS) when quality was still sufficient for the live weight gain of sheep and cattle.

Herbage N and total N

Figures 5, 6, 9 and 10, show faba bean as the most appropriate of these forage crops if the main aim is to maximize N yield and maintain a herbage N content of at least 2.4% (15% CP). For faba bean to perform optimally, it should be sown from early March until mid-April and harvested at the end of November with an N yield of up to 539 kg ha⁻¹. In addition, faba bean maintained a high herbage N content ($\geq 2.4\%$) towards crop maturity. Towards the end of the season, faba bean still had the highest herbage N content of $>1.6\%$ (10% CP) when harvested at the end of November.

As well as a high ME, Italian ryegrass also maintained a N content of $\geq 2.4\%$ when sown in early to mid-March and harvested in mid-October. However, the 317 kg N ha⁻¹ harvested required 72 kg urea ha⁻¹ and 150 kg DAP ha⁻¹ of applied N suggesting a further 60 kg ha⁻¹ from soil N. The more consistent quality and prolonged vegetative growth of Italian ryegrass means it offers

flexibility in the timing of harvest to accommodate the following crop.

A faba bean-oat intercrop could be sown in mid-March and harvested in mid-October to produce 445 kg N ha⁻¹ (59.5% oats, 40.5% faba bean) at a herbage N content of 2.4%. A later harvest, for example in the second week of November produced 433 kg N ha⁻¹ at (62.8% oats, 37.2% faba bean) a minimum requirement of herbage N (1.6%) for growth of sheep and cattle. Oats when mixed with faba bean showed a slightly greater herbage N content (% CP) at most harvest dates in 2009 than the oat monoculture. As reported by Lauriault & Kirksey (2004), a CP of 14.8% in an oat monocrop was lower than in oat intercrops with hairy vetch or winter pea with 17% and 19.9% CP, respectively. Similarly, Robinson (1960) reported that intercropping of pea (*Pisum sativum* L.) with oat enhanced forage CP concentration compared with an oat monoculture in Minnesota.

Conclusion

The present results indicate oats had a greater maximum TDM yield compared with faba bean, Italian ryegrass or a faba bean-oat intercrop. It is suggested that oats and Italian ryegrass should be sown in early or mid-March, while faba bean can be sown in the middle of March or middle of April to maximize DM yield. Oats are a suitable crop to be sown to maximize total ME per ha. This could be obtained by sowing in early March and harvesting at the end of August. Whereas, to maximize total N yield per ha, faba bean would be appropriate. Crops could be sown between early March and mid-April and harvested at the end of November. Italian ryegrass is another option for farmers to maximize total ME by sowing from early March to mid-April and harvesting before the end of November and sown in early to mid-March and harvested in the middle of October to maximize N content per ha. Italian ryegrass maintained quality of ME and N content for longer than the other species. Thus, Italian ryegrass offers flexibility for harvest while maintaining quality because it remains vegetative throughout the winter spring period.

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