

Grange Beef Research Centre

GRASSLAND AND FORAGE CONSERVATION

Estimation of pasture and grass silage intake by three genotypes of beef cattle

The profitability of beef production depends on the efficient conversion of pasture and supplementary feeds into beef. The amount of feed consumed by beef cattle is likely to be influenced by their genotype. However, there is limited information quantifying the dry matter intake (DMI) of beef cattle when grazing pasture. The objective was to estimate the DMI of steers of high or low genetic merit for beef production compared with Holstein-Friesian (HF) steers, when grazing pasture during summer and when offered grass silage indoors during winter.

A total of 79 spring-born steers included 56 progeny of 22 beef sires of high (H, n=11 sires) and low (L, n=11) genetic merit based on the Irish Cattle Breeding Federation genetic index – the ‘Beef Carcass Sub Index (BCSI)’. Sire breed was balanced across beef genotype and consisted of Charolais (n=5), Belgian Blue (n=1), Limousin (n=3) and Simmental (n=2). There were also 23 progeny from HF sires (n=5) and dams. From 13th April to 25th October, steers rotationally grazed pasture and were then housed and offered grass silage until 21st December. Pasture DMI was estimated over 6 days in late July/August using an n-alkane marker method and a herbage disappearance method. Daily silage DM intake was estimated over 56 days as the difference between available and residual silage mass. Linear models were used to test for the effect of genotype (H, L, HF) on mean live weight (LW) and DM intake. Breed of dam and sire were included as factors and age of steer was a covariate in the model. Contrast statements were used to test for the effects of H v. L beef genotypes and beef v. HF genotypes.

Pasture and silage DMI did not differ between the genotypes (Table 31). Relative to LW, DMI for both forages was higher for L than H beef genotypes, however only relative silage DMI was higher for HF than beef genotypes. DMI of pasture and grass silage by individual steers was poorly correlated. There was no difference in mean DMI of pasture using the n-alkane and disappearance methods.

Table 31: Mean live weight (LW), dry matter intake (DMI) and DMI relative to LW of beef steers of high (H) and low (L) genetic merit for beef production, compared with Holstein-Friesian (HF) steers, when grazing pasture during summer and when offered grass silage during winter

Diet	Trait	Genotype			sed ²	P-value	
		H	L	HF		H v. L	Beef v. HF
Grazed pasture	Mean LW ¹ (kg)	531	506	457	19.2	0.103	<0.001
	DMI (kg/d)	7.68	8.20	7.53	0.481	0.171	0.230
	DMI (kg DM/kg LW)	1.46	1.63	1.65	0.095	0.024	0.139
Grass silage	Mean LW ¹ (kg)	586	561	517	21.0	0.136	<0.001
	DMI (kg/d)	7.57	7.62	7.56	0.290	0.815	0.841
	DMI (kg DM/kg LW)	1.30	1.36	1.46	0.036	0.018	<0.001

¹Mean LW over intake period. ²Standard error of the difference

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Effects of seed mixture and nitrogen fertilisation on the yield of grass – clover swards

The yield of multi-species pasture mixtures is likely to depend on the relative proportions of plant species in the seed mixture, overall seeding rate and soil fertility. It is also likely to vary from one location to another. The objective of this study was to determine the effects of changes in the relative proportions of two grass and two clover species in a seed mixture, overall seeding rate and N fertilisation, on pasture yield at two sites in Ireland. Data for the second year are presented. Two grass species, perennial ryegrass (Lper) and timothy (Ppra), and two clover species, white clover (Trep) and Caucasian clover (Tamb), were used. Four monocultures of seed and 11 seed mixtures with different proportions of each species were defined using a simplex design (Cornell, 2002). There were four mixtures dominated by each species (0.7 of one species and 0.1 of each other species), six mixtures dominated by pairs of species (0.4 of each of two species and 0.1 of the other species) and one mixture with each species equally represented (0.25 of each species). Treatments were repeated at two seeding rates (12 and 20 kg viable seed/ha) at an N fertiliser level of 100 kg/ha/y. The effect of a second level of N fertiliser (200 kg N/ha/y) was tested on the four monocultures and five selected mixtures, at the two seeding rates. The 48 treatments were assigned randomly to plots (2 m × 5 m) at two sites: Fermoy, Co. Cork and Athenry, Co. Galway. Plots were sown in July/August 2005 and managed by cutting with seven harvests from 10 April to 13 November, 2007. Fertiliser N, P (35 kg/ha/y) and K (150 kg/ha/y) were applied after each harvest. Dry matter (DM) yields of sown and unsown species were measured at each harvest.

The results show that there are benefits to be gained by going beyond perennial ryegrass as the only grass species in the seed mix. Averaged across the two sites and seeding rates timothy was consistently the highest yielding species after 2 years (Figure 6). Any of the seed mixtures which contained the two grasses and at least 10% of white clover were most productive. These mixtures also strongly reduced the ingress of weeds into the swards which meant that no herbicides were needed. Caucasian clover established poorly in all pastures. The results were consistent across both sites. The implication is that more varied pasture seed mixtures could have something to offer in low input beef systems.

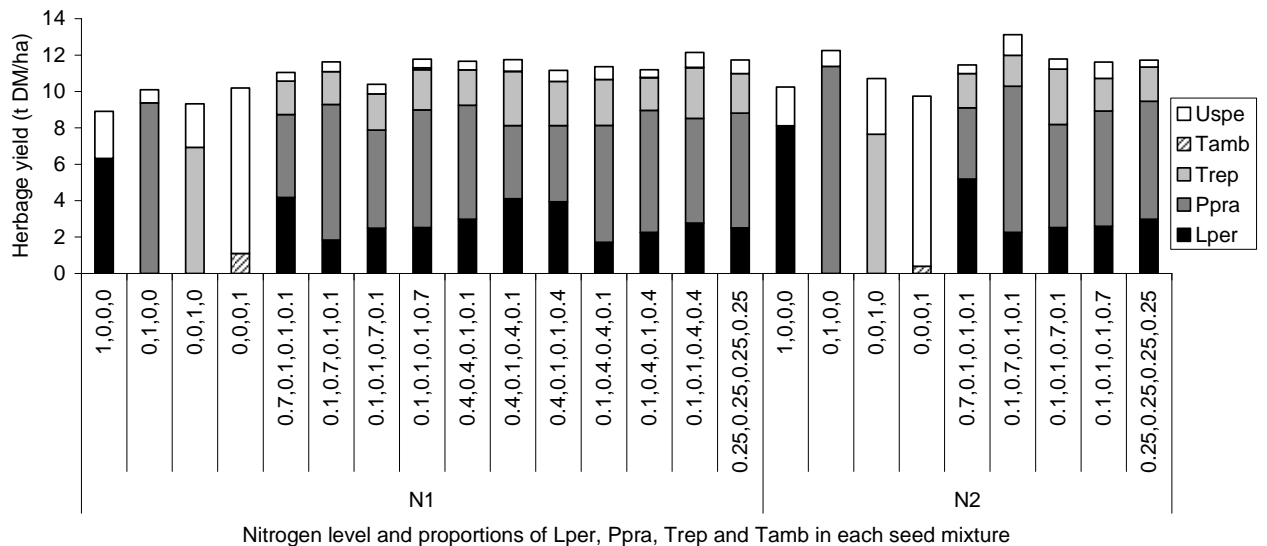


Figure 6. Mean annual herbage yields of perennial ryegrass (Lper), timothy (Ppra), white clover (Trep), Caucasian clover (Tamb) and unsown species (Uspe, or weeds) in the second year after sowing from seed mixtures with different species proportions and two levels of N fertiliser. The numbers underneath the bars represent the proportions of Lper, Ppra, Trep and Tamb sown, respectively.

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Performance of weanling beef heifers grazing pasture or consuming grass silage during winter

Perennial pastures form the main source of nutrients for grazing beef cattle in Ireland. However, pasture growth rate varies over the year and in winter insufficient pasture is available to meet the total feed demand of a calf-to-beef herd. A common solution is to conserve surplus spring/summer pasture as silage or hay to be fed back to the herd in winter. A potential alternative is for the weanling cattle in the herd to graze during winter pasture which has accumulated since the autumn. The objective of this study was to compare the growth and feed intake of weanling heifers grazing pasture with that of heifers offered grass silage indoors during winter.

Fifty weaned, spring-born Charolais × Limousin heifers with an initial mean (SD) live weight (LW) of 275 (27.0) kg and a mean age was 252 (28.0) days, were blocked on LW and assigned at random to two dietary treatments of grazed pasture and grass silage. The duration of the study was from 28 November 2006 to 18 April 2007 (141 days). For the pasture treatment, heifers were rotationally stocked in three replicate groups on pasture accumulated since the previous autumn. Using portable electric fences, heifers were offered fresh pasture daily and did not have access to the previous day's pasture. Dry matter (DM) allowance of ~3.5 kg DM/100 kg LW/d and post-grazing pasture mass of 800-900 kg DM/ha to ground level were achieved by varying the size of the area grazed each day. For the silage treatment, heifers were housed in five pens (five heifers/pen). Grass silage was offered daily at ~2 kg DM/100 kg LW/d. Daily feed DM intake was estimated as the difference between mass (kg DM) of available and residual feed (after 24 h) divided by the number of heifers per group. Pasture mass was estimated to ground level using a rising plate meter (Jenquip Ltd., Fielding, New Zealand) calibrated on five dates during the study.

The results showed that weanling heifers grazing pasture at a mean daily DM allowance of 11 kg DM/heifer/d gained more LW than heifers offered grass silage indoors during winter (Table 32). This result was associated with a higher DM intake and similar FCE for the grazed heifers.

Table 32: Mean final LW, LWG, feed DM allowance, DM intake and FCE of weanling heifers grazing pasture or consuming grass silage indoors during the winter of 2006/07 (141 days)

Response variable	Treatment	28 Nov.- 2 Jan.	3 Jan.-22 Jan.	23 Jan.- 19 Feb.	20 Feb.- 22 Mar.	23 Mar.- 18 Apr.	Mean
Final LW (kg)	Pasture	292	294	308	339	358	311
	Silage	281	291	306	326	333	302
	P value	0.003	0.362	0.601	0.027	<0.001	<0.001
LWG (kg/d)	Pasture	0.47	0.12	0.51	1.00	0.69	0.59
	Silage	0.14	0.51	0.52	0.65	0.27	0.45
	P value	<0.001	0.001	0.858	<0.001	<0.001	0.004
DM allowance (kg/heifer/d)	Pasture	8.3	9.9	11.0	11.3	12.6	10.9
	Silage	4.9	5.2	5.8	5.8	6.7	5.8
	P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
DM intake (kg/heifer/d)	Pasture	5.2	6.4	6.9	6.3	6.7	6.3
	Silage	4.3	4.6	5.3	5.3	5.8	5.2
	P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
FCE (g LW/kg DM)	Pasture	90	16	75	161	102	95
	Silage	34	108	99	122	46	86
	P value	0.070	0.023	0.287	0.120	0.003	0.202

Evaluation of different red clover cultivars for cutting and grazing

Swards that contain red clover (*Trifolium pratense*) and perennial ryegrass (*Lolium perenne*) have the potential to yield more than 16 t of DM/ha per year under a cutting regime with no inorganic nitrogen inputs. However, most of the yield is achieved by early July. For economic reasons, the relatively low production of herbage after mid-summer would require grazing these swards for at least the second half of the grazing season, and red clover has traditionally not persisted when grazed. Therefore, studies have started at Grange where conventional cultivars of red clover are being compared with cultivars from New Zealand. The latter have prostrate or creeping growth habits that could make them more tolerant of grazing, but possibly lower yielding, than the conventional cultivars with very erect growth habits. The challenge is to identify the critical morphological and physiological characteristics of red clover for yield and persistence, and how defoliation management practices and cultivars modify these. This is an on-going study within the Grazing Legumes project.

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Baled silage making and storage practices on farms

As part of a national survey to determine the proportion of bales with visible mould growth on farms in Ireland, data were collected on current bale-making and storage practices. In February 2004, baled silage was surveyed on 30 farms in six separate routes throughout Ireland. Each route was sub-divided into five sections with six random farms per quintile visited. A detailed questionnaire was completed on each farm, with information being sought from the farmer on numerous aspects of the baled silage making process. Additional observations on bale storage practices were recorded on-site by the authors and two bales in readiness for feeding were examined for polythene film damage on each farm (60 bales per region; a total of 360 bales).

Results regarding production of baled silage are in Table 33 and the authors' observations on bale storage and polythene film damage on bales are presented in Table 34. It is concluded that bale wrapping, handling and storage were typical of Irish on-farm practices in 1999, although there have been some noteworthy changes. For example, the use of plastic netting rather than twine to secure bales increased from 0.09 to 0.71 and the practice of wrapping bales close to the storage site and not in the field rose from 0.28 to 0.40.

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Table 33: Characteristics of grass crops and baled silage technologies on Irish farms (n=180)

Characteristic	Farmers' answer	Proportion of farms visited	Characteristic	Farmers' answer	Proportion of farms visited
Age of pasture (years)	<10	0.47	Weather during wilting	Dry	0.78
	≥10	0.40		Wet	0.22
	Not reseeded	0.13	Additive applied	No	0.98
Ryegrass dominant sward	Yes	0.47	Bale tying	Yes	0.02
	No	0.53		Netting	0.71
Grass growth stage at harvest	Stemmy	0.68	Location of wrapping	Twine	0.29
	Leafy	0.31		Site of baling	0.60
	Both	0.01		Bale storage area	0.40
Harvest date	May	0.08	No. of film layers	4	0.79
	June	0.49		Unknown	0.21
	July	0.29	Film colour	Black	0.98
	August	0.10		White	0.02
	September	0.04		Labour source	Baling - contractor
Wilt duration (days)	< 1	0.06	Baling - farmer		0.30
	1	0.46	Wrapping - contractor		0.73
	2	0.34	Wrapping - farmer	0.27	
	3	0.10			
	>3	0.04			

Table 34: Authors' observations on bale storage and damage to the bale film on Irish farms

Bale storage		Proportion of farms (n=180)	Extent of visible damage on bales		Proportion of bales
Bale orientation (part touching ground)	Flat end	0.45	Film damage (n=360 bales)	Not visibly damaged	0.51
	Curved	0.49		Visibly damaged	0.49
	Both	0.06			
Height of bale storage	Ground tier only	0.64	Cause of damage (n=179 bales)	Bird	0.54
		0.14		Machinery	0.21
	Two tiers Three & four tiers	0.22		(total >1.0)	Cat
Ground surface type	Grass	0.34		Rodent	0.04
	Gravel	0.44		Other	0.30
	Concrete	0.22		Plastic repair patches	0.07
Bale protection	Livestock-proof fencing	0.94			
(total >1.0)	Anti-bird netting	0.04	Location of damage (n=248 loci)	End (Upper)	0.15
	Anti-bird paint	0.09		End (Lower)	0.03
	Tyres	0.02		Barrel (Upper)	0.44
	Other protection mechanisms	0.04		Barrel (Lower)	0.18
	None obvious	0.02		Shoulder (Upper)	0.16
Storage location	Farmyard Remote field	0.81		Shoulder (Lower)	0.04
		0.19			

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Baled silage characteristics associated with the visible occurrence of fungi

The extent of visible fungal growth and the identity of the predominant fungi causing spoilage of baled grass silage were recorded on 180 farms in Ireland. The extent of fungal growth on bales ranged from 0 to 0.82 surface coverage, with the mean proportion coverage of 0.06. The fungus affecting the largest surface area on bales was *Penicillium roqueforti*. This study aimed to establish how colonisation by the most common fungi is related to silage characteristics and on-farm practices of bale management.

In February 2004, baled silage was surveyed on 30 farms in each of six regions throughout Ireland. A detailed questionnaire was completed on each farm visited, with information being

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sought from the farmer on numerous aspects of the baled silage making process. Additional observations on bale storage practices were recorded on site (text box, Figure 7).

Two bales in readiness for feeding were examined in detail on each farm (60 bales per region; a total of 360 bales). On removal of the polythene film, the predominant visible fungal colony, based on the largest area of the bale surface which had been colonised, was sampled and later identified. For chemical analysis, five grab samples (total weight *ca.*0.4 kg) were taken from parts of the bale surface that were without visible fungal contamination or spoiled material. Silage was assayed for dry matter (DM) content, pH, and concentrations of lactic, acetic, propionic and butyric acids, ammonia-N and ethanol.

The occurrence of particular fungi was analysed in relation to silage characteristics using canonical correspondence analysis (CCA) (CANOCO for Windows, version 4). The 13 semi-quantitative and qualitative variables and the eight quantitative variables of the chemical composition of silage constituted the pool of explanatory variables. The fungal species included in the analysis were those that colonised the largest surface area on bales, namely *P. roqueforti*, *Schizophyllum commune*, *Pichia fermentans* and *Penicillium paneum*.

A Monte Carlo permutation test showed that differentiation of the species according to axis 1, and subsequently all canonical axes, was statistically significant ($P < 0.01$), indicating that the variation in the species dataset was not random in relation to variation in the characteristics of the baled silage shown in Figure 7. Eigenvalues for the first two axes were 0.357 and 0.149 and both axes explained proportionally 0.17 of the variance in the species data. Forward selection of silage characteristics showed that only region ($P < 0.01$), lactic acid concentration ($P < 0.01$), butyric acid concentration ($P < 0.05$) and weather at harvest ($P < 0.05$) contributed to the variance found in the species data. These four silage variables explained proportionally 0.63 of the variance.

P. roqueforti and *P. paneum* were more common in bales that were harvested in dry weather and had higher concentrations of butyric and propionic acids. *P. fermentans* occurred in wetter silage, harvested later in the summer, and on bales that were surrounded by apparently undamaged polythene film; it was more common in the northern half of Ireland. *S. commune* was distinctly different from the previous three fungi mentioned in that its occurrence was positively correlated with (i) bales stored more than one tier high, (ii) where visible damage to the polythene film was evident and (iii) in silage with a high pH and DM content and lower lactic acid, acetic acid and ammonia-N concentrations.

It is concluded that growth of spoilage fungi on baled silage is not a random occurrence but is facilitated where in-bale environments allow the fungi to survive, colonise and reproduce, depending on the nutritional and physical requirements and tolerances of particular species.

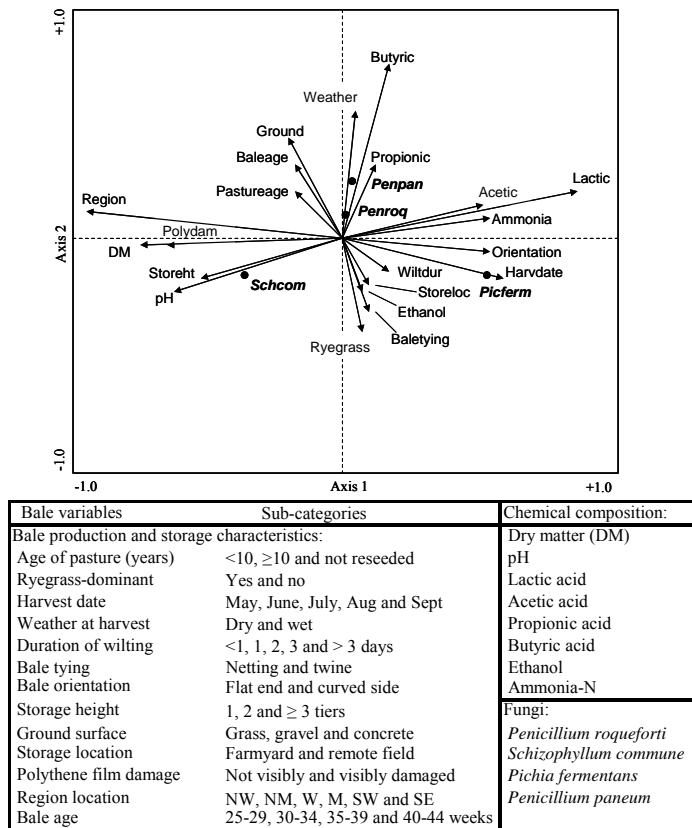


Figure 7. Canonical correspondence analysis of fungi isolated from baled grass silage sampled in Ireland

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The effect of dry matter concentration on the bacterial community composition of baled silage

Wilting is an integral part of baled silage production as it creates conditions more inhibitory to undesirable microorganisms. This study investigated the effects of herbage dry matter (DM) concentration on bacterial community composition during ensiling, employing traditional methods and culture-independent Terminal Restriction Fragment Length Polymorphism (T-RFLP).

Herbage was ensiled in cylindrical bales after 0 (185 ± 7.0 g/kg DM) and 48 (406 ± 29.8 g/kg DM) h wilting. Triplicate bales at each DM level were core sampled prior to ensiling and after 2, 6 and 14 d ensilage. Specific bacteria were enumerated on selective media pre and post ensiling (traditional methods). Total bacterial DNA was extracted from all silage samples. Terminal restriction fragment (TRF) lengths were determined by amplifying the bacterial 16S small subunit rRNA gene using primer set F27 and R1492, and creating the TRF profile using endonuclease Msp1 (Liu *et al.*, 1997). TRF lengths were determined by

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electrophoresis using an automated sequencer (Beckman Coulter, CEQ2000) and analysis of fragment profiles was performed using the BC fragment analysis package v.4.0. Bacterial count data were subjected to two-way analysis of variance (2 x 4 factorial) using the GLM procedures of SAS, v.8.2. Multidimensional scaling (MDS) ordination was performed in Primer v.6.1.2 to assess T-RFLP community data. Sample composition (top 20 TRFs) was reduced to presence/absence of each TRF, and the Bray-Curtis coefficient was used to calculate similarity measures. These measures can be interpreted as relative distances between points on an MDS ordination plot in 2-dimensional (2-D) space. The greater the distance between samples (symbols) on the MDS plot, the larger the dissimilarity (difference in bacterial community structure) relationship between the samples.

Although lactic acid bacteria (LAB) numbers were higher on day 0 in the high DM herbage prior to ensiling, numbers were lower ($P < 0.001$) for this treatment at each subsequent stage of ensiling (Table 35). The decline in *Enterobacteria* numbers after day 2 was greatest ($P < 0.01$) for the low DM herbage. *Clostridia* numbers increased ($P < 0.01$) slightly in the low DM herbage during ensiling. Silage fermentation proceeded rapidly after ensiling as plant cells lysed under anaerobic conditions. Fermentation was more restricted in the high DM herbage as evidenced by the lower LAB numbers and higher *Enterobacteria* numbers. The low degree of clostridial activity in the high DM herbage reflects the inhibitory effects of high DM concentration on *Clostridia*.

Table 35: Treatment effects on herbage bacterial composition
(Log₁₀ colony forming units/g herbage)

<u>DM</u>	<u>Time (d)</u>	<u>LAB</u>	<u>Enterob.</u>	<u>Clostridia</u>	<u>Bacilli</u>
Low	0	4.7	3.5	1.2	2.2
Low	2	8.3	6.0	0.6	1.8
Low	6	7.6	3.2	1.3	2.2
Low	14	9.3	0.5	2.3	1.8
High	0	5.7	4.5	1.2	2.0
High	2	6.7	4.2	1.3	1.5
High	6	7.1	3.5	1.2	1.6
High	14	7.6	2.0	1.4	1.6
	s.e.m.	0.20	0.36	0.18	0.19
<u>Levels of significance</u>					
DM		***	NS	NS	*
Day		***	***	**	NS
DM x time		***	**	**	NS

DM = dry matter; LAB = lactic acid bacteria; * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, NS = not significant, s.e.m. relates to the interaction between DM and time.

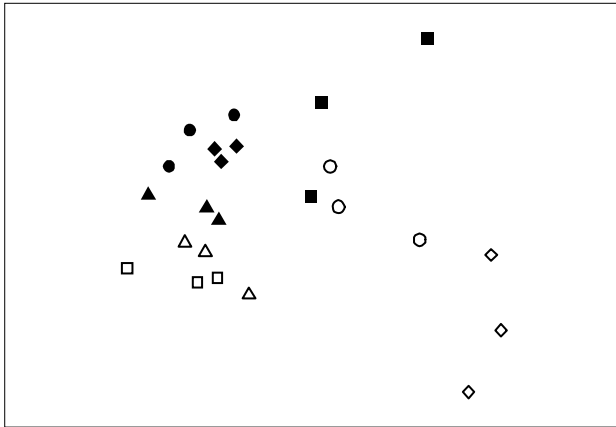


Figure 8. MDS ordination plot of T-RFLP data for low (full symbols) and high DM (empty symbols) herbage on days 0 (▲), 2 (■), 6 (◆) and 14 (●) of ensilage. *Note:* Samples plotted close together represent samples of similar bacterial community composition.

Figure 8 reveals a shift in bacterial community composition as the fermentation proceeds (e.g. between days 0 - 2 for the low DM herbage), but also a marked shift in response to DM concentration (low DM herbage located in top half of MDS plot). Bacterial composition for day 0 and day 2 of the high DM herbage are closely related suggesting a slower onset of fermentation.

It is concluded that herbage DM concentration has a major effect on silage bacterial composition and in turn on the outcome of preservation. While traditional methods (count data) reveal differences in the numbers of bacteria present, T-RFLP gives a clearer picture of treatment effects on silage bacterial community composition.

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The effect of contrasting additive treatments on the fermentation characteristics of wilted, unchopped grass

In the absence of herbage being chopped and bruised during harvesting, the onset of fermentation (increase in lactic acid, decrease in pH) in baled silage is slower than for precision-chop silage. Correspondingly, the overall concentration of fermentation products is lower, making the environment in the bale more conducive to the activities of undesirable microorganisms. The aim of this study was to identify additive treatments for use in baled silage production that would facilitate the creation of conditions that are comparable to those of precision-chop silage. Previous studies confirmed that the laboratory silos used in this study are adequate models for studying the ensilage of baled and precision-chop silages.

Grass was ensiled after a 24 h wilt period (dry matter = 246 ± 3.4 g/kg) in 36 laboratory silos. The herbage for half of these silos was precision-chopped prior to ensiling. Three randomly selected samples (5 kg) of both unchopped (UC, as a model for baled silage) and chopped herbage (PC) were assigned to the following additive treatments: (1) no additive (control

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treatment), (2) lactic acid bacterial inoculant (LAB; Bio-Sil®, *Lactobacillus plantarum* DSM 8862 and *Lb. plantarum* DSM 8866; Dr. Pieper technologie- und Produktentwicklung, GmbH), at 1 g/t (3×10^5 colony forming units/g herbage), (3) sucrose, at 5 kg/t, (4) LAB plus sucrose (both prepared and applied as above), (5) formic acid based additive (Add SafeR®, at 70 g ammonia and 640 g formic acid per 1 kg additive; Trouw Nutrition, UK Ltd.), at 3 l/t and (6) antimicrobial mixture (AMM; KofaSil®, 80 g hexamethylene tetra-amine, 120 g sodium nitrite, 150 g sodium benzoate, 50 g sodium propionate and 600 g water per kg additive; Addcon Agrar, GmbH), at 3 l/t. A constant weight (4 kg) of wilted herbage was then ensiled and the silos were stored at 15°C for 110 days before being sampled. Aqueous extracts were used for the determination of pH, fermentation products and ammonia-N, as described previously (McEniry *et al.*, 2006). Silage data were analysed by a two-way analysis of variance for a 2 x 6 factorial arrangement of treatments using the GLM procedures of SAS, Version 8.2.

When no additive was applied, UC silage was poorly preserved, showing evidence of considerable clostridial activity (high butyric acid and ammonia-N values), while PC silage underwent a more lactic acid dominant fermentation with relatively little clostridial activity (Table 36). In general, lactic and acetic acid concentrations were higher ($P < 0.001$) while silage pH, butyric acid ($P < 0.001$), ethanol ($P < 0.01$) and ammonia-N ($P < 0.001$) concentrations were lower in the PC compared to the UC silages. Thus the implication of this experiment is that baled silage should have a greater requirement for its fermentation to be assisted than comparable precision-chop silage. This could be provided by more extensive, rapid wilting (as occurs on most farms) or by the use of effective silage additives.

In the PC silage where a successful fermentation prevailed, the addition of additive treatments had relatively little impact, with the effects of LAB, sucrose and LAB + sucrose on fermentation being small. However, there was some evidence of the formic acid based additive restricting fermentation. The LAB + sucrose treatment restricted clostridial activity more in the UC silage than did LAB or sucrose applied alone. Both the formic acid based additive and AMM restricted clostridial activity with the UC silage. This latter effect would become even more evident, than shown in Table 36, if the ammonia-N value was corrected for the ammonia contributed by the ingredients in these two additives.

Overall, the addition of the formic acid and AMM based silage additives appeared to result in greater inhibition of undesirable microbial activity as evidenced by the reduced concentrations of ethanol, butyric acid and (corrected) ammonia-N.

Table 36: Treatment effects on silage pH, fermentation products (g/kg dry matter) and ammonia-N (g/kg N)

Treatment		pH	LA	AA	Eth	BA	NH ₃ -N
<u>Chop</u>	<u>Additive</u>						
UC	Control	4.23	101	8	25	20	122
UC	LAB	4.13	113	8	20	15	97
UC	Sucrose	4.30	96	11	21	16	103
UC	LAB + Suc.	4.07	114	9	18	9	70
UC	Formic acid	4.30	102	12	13	5	102
UC	AMM	4.07	107	21	9	2	92
PC	Control	3.90	148	15	13	1	77
PC	LAB	3.90	136	14	15	1	62
PC	Sucrose	3.90	138	19	15	0	68
PC	LAB + Suc.	3.90	130	15	13	0	62
PC	Formic acid	3.90	116	15	11	1	88
PC	AMM	4.03	127	25	10	1	83
	s.e.m.	0.029	6.1	4.6	2.9	1.8	5.5
<u>Levels of significance</u>							
Chop		***	***	*	**	***	***
Additive		***	NS	NS	*	***	***
Chop x additive		***	*	NS	NS	***	**

LA = lactic acid, AA = acetic acid, Eth = ethanol, BA = butyric acid, NH₃-N = ammonia-N; * = P<0.05, ** = P<0.01, *** = P<0.001, NS = not significant, s.e.m. relates to the interaction between chop and additive treatment.

It is concluded that the generally poorer fermentation in the unchopped herbage would suggest that there is a greater requirement for the fermentation to be assisted in baled silage. Additives such as the LAB + sucrose, the formic acid and the AMM based additives could assist baled silage fermentation, giving preservation approaching that of comparable precision-chop silage.

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Using sodium benzoate to improve the aerobic stability of *Lactobacillus plantarum* treated silages

The indigenous epiphytic microflora on herbage are a diverse collection of microbes. In Ireland there are sufficient lactic acid bacteria present to dominate fermentation during ensilage provided requirements such as anaerobiosis, supply of substrate, absence of contamination, etc., are fulfilled. Whereas inoculation of herbage with large numbers of homofermentative lactic acid bacteria at harvesting can sometimes benefit fermentation, this can predispose the silage to yeast initiated respiration (i.e. aerobic deterioration) during feedout. This experiment evaluated the effects of the anti-mycotic sodium benzoate and its rate of application on the aerobic stability of grass and maize silages made using *Lactobacillus plantarum*.

Unwilted grass from a *Lolium perenne* sward was cut to a 6 cm stubble height and precision-chopped on 27 Sept. Forage maize (*Zea mais* cv. Justina) grown using plastic mulch was cut

Grange Beef Research Centre

to a 20 cm stubble height and precision-chopped (including kernel cracker) on 29 Sept. Sucrose was evenly mixed with the grass at 15 g/kg to elevate fermentable substrate content. Each crop was ensiled (6 kg herbage per laboratory silo; O'Kiely & Wilson, 1991) with the following treatments applied to triplicate silos: no additive (NA), formic acid (FA; 85% ammonium tetraformate salt at 3 ml/kg; Add-SafeR, Trouw Nutrition UK Ltd.), and *Lactobacillus plantarum* (Lp; strain MTD/1 (NCIMB 40027) at 10^9 colony forming units (cfu)/kg herbage; Ecosyl Products Ltd.) with 0, 200, 400 or 800 mg sodium benzoate (SB) per kg herbage (Lp and SB were applied separately). Additives were applied with distilled water to achieve a total application of 10 ml liquid per kg herbage. Silos filled with grass and maize were sealed and stored at 15°C for 68 and 66 days, respectively. Silage composition and aerobic stability data were subjected to 2-way analysis of variance (Unistat 5.6 (Unistat Ltd., 4 Shirland Mews, London W9 3DY, UK)) using a model that accounted for crop, additive and their interactions.

Table 37: Chemical composition and aerobic stability of grass and maize silages

	Grass						Maize						sem ⁸	Significance (P=)		
	NA	FA	Lp + SB (mg/kg)				NA	FA	Lp + SB (mg/kg)					Crop	Add.	CxA
			0	200	400	800			0	200	400	800				
WSC ¹	8.5	21.0	11.1	20.2	26.3	26.2	8.0	8.4	6.5	11.7	6.8	7.2	3.32	<0.001	0.040	0.048
pH	3.89	3.83	3.85	3.80	3.82	3.84	3.82	3.90	3.83	3.81	3.81	3.80	0.021	0.344	0.052	0.041
FP ¹	192	173	188	197	196	177	75	59	73	70	81	67	8.2	<0.001	0.102	0.943
LA ¹	172	152	160	177	175	154	49	22	44	50	53	51	6.5	<0.001	0.003	0.368
LA ²	900	875	850	900	894	869	651	381	611	722	653	781	26.2	<0.001	<0.001	<0.001
Ethanol ¹	10.1	15.3	20.7	13.5	12.1	13.4	12.1	25.6	12.4	8.3	10.2	5.8	3.10	0.328	0.012	0.054
Acetic ¹	9.0	6.1	7.7	6.6	8.7	9.7	13.7	10.8	15.5	11.4	17.7	9.7	2.10	<0.001	0.235	0.386
NH ₃ -N ³	55	65	50	49	52	38	40	54	38	31	37	35	4.6	<0.001	0.001	0.649
HTR ⁴	43	89	37	37	51	144	124	136	77	139	140	192	28.0	<0.001	0.014	0.818
MaxTR ⁵	13.2	9.0	16.6	17.1	11.7	3.1	14.5	6.0	13.6	9.0	9.8	0.6	4.41	0.274	0.056	0.943
ATR120 ⁶	31	10	35	35	25	5	11	13	21	12	12	1	7.6	0.013	0.038	0.516
ATR192 ⁷	71	27	75	71	53	13	30	18	31	18	18	1	10.4	<0.001	0.001	0.219

WSC=water-soluble carbohydrates, FP=fermentation products (lactic acid+volatile fatty acids+ethanol), LA=lactic acid; ¹g/kgDM, ²g/kg FP, ³g/kgN, ⁴Hours to >2°C rise, ⁵Max. °C rise, ⁶Accumulated °C rise to 120 h, ⁷Accumulated °C rise to 192 h, ⁸Interaction.

The mean composition of the grass at ensiling was 4.9 log₁₀ cfu lactic acid bacteria/g, 164 g dry matter (DM)/kg, crude protein 184 g/kgDM, *in vitro* DM digestibility 774 g/kg, ash 104 g/kgDM, water-soluble carbohydrates (WSC) 117 g/kgDM (added sucrose not included) and buffering capacity 542 mEq/kgDM. The corresponding values for maize were 5.7 log₁₀ cfu /g, 283 g/kg, 79 g/kgDM, 759 g/kg, 33 g/kgDM, 80 g/kgDM, 213 mEq/kgDM and starch 301 g/kgDM. Propionic and butyric acid concentrations in silage were < 1 g/kgDM for all treatments. Silages made from both crops (even when no additive was used) were well preserved, having undergone lactic acid dominant fermentations with little evidence of clostridial activity (Table 37). Reflecting its higher water activity and buffering capacity, and evident surplus of WSC, grass underwent a considerably more extensive (P<0.001) fermentation than maize. However, grass silages were surprisingly less stable (P<0.05) than maize silages when exposed to air (shorter interval to temperature rise) and subsequently underwent more extensive aerobic deterioration (higher accumulated temperature rises; P<0.05). FA tended to restrict fermentation, particularly lactic acid production. Lp did not create a more homolactic fermentation, while application of SB with Lp increased residual WSC (especially with grass) and tended to create a more lactic acid dominant fermentation. FA improved aerobic stability and restricted aerobic deterioration. Sequential rates of SB addition improved aerobic stability and reduced deterioration. Lp did not alter these characteristics.

It is concluded that although Lp did not disimprove silage aerobic stability or deterioration, sequential rates of SB addition progressively improved these characteristics.

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Harvest index of barley, wheat and triticale during advancing stages of ripening

Cereal harvest index is defined as the grain yield expressed as a proportion of total above ground biomass. The greater the proportion of grain, and thus the smaller the combined proportion of straw + chaff present, the higher the potential feed value of the whole crop. This experiment quantified the harvest index for winter wheat, barley and triticale harvested at a succession of stages of ripeness.

Plots of barley (20 m × 3 m; *Hordeum vulgare* L., cv. Regina; sown 18 October; 181 kg inorganic fertiliser N/ha) and wheat (20 m × 3 m; *Triticum aestivum* L., cv. Madrigal; sown 12 January; 136 kg inorganic N/ha) in Year 1 and of barley (32 m × 3 m; cv. Regina; sown 9 October; 150 kg inorganic N/ha), wheat (24 m × 3 m; cv. Falstaff; sown 30 October; 224 kg inorganic N/ha) and a semi-dwarf variety of triticale (40 m × 3 m; X *Triticosecale* Wittmack, cv. Fidelio; sown 26 October; 180 kg inorganic N/ha) in Year 2 were managed as for commercial grain production. For each cereal, a randomised complete block design was used with five harvest times (H1 to H5) and four replicates (prevailing weather conditions in Year 2 permitted only four harvest times for barley). Harvest times were based on target grain dry matter (DM) concentrations of 600, 660, 720, 780 and >800 g/kg. At each harvest, 30-60 stems were cut at ground level. Grain was separated from the remainder (straw and chaff) and the dry weight of each fraction was determined. Grain yield (fresh and DM) was measured after combine harvesting the entire plot. Linear and quadratic regression functions were used to describe the relationships between measured parameters and the number of days from harvest 1 (H1) using Unistat 5.6 (Unistat Ltd., 4 Shirland Mews, London W9 3DY, England).

Table 38: Regression of grain yield (fresh and DM), grain DM content and crop harvest index on days from H1 (x)

	a [#]	b [#]	c [#]	R ²	Sig.
Barley: Year 1					
Fresh yield (t/ha)	12.4	-0.50	0.015	0.88	***
DM yield (t/ha)	6.7	0.07	-0.004	0.34	*
DM (g/kg)	542	35.9	-1.08	0.95	***
Harvest index ¹	480	4.5	-0.19	0.45	**
Barley: Year 2					
Fresh yield (t/ha)	11.5	-0.39		0.98	***
DM yield (t/ha)	6.2	0.10	-0.012	0.62	**
DM (g/kg)	541	25.5		0.98	***
Harvest index ¹	436	12.3	-0.79	0.80	***
Wheat: Year 1					
Fresh yield (t/ha)	12.6	-0.43	0.013	0.59	***
DM yield (t/ha)	7.8	-0.01		0.01	
DM (g/kg)	626	24.8	-0.72	0.91	***
Harvest index ¹	439	1.5		0.38	**
Wheat: Year 2					
Fresh yield (t/ha)	16.5	-0.10	-0.014	0.86	***
DM yield (t/ha)	9.6	0.13	-0.008	0.20	
DM (g/kg)	569	16.0		0.92	***
Harvest index ¹	520	-1.46	0.274	0.70	***
Triticale: Year 2					
Fresh yield (t/ha)	15.0	-0.60	0.017	0.93	***
DM yield (t/ha)	8.4	-0.06	0.003	0.15	
DM (g/kg)	556	25.2	-0.58	0.98	***
Harvest index ¹	475	3.9	-0.16	0.32	*

¹Grain DM relative to crop DM (g/kg); [#]y=a+bx+cx².

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The harvest interval for barley was from 6-29 July and 5-18 July in Years 1 and 2, respectively, with corresponding intervals of 16 Aug.-7 Sept. and 6-21 Aug. for wheat, and 12 Aug.-2 Sept. for triticale (Year 2). Wheat and triticale had higher yields than barley (Table 38). Grain fresh yields declined and DM contents increased ($P < 0.001$) with ripening (later harvesting). For wheat and triticale, grain DM yields did not change ($P > 0.05$) during the ripening phases studied, while the effects recorded with barley occurred mainly at H5 and were attributed to the loss of ripe grain following shattering from the ear prior to harvesting (data not shown). Each of the crops had therefore reached physiological maturity at H1.

The harvest index for barley ranged from 480–506 g/kg in Year 1 and from 436–484 g/kg in Year 2 (Table 38). A quadratic pattern ($P < 0.01$ in Year 1, $P < 0.001$ in Year 2) was observed in both seasons, indicating an initial increase in harvest index followed by a decline. The larger decline in Year 2 than in Year 1, as indicated by the larger negative quadratic regression coefficient, was probably as a result of grain shedding between H4 and H5.

The harvest index for wheat increased from 439 g/kg to 472 g/kg in Year 1 and from 520 g/kg to 560 g/kg in Year 2. A linear ($P < 0.01$) pattern of increase was detected in Year 1 and a quadratic ($P < 0.001$) pattern in Year 2. The lower harvest index in Year 1 reflected the later sowing date for that crop, with a resultant reduced grain yield potential.

The harvest index for triticale followed a quadratic profile ($P < 0.05$), indicating an initial increase followed by a small decline.

Across all crops, the relatively small magnitude of the linear and quadratic coefficients relative to the intercept values indicates that changes in harvest index between harvest dates were modest.

It is concluded that about half of above ground biomass of these cereal crops was present in the grain. Despite differences among crops and across years, the relatively modest increases observed in harvest index indicated that grain filling was almost complete at the initial harvest date for each crop. Thus, stage of ripening (within the range examined) would have had little effect on the proportion of grain present if these crops had been harvested and conserved as whole crops.

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Intake and digestibility in cattle offered whole-crop wheat or barley silages of contrasting grain to straw ratios

Because digestible energy is higher in grain *versus* straw of cereals, reducing the amount of straw, and thus increasing the proportion of grain in the mixture, should increase its feeding value when harvested as whole-crop cereal silage. This can be achieved by elevating the crop cutting height at harvest. However, previous research found no difference in intake or carcass gain when beef cattle were offered wheat or barley silage harvested at a normal or an elevated height. It was postulated that the increase in grain to straw ratio (G:S; due to the higher cutting height) was insufficient to cause a significant improvement in animal performance. There is little published information on the effects of the G:S ratio in whole-crop cereals on feed intake or diet digestibility in cattle. Therefore, the objectives of this study were to quantify the intake and digestibility in cattle offered varying G:S ratios of whole-crop wheat or barley silages.

The feedstuffs used were derived from the whole-crop and head-cut cereal silages used by Walsh et al. (2007). The wheat and barley silages were each separated by means of a combine harvester and the two components (G and S (straw+chaff)) for each cereal were then ensiled individually. Separate groups of four Aberdeen Angus cross-bred steers (mean bodyweight 407 (s.d. 24.2) kg) were assigned to two Latin Square experiments, one for wheat and the other for barley. The steers in each 4 x 4 Latin Square were offered G:S ratios of: 0:100, 30:70, 60:40 and 90:10, each for a period of 34 d. A period was composed of 14 d for dietary adaptation and 10 d for measurement of *ad libitum* feed intake. This was followed by 2 d to acclimatise to a restricted level of feeding and 8 d of *in vivo* digestibility measurement. Each treatment was supplemented with feed grade urea, ammonium sulphate and a mineral+vitamin mix. Following dietary adaptations, animals were weighed at the start and end of each 10 d *ad libitum* intake interval. The amount of feed offered was adjusted daily so that refusals were *ca.* 0.05 of feed offered. At the end of the *ad libitum* interval, feed offered was restricted to 0.95 of *ad libitum* intake for the remaining 10 d and apparent diet digestibility was determined in the final 8 d. Feed intake and digestibility data were analysed using the general linear model procedure, PROC GLM (SAS, 2005) appropriate for a Latin Square design using a model with terms for animal, period and treatment. Contrast statements were used to test for linear and quadratic effects. The sums of squares due to treatment were tested using the 'PDIFF' statement in SAS.

Table 39: Intake and digestibility in steers

	Treatment				Significance ¹		
	0 : 100	30 : 70	60 : 40	90 : 10	s.e.m.	L	Q
Barley							
Total DM intake	8.44	8.62	8.81	8.17	0.572		
<i>In vivo</i> apparent digestibility (g/g)							
Dry matter	0.653	0.658	0.698	0.753	0.0050	***	**
Organic matter	0.675	0.682	0.718	0.771	0.0043	***	**
Neutral detergent fibre	0.592	0.541	0.487	0.401	0.0240	**	
Nitrogen	0.700	0.671	0.685	0.733	0.0075	*	**
Starch	0.979	0.932	0.921	0.924	0.0104	**	
Wheat							
Total DM intake	7.41	7.61	7.41	8.11	0.555		
<i>In vivo</i> apparent digestibility (g/g)							
Dry matter	0.685	0.699	0.736	0.771	0.0065	***	
Organic matter	0.713	0.727	0.759	0.791	0.0066	***	
Neutral detergent fibre	0.578	0.497	0.453	0.355	0.0243	***	
Nitrogen	0.690	0.690	0.713	0.735	0.0093	**	
Starch	0.992	0.990	0.986	0.978	0.0023	**	

¹L, Q = Significance level of linear (L) and quadratic (Q) effects - * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

The mean composition of barley grain and straw were dry matter (DM); 573 and 466 g/kg, neutral detergent fibre (NDF); 141 and 556 g/kg DM, and starch; 638 and 198 g/kg DM, respectively, with corresponding values for wheat of 551 and 495 g/kg, 168 and 444 g/kg DM, and 638 and 309 g/kg DM. There was a positive linear ($P < 0.001$) (and quadratic ($P < 0.01$) for barley) effect on the digestibility of DM, organic matter and N as G:S increased, and a corresponding negative linear effect on NDF and starch digestibility ($P < 0.01$) for both cereal types (Table 39). It is concluded that increasing the proportion of grain in whole-crop wheat or barley silage based diets from 0 to 0.9 increased the intake of digestible nutrients. These increases were linear for both wheat and barley.

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Rumen fermentation characteristics in cattle offered whole-crop barley silages of contrasting grain to straw ratios

In an attempt to improve the feeding value of whole-crop cereal silage, the cutting height of the crop at harvest is sometimes raised in order to reduce the straw content and thereby increase the proportion of grain in the resulting feedstuff. Walsh et al. (2007) found no difference in intake or carcass gain when beef cattle were offered wheat or barley silage harvested at a normal or an elevated height. It was suggested that the increase in grain to straw ratio (due to the higher cutting height) was insufficient to cause a significant improvement in animal performance. There is little published information on the effects of the grain (G) to straw (S) ratio (G:S) in whole-crop cereals on rumen metabolism in cattle. Therefore, the objective of this study was to quantify the rumen fermentation characteristics in cattle offered varying G:S ratios of whole-crop barley silage.

The feedstuffs used were derived from whole-crop cereals silages. The whole-crop barley and head-cut barley were separated by means of a combine harvester and the two components (grain and straw) were then ensiled. Four Holstein-Friesian steers (mean 659 (s.d. 56.9) kg) fitted with rumen cannulae of 10 cm internal diameter (Bar Diamond, Inc., Parma, ID, USA) were offered the four experimental treatments of four ratios of G:S: 0:100, 30:70, 60:40 and 90:10. The experiment was a balanced Latin Square design, consisting of four periods, each of 18 d duration, with 14 d for dietary adaptation followed by 4 d of sampling. Animals were offered their daily allocation of feed in four meals at 0900, 1100, 1400 and 1700 from d 15 to 18 to reduce the opportunity for dietary selection. Each treatment was supplemented with feed grade urea, ammonium sulphate and a mineral+vitamin mix. Rumen fluid samples were collected through the rumen cannulae at 0900 (before feeding), 1000, 1100, 1300, 1500, 1700, 1900, 2100 on d 14 and 0100 and 0900 on d 15 of each period. Rumen fluid pH was measured immediately after collection using an Orion digital pH meter (SA720) and glass electrode. A 20 ml sub-sample was acidified with 0.5 ml of 9M sulphuric acid and stored at -18°C for subsequent analysis. Mean rumen fermentation variables were analysed using the general linear model procedure, PROC GLM (SAS, 2005) appropriate for a Latin Square design using a model with terms for animal, period and treatment. Contrast statements were used to test for linear and quadratic effects. The sums of squares due to treatment were tested using the 'PDIFF' statement in SAS.

Table 40: Rumen fermentation characteristics in steers

	Treatment				Significance ¹		
	0 : 100	30 : 70	60 : 40	90 : 10	s.e.m.	L	Q
pH	6.80	6.70	6.59	6.38	0.046	***	
D-lactic acid (mg/l)	55	103	60	65	15.1		
L-lactic acid (mg/l)	41	80	34	46	14.0		
Ammonia (mg/l)	134	173	155	208	6.9	***	
Total VFA (mmol/l)	96	116	145	180	14.5	**	
<i>Molar proportions (mmol/mol)</i>							
Acetic acid	673	651	572	486	27.0	**	
Propionic acid	171	162	172	193	3.4	**	**
<i>iso</i> -butyric acid	22	26	33	37	3.0	**	
<i>n</i> -butyric acid	86	103	139	161	10.9	**	
<i>iso</i> -valeric acid	31	39	58	75	7.4	**	
<i>n</i> -valeric acid	16	19	27	49	8.4	*	
Acetate:Propionate ratio	4.0	4.1	3.4	2.6	0.19	**	
Non-glucogenic ratio	5.3	5.7	5.4	4.7	0.17	*	*

¹L, Q = Significance level of linear (L) and quadratic (Q) effects - * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

The mean DM, neutral detergent fibre and starch (g/kg) of the grain and straw were 570 140 and 616, and 489, 497, and 219, respectively. A negative linear effect of G:S ratio was found on rumen pH ($P<0.001$), the molar proportion of acetic acid ($P<0.01$) and the acetate:propionate ratio ($P<0.01$) (Table 40). It was also found to have a negative linear and quadratic effect ($P<0.05$) on the non-glucogenic ratio (NGR). Increasing the G:S ratio had a positive linear effect on rumen ammonia ($P<0.001$), total VFA concentration ($P<0.01$), the molar proportions of *iso*- and *n*- butyric acid, molar proportion of *Iso*- ($P<0.01$) and *N*- ($P<0.05$) valeric acid, while the effect on propionic acid was both linear and quadratic ($P<0.01$).

It is concluded that increasing the G:S increased the concentration of fermentation products (total VFA, ammonia, and the molar proportions of the VFA's, except acetic acid) in the rumen and altered the mean profile of fermentation products from acetic acid towards the C₃-C₅ fatty acids (propionic, butyric and valeric).

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Forage maize yield and maturity: interaction of harvest date, plastic mulch and cultivar

Forage maize can supply high yields of quality forage on some Irish farms. The variability in yield, quality and maturity at harvest reflects the responses to prevailing weather conditions, particularly temperature during April to September. The use of plastic mulch promotes higher yields of quality feedstuff and has permitted the crop to extend into areas once considered unsuitable. In this experiment two cultivars of differing maturity were grown with or without plastic mulch to examine how yield and composition altered during the harvest window of early September to early November.

Two forage maize cultivars of different maturity characteristics (Tassilo: FAO 210 (early) and Benicia: FAO 270 (late)) were sown at Knockbeg, Co. Carlow in 2003 either uncovered (NP – no plastic) or under complete cover clear polythene mulch (P; 6 micron; I.P. Europe Ltd). Each plot consisted of 4 rows (70 cm spacing) of 10 m length. Plots were sown in triplicate on 23 April using a Samco precision seed drill at 100,000 seeds/ha. Standard weed control (4.5 l atrazine/ha) and fertiliser (150 kg N, 50 kg P, 200 kg K/ha) were applied pre sowing to all plots. Samples of 1 m length per plot were taken at ten day intervals from 10 Sept. to 9 Nov. Crop yield and the proportion present in cob (kernel + rachis) and stover were determined. Data were analysed by repeated measures analysis of variance using a model that accounted for cultivar, plastic mulch, harvest date and their interactions.

Crop yields were considerably higher and maturities much more advanced at each harvest compared with those reported for the previous year. This likely reflected the higher temperatures recorded at critical stages during the growing season in 2003. Mean dry matter (DM) yields increased towards a maximum value (*ca.* 19.5 t DM/ha) in mid-Oct., and declined by early Nov. to similar values to early Sept. (Table 41). In contrast, between 10 Sept. and 9 Nov. there was a progressive increase in the mean DM concentration in the whole plant (238 to 473 g/kg), cob (349 to 603 g/kg) and stover (186 to 342 g/kg), and in the mean proportion of total DM present in the cob (428 to 625 g/kg). Although Tassilo had a lower mean DM yield than Benicia (17.3 vs. 19.8 t/ha) its more advanced maturity was evident in the higher mean DM concentration in the whole plant (384 vs. 317 g/kg), cob (559 vs. 458 g/kg) and stover (254 vs. 238 g/kg), and in the higher proportion of total DM present in the cob (618 vs. 489 g/kg). Plastic mulch increased mean DM yield (17.3 to 19.8 t/ha) and advanced mean maturity as shown by higher DM concentration in the whole plant (311 vs. 390 g/kg), cob (449 vs. 568 g/kg) and stover (230 vs. 268 g/kg), and by the higher proportion

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of total DM present in the cob (500 vs. 606 g/kg). There was not an interaction ($P>0.05$) between cultivar and plastic mulch for crop DM yield or plant DM concentration. The effects of plastic mulch were larger with Benicia than Tassilo for both cob DM concentration and the proportion of crop DM present in the cob. In contrast, the effects of plastic mulch on stover DM concentration were larger with Tassilo than Benicia.

It is concluded that the crop DM yield and DM concentration benefits of cultivar and plastic mulch occurred independently of one another, and their combined effects were additive.

Table 41: Crop yield and physical composition

Harvest date (H)	Cultivar (C)	Plastic mulch (M)	Crop DM yield (t/ha)	DM (g/kg)			Cob in crop (g/kg)
				Plant	Cob	Stover	
10-Sep	Tassilo	NP	13.71	224	349	171	460
	Tassilo	P	20.12	299	491	198	569
20-Sep	Benicia	NP	16.37	188	185	189	225
	Benicia	P	19.07	239	372	184	456
	Tassilo	NP	15.90	278	426	197	541
	Tassilo	P	19.91	366	557	219	661
30-Sep	Benicia	NP	17.92	224	257	212	305
	Benicia	P	19.54	286	449	202	534
	Tassilo	NP	16.68	298	522	183	596
	Tassilo	P	19.54	353	571	209	645
10-Oct	Benicia	NP	18.45	243	393	185	443
	Benicia	P	23.64	298	516	186	587
	Tassilo	NP	16.67	372	556	245	611
	Tassilo	P	17.48	447	617	291	659
20-Oct	Benicia	NP	20.55	279	408	226	415
	Benicia	P	23.17	370	558	243	609
	Tassilo	NP	15.50	387	570	260	603
	Tassilo	P	19.50	486	650	334	642
30-Oct	Benicia	NP	19.33	305	478	224	495
	Benicia	P	23.80	398	590	277	574
	Tassilo	NP	18.37	382	578	245	623
	Tassilo	P	17.22	481	653	313	670
09-Nov	Benicia	NP	18.51	314	480	236	491
	Benicia	P	18.82	407	597	284	572
	Tassilo	NP	15.38	449	590	300	674
	Tassilo	P	15.65	557	697	384	694
Sig	Benicia	NP	18.53	409	494	344	523
	Benicia	P	19.19	475	631	341	610
	H		***	***	***	***	***
	C		***	***	***	*	***
s.e.m	M		***	***	***	***	***
	HxC		***	NS	**	*	*
	HxM		***	*	**	**	***
	CxM		NS	NS	*	*	**
	HxCxM		***	NS	NS	NS	NS
	HxCxM		0.272	10.3	12.9	10.8	20.8

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RMIS No. 5137

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Intake, performance and methane emissions of finishing beef cattle offered maize silages harvested at different stages of maturity

Delaying harvest date of forage maize grown for silage has significant effects on the chemical composition of both the stover and cob components of the plant. The aim should be to harvest the crop at a stage of maturity which maximised its nutritional value to the animal. This study examined the effects of harvesting maize silage at different stages of maturity on the intake, performance and methane (CH₄) emissions of finishing beef steers.

Sixty continental cross-bred steers of mean initial live weight 531 (s.d. 23.8) kg were blocked on weight and assigned to one of 5 dietary treatments in a randomised complete block design. The maize crop (*cv.* Justina) was sown in April 2006 and grown under plastic mulch. The four harvest dates were, (1) 13 Sept., (2) 28 Sept., (3) 09 Oct. and (4) 23 Oct. On all four treatments, maize silage was offered *ad libitum* and supplemented with 3 kg concentrates per animal per day. A fifth treatment, *ad libitum* concentrates (ALC), supplemented with 5 kg grass silage per head per day, was used as a control. Methane measurements were taken using the SF₆ tracer technique. A kill-out rate of 510 g/kg was assumed to estimate initial carcass weight. Diets were offered individually for 110 days, after which animals were slaughtered and carcass data recorded. Data were analysed by one way ANOVA accounting for treatment and block using the PROC GLM procedure in Statistical Analysis Systems (SAS 2002-2003).

Table 42: Intake, performance and carcass traits of finishing steers

	Harvest date				ALC ¹	s.e.m. ²
	1	2	3	4		
Forage intake (kg DM/day)	8.30 ^b	9.37 ^a	8.55 ^b	8.47 ^b	1.79 ^c	0.172
Total intake (kg DM/day)	10.87 ^b	11.94 ^a	11.12 ^b	11.04 ^b	10.99 ^b	0.189
Live weight gain (g/day)	1208 ^b	1353 ^{ab}	1246 ^b	1298 ^b	1455 ^a	51.4
Carcass gain (g/day)	844 ^a	849 ^a	881 ^a	887 ^a	1002 ^b	37.2
Carcass weight (kg)	363 ^b	365 ^b	368 ^b	369 ^b	381 ^a	4.2
Kill out (g/kg)	548	536	551	547	552	4.8
Conformation score ³	2.75	2.73	2.92	3.08	2.92	0.12
Fat score ⁴	3.42	3.34	3.33	3.42	3.83	0.144
Kidney & channel fat (g) ⁵	23.9 ^a	24.2 ^a	18.5 ^b	23.4 ^a	21.5 ^{ab}	1.44
FCR ⁶	13.0 ^a	14.2 ^a	12.9 ^a	12.8 ^a	11.1 ^b	0.58
CH ₄ (l/ kg DMI)	40.5 ^a	34.3 ^{bc}	36.0 ^{ab}	35.9 ^b	30.3 ^c	1.57
CH ₄ (l/ kg carcass gain)	496 ^a	495 ^a	435 ^a	440 ^a	331 ^b	25.3

¹ Includes intakes during adaptation ²s.e.m. for n=12; ³Scale EUROP with P = 1 and E = 5; ⁴Scale 1 (leanest) to 5 (fattest); ⁵per kg carcass; ⁶Feed conversion ratio expressed as kg DM intake / kg carcass gain. *P<0.05; **P<0.01; ***P<0.001.

The mean (s.d.) dry matter (DM; g/kg) (uncorrected for volatiles) of each of the maize silages 1 to 4 was 274 (13.2), 310 (7.1), 333 (6.5) and 328 (9.9), with corresponding starch (g/kg DM) 315 (20.3), 362 (13.2), 381 (17.8), 386 (14.9), DM digestibility (g/kg) 710 (17.8), 723 (13.8), 734 (22.0), 715 (13.9) and neutral detergent fibre (g/kg) 485 (13.8), 447 (17.3), 437 (16.5), 434 (11.8). Maize silage and total DM intakes were higher ($P<0.001$) for harvest 2 than the other harvests (Table 42). Total DM intake was also higher ($P<0.01$) for harvest 2 than ALC. Emissions of CH₄ per kg DMI were higher ($P<0.05$) for maize silage 1 than maize silages 2 and 4, with ALC producing less than the all the maize silages. Emissions of CH₄ per kg of carcass gain did not differ across the maize treatments but all were higher ($P<0.05$) than ALC. Liveweight gain was higher ($P<0.01$) for ALC than maize silage 1, 3 and 4 but not 2. Carcass gain and carcass weight did not differ across the maize silage treatments, but all were lower ($P<0.05$) than ALC. There was no effect of treatment on carcass conformation. Fat score was higher ($P<0.05$) for ALC than the maize silage treatments. FCR was not affected by maize silage harvest date but was superior for ALC than the other treatments, most notably

when compared with maize silage harvest 2 ($P<0.001$). Kidney and channel fat was lower ($P<0.05$) for maize silage 3 than the other treatments. ALC supported the highest killout rate, with animals offered maize silage from harvest II exhibiting the lowest ($P<0.05$) kill out.

It is concluded that maize silage and total DM intake were highest with maize silage 2. This increased intake did not increase carcass growth or alter feed conversion ratio. Delaying date of maize harvest beyond 13 September reduced CH₄ emissions on a DMI basis but did not result in a decrease when expressed per kg carcass gain. Cattle offered *ad libitum* concentrates were superior to those fed maize silage in terms of growth, reduced methane emissions when expressed relative to DMI and carcass gain, carcass weight and feed conversion ratio.

RMIS No. 5137

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Red clover for silage: management impacts on protein content in the season after sowing

A previous report indicated that the inclusion of grass with red clover (*Trifolium pretense*) improved crop yield and digestibility. Red clover cultivar (Merviot vs. Ruttinova) impacted on annual yield while an earlier harvesting schedule improved herbage digestibility. In contrast, the application of inorganic N to red clover in spring resulted in no benefit. This paper reports the treatment effects on crop crude protein concentration.

Within a randomised complete block (n=4) design, field plots (24 per block, each 10m x 2m) were used to evaluate a 2 (cultivars) x 2 (alone or with companion grass) x 2 (harvest schedule) x 2 (application of N fertiliser in spring) combination of factors relating to red clover, and a 2 (harvest schedule) x 4 (application of N fertiliser in spring) combination of factors relating to a monoculture of perennial ryegrass. Two cultivars of red clover (Merviot and Ruttinova) were each autumn sown in monoculture or with perennial ryegrass (*Lolium perenne*, cv. Greengold). They received 0 or 50 kg inorganic N fertiliser/ha in mid-March and had a first-cut harvest date of 2 June or 19 June. Sequential harvests following 2 June were taken after 50, 44 and 97 days, with the corresponding durations after 19 June being 44, 42 and 88 days. Monoculture plots of perennial ryegrass (cv. Greengold) received 0, 50, 100 or 150 kg inorganic N/ha in mid-March and immediately after the first three harvests, and had similar harvest dates to the red clover. All plots were harvested to a 5 cm stubble height and received P and K after each harvest. Clover data were analysed using a General Linear Model that accounted for each of the four factors and all two-, three- and four-way interactions. Linear and quadratic equations were fitted to the data from the ryegrass monocultures treated with different rates of N fertiliser.

Grange Beef Research Centre

Table 43: Herbage crude protein contents for red clover treatments for each harvest in the first year after sowing

Cultivar	Grass ¹	N ²	Date ³	H ⁴ 1	H 2	H 3	H 4
Merviot	No	No	Early	176	195	237	276
	No	No	Late	190	231	250	272
	No	Yes	Early	168	205	242	271
	No	Yes	Late	169	223	243	274
	Yes	No	Early	138	169	200	231
	Yes	No	Late	142	202	220	219
	Yes	Yes	Early	144	166	196	229
	Yes	Yes	Late	149	188	201	214
Ruttinova	No	No	Early	177	206	226	274
	No	No	Late	205	226	273	279
	No	Yes	Early	186	217	241	270
	No	Yes	Late	204	229	258	279
	Yes	No	Early	142	193	196	231
	Yes	No	Late	158	211	241	230
	Yes	Yes	Early	145	169	189	218
	Yes	Yes	Late	160	205	235	220
s.e.m. ⁵				8.2	8.4	13.0	6.9

¹With companion grass; ²Application of inorganic N in spring; ³Early or late first-cut harvest schedule; ⁴Harvest; ⁵For 4-way interaction.

Merviot had a lower crude protein content than Ruttinova in Harvests 1 (159 vs. 172 (sem 2.9) g/kgDM; P<0.01) and 2 (197 vs. 207 (3.0) g/kgDM; P<0.05) (Table 43). Red clover monocultures had a higher (P<0.001) crude protein content compared with binary mixtures with ryegrass in Harvests 1 (184 vs. 147 (2.9) g/kgDM), 2 (216 vs. 188 (3.0) g/kgDM), 3 (246 vs. 210 (4.6) g/kgDM) and 4 (274 vs. 224 (2.4) g/kgDM). Applying N fertiliser in spring had no effect (P>0.05) on crude protein at any harvest. Herbage from the early harvest regime had a lower (P<0.001) crude protein content for Harvests 1 (159 vs. 172 (2.9) g/kgDM), 2 (190 vs. 214 (3.0) g/kgDM) and 3 (216 vs. 240 (4.6) g/kgDM). This result for Harvest 1 was surprising, but was consistent across both red clover cultivars, whether as monocultures or in binary mixtures with ryegrass. The late harvest schedule increased (P<0.05) crude protein content more for Ruttinova than Merviot in Harvest 3. There were no (P>0.05) three- or four-way interactions. The relationships between inorganic N fertiliser inputs and the crude protein content of the ryegrass monocultures were significant (P<0.001) for each harvest (Table 44). Monocultures of red clover had the same crude protein content as monocultures of ryegrass receiving 150, 152, 161 and >200 kg inorganic N fertiliser (estimated by regression) for Harvests 1, 2, 3 and 4, respectively.

Table 44: Relationships between N fertiliser input (x; kg/ha) and ryegrass crude protein (y; g/kgDM)

H ¹	D ²	a [#]	s.e.	b [#]	s.e.	c [#]	s.e.	Sig.	R ²
1	E	118	6.2	0.44	0.066			***	0.76
1	L	127	6.1	0.37	0.066			***	0.69
2	E	93	5.8	0.60	0.062			***	0.87
2	L	137	7.6	0.80	0.081			***	0.87
3	E	115	8.5	0.70	0.091			***	0.81
3	L	153	7.5	0.16	0.240	0.004	0.0015	***	0.89
4	E	168	5.1	0.99	0.164	-0.003	0.0010	***	0.93
4	L	185	4.7	0.46	0.051			***	0.86

¹Harvest; ²Date: Early (E) or late (L) first-cut harvest schedule; [#]y=a+bx+cx².

It is concluded that herbage crude protein concentration was generally higher for swards with Ruttinova than Merviot red clover, for monocultures of red clover compared with binary mixtures with ryegrass, and for swards managed in the late rather than the early harvest schedule. In contrast, applying inorganic N fertiliser in mid-March did not impact on herbage crude protein concentration. Quite high rates of inorganic N application were required with monocultures of ryegrass to attain the same crop crude protein content as was obtained from red clover monocultures.

O'Kiely, P. and Black, A.D.

RMIS No. 5137

Red clover for silage: management impacts on ensilability indices in the second season after sowing

The ensilability of swards containing red clover (*Trifolium pratense*) is influenced by a range of management factors. This experiment quantified the impacts of cultivar, companion grass, harvest schedule and N fertiliser on herbage ensilability at each of four harvests in the second year after sowing.

Within a randomised complete block (n=4) design, field plots (16 per block, each 10m x 2m) were used to evaluate a 2 (cultivars) x 2 (alone or with companion grass) x 2 (harvest schedule) x 2 (application of N fertiliser in spring) combination of factors. Two cultivars of red clover (Merviot and Ruttinova) were each sown in autumn as a monoculture or with perennial ryegrass (*Lolium perenne*, cv. Greengold). They received 0 or 50 kg inorganic N fertiliser/ha in mid-March and had a first-cut harvest date of 31 May or 13 June. Sequential harvests following 31 May were taken after 46, 48 and 57 days, with the corresponding durations after 13 June being 47, 42 and 49 days. All plots were harvested to a 5 cm stubble height and received P and K after each harvest. Clover data were analysed using a General Linear Model that accounted for each of the four factors and all two-, three- and four-way interactions.

The mean annual proportion of red clover in the monocultures was 0.79 compared with 0.70 for the binary mixtures (s.e.m. 0.026; P<0.05). The corresponding values for no N or N being spread in March were 0.79 and 0.70 (s.e.m. 0.026; P<0.05) and for the early and late harvest regimes were 0.80 and 0.69 (s.e.m. 0.026; P<0.01). Whereas red clover cultivar had little effect on ensilability indices (Table 45), inclusion of ryegrass with red clover reduced sward buffering capacity (BC) at Harvests 1 (P<0.001), 2 (P<0.01) and 4 (P<0.05), and increased (P<0.05) water-soluble carbohydrates (WSC) at Harvest 4. Spring application of N increased (P<0.05) WSC at Harvests 1 and 3, and reduced BC at Harvest 1 (P<0.001) but increased (P<0.05) it at Harvest 3. It increased (P<0.01) dry matter (DM) content at Harvest 1 but reduced (P<0.05) it at Harvest 3. The late harvest schedule increased (P<0.001) DM content at Harvests 1 and 3, reduced WSC at Harvests 1 (P<0.001), 2 (P<0.05) and 3 (P<0.001), and reduced (P<0.001) BC at Harvests 2 and 3. A small number of 2- and 3-way interactions occurred.

It is concluded that both red clover cultivars had similar ensilabilities. Binary mixtures of red clover and ryegrass should be easier to preserve as silage than red clover monocultures due to higher WSC and/or lower BC. Spring applied N generally improved ensilability by increasing WSC and/or reducing BC. Much of the effects of binary mixtures versus monocultures, or of spring applied N, were due to increasing the proportion of ryegrass in the sward. The impact of the late harvest regime was more difficult to assess as it generally increased DM but reduced WSC and BC.

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Table 45: Herbage ensilability indices for each harvest in the second season after sowing

Red clover cultivar	Grass ¹	N ²	Harv. sched. ³	Harvest 1			Harvest 2			Harvest 3			Harvest 4		
				DM ⁴	WSC ⁵	BC ⁶	DM	WSC	BC	DM	WSC	BC	DM	WSC	BC
Merviot	No	No	Early	148	73	433	130	85	499	126	76	538	159	50	511
	No	No	Late	153	33	411	138	82	447	148	27	348	167	46	527
	No	Yes	Early	148	75	411	134	83	499	127	72	537	141	47	555
	No	Yes	Late	172	44	412	137	70	464	137	34	445	148	49	557
	Yes	No	Early	145	67	393	136	96	495	128	67	560	139	44	546
	Yes	No	Late	154	32	388	134	54	414	144	27	348	147	52	505
	Yes	Yes	Early	146	100	383	131	77	486	134	81	546	141	41	540
	Yes	Yes	Late	160	49	325	133	84	453	126	40	454	157	74	471
Ruttinova	No	No	Early	139	65	442	129	75	514	125	66	565	152	42	562
	No	No	Late	152	67	425	130	65	478	144	30	388	149	42	595
	No	Yes	Early	144	82	406	129	75	517	116	72	561	146	46	539
	No	Yes	Late	164	34	417	132	66	455	135	38	444	152	40	537
	Yes	No	Early	137	77	415	130	78	503	125	69	549	151	49	538
	Yes	No	Late	138	33	408	133	65	459	144	32	396	162	51	503
	Yes	Yes	Early	146	97	375	133	65	493	119	70	546	155	64	535
	Yes	Yes	Late	151	34	355	133	60	419	144	30	395	151	79	512
s.e.m. ⁷				5.4	8.1	16.0	4.0	8.7	11.8	4.5	4.4	27.0	8.2	9.3	21.8

¹With companion perennial ryegrass; ²Application of inorganic N in spring; ³Early or late first-cut harvest schedule; ⁴Dry matter (g/kg); ⁵Water-soluble carbohydrates (g/kgDM); ⁶Buffering capacity (mEq/kgDM); ⁷For 4-way interaction.

O'Kiely, P. and Black, A.D.

RMIS No. 5137

Red clover for silage: management impacts on chemical composition in the season after sowing

Red clover (*Trifolium pratense* L.) is widely regarded as a specialist forage crop that can be ensiled. The yield, quality and preservation of red clover crops for silage are likely to depend on several management. In Ireland, the effects of cultivar, companion perennial ryegrass (*Lolium perenne* L.), N fertiliser and harvest schedule on the yield and digestibility of red clover crops during the first season after sowing were reported previously. It was shown that the inclusion of ryegrass with red clover improved forage yield and digestibility. An early first harvest date improved digestibility at the expense of yield and red clover cultivar affected annual yield. Spring application of inorganic N fertiliser resulted in no benefit. This paper reports the treatment effects on crop crude protein (CP) and three indices for pre-disposition to successful preservation as silage: herbage dry matter (DM) and water-soluble carbohydrate (WSC) contents and buffering capacity (BC).

A field experiment was conducted at the Teagasc Grange Beef Research Centre, Dunsany, County Meath, Ireland (53°30'N, 6°40'W, 92 m above sea level). A 2⁴ factorial of treatments relating to the management of red clover crops was laid out in a randomised complete block (n=4) design with 64 plots (each 10 m x 2 m). The crops were two cultivars of early flowering, diploid red clover (Merviot and Ruttinova; derived from different genetic sources), each sown (Sept. 2001) in monoculture or with perennial ryegrass (cv. Greengold). The crops received 0 or 50 kg inorganic N fertiliser ha⁻¹ in mid-March and had a first-cut harvest date of 2 June or 19 June. Subsequent harvests were taken 50, 94 and 191 days after 2 June or 44, 86 and 174 days after 19 June. All plots were harvested to a stubble height of 5 cm and received

22 kg P and 95 kg K ha⁻¹ after the first, second and third harvests, and double those rates after the fourth harvest. Harvested herbage samples were immediately frozen (-20°C) until further processing. For each crop, herbage DM content was determined by oven drying a sub-sample at 98°C for 16 h. A second sub-sample was dried at 40°C for 48 h, milled (1 mm screen) and assayed for CP (LECO FP-428 N analyser), WSC (anthrone method) and BC. Data were analysed using a General Linear Model that accounted for each of the four factors and all interactions.

Table 46: Main effects of management factors on herbage composition of red clover crops for each harvest (H) in the first year after sowing

	H 1				H 2				H 3				H 4			
	DM	CP	WSC	BC	DM	CP	WSC	BC	DM	CP	WSC	BC	DM	CP	WSC	BC
Cultivar																
Merviot	166	159	73	456	147	197	65	516	136	223	51	522	249	248	72	425
Ruttinova	161	172	66	475	146	207	53	529	136	232	45	524	247	250	71	434
<i>P</i> value	.182	.003	.211	.069	.702	.029	.008	.185	.921	.185	.054	.876	.725	.613	.808	.192
Ryegrass																
Mono. ¹	163	184	50	490	146	216	51	551	134	246	46	562	239	274	65	471
Mixture ²	163	147	89	441	147	188	67	495	139	210	50	485	257	224	77	389
<i>P</i> value	.987	***	***	***	.758	***	***	***	.055	***	.179	***	.006	***	***	***
N fert.																
No	163	166	70	471	144	204	56	532	134	230	47	528	249	251	71	436
Yes	164	165	69	460	148	200	62	514	139	225	49	518	247	247	71	424
<i>P</i> value	.906	.897	.773	.245	.232	.320	.183	.071	.124	.473	.681	.495	.817	.179	.950	.097
First cut																
Early	150	159	89	443	168	190	75	526	138	216	55	482	249	250	63	435
Late	176	172	50	488	125	214	43	519	135	240	40	564	247	248	80	424
<i>P</i> value	***	.003	***	***	***	***	***	.485	.350	***	***	***	.703	.625	***	.127

DM = Dry matter (g kg⁻¹); CP = Crude protein (g kg DM⁻¹); WSC = Water-soluble carbohydrate (g kg DM⁻¹); BC = Buffering capacity (mEq kg DM⁻¹); *** *P* < 0.001; ¹Monoculture; ² Red clover/ryegrass mixture.

There were significant (*P* < 0.05) main effects (Table 46) and some two-way interactions between management factors in their effects on herbage chemical composition. There were no significant three- or four-way interactions.

The inclusion of ryegrass with red clover improved the ensilability indices by generally increasing WSC and lowering BC at a relatively similar DM content (Table 46). Because red clover is a legume it had a higher concentration of CP and proportionately less WSC than ryegrass. Non-structural carbohydrates are used in the fermentation process during ensilage. Therefore, the addition of ryegrass as a source of WSC could be recommended for the preservation of red clover-based crops as silage. The addition of ryegrass also improved yield and digestibility (reported previously) and the benefits of its inclusion are consistent with other research.

The impact of ryegrass on chemical composition depended on the harvest schedule. In particular, for the first cut, the increase in WSC due to ryegrass was larger and the decreases in CP and BC were smaller for the 2 June than 19 June harvest dates. These differences were possibly due to an increased proportion of lignified stem in the crops, but more so for ryegrass than red clover. This result and previous results for yield and digestibility highlight the quantity versus quality dilemma in producing any temperate forage crop for silage.

Grange Beef Research Centre

Nevertheless, the results imply that the ensilability of the first cut crop would be improved by the earlier harvest date, particularly if ryegrass is included.

The effects of harvest schedule on CP and ensilability indices of subsequent cuts were artefacts of the different durations of regrowth and timing of cuts that were imposed during the rest of the growth season. While it is difficult to establish the effects and causes of the two harvest schedules after the first cut, there were differences in herbage chemical composition across the four harvests (Table 46). Based on these results, it is possible to rank the crops in terms of risk of not achieving lactic acid dominant silage fermentation in the order of Harvests $4 < 1 < 2 < 3$. In contrast, herbage CP contents were in the order Harvests $1 < 2 < 3 < 4$. Thus, although CP can be a major contributor to BC, other factors clearly contributed in this study.

In comparison to the effects of ryegrass and harvest schedule, red clover cultivar had a relatively minor impact on CP and ensilability indices. Merviot appeared easier to preserve as silage than Ruttinova because of a higher mean WSC content and lower mean BC (and CP) content at a similar DM (Table 46). The effect of cultivar was also expressed when ryegrass was included and was most obvious in the first two harvests of the growth season. For most indices, the differences between cultivars did not depend on timing of the first cut, although the increase in BC due to the later first cut was smaller for Merviot than Ruttinova crops. Merviot was likely to be easier to preserve although its annual yield could be lower (previous results).

There was no effect of the spring application of inorganic N fertiliser on mean CP content or ensilability indices at any harvest (Table 46). This result was consistent with the absence of yield benefits reported previously and implies that neither red clover nor the ryegrass grown with red clover responded measurably to the applied N. This suggests that all crops were able to meet their N demands using alternative sources of N (e.g. N₂ fixation, soil N mineralisation).

This experiment has demonstrated significant impacts of management factors on the yield, quality and ensilability of red clover crops. However, in general, the indices of ensilability (DM, WSC and BC) suggested that it would have been difficult to achieve good preservation with any of the crops unless extensive wilting and/or application of sufficient effective additive were employed in addition to the management practices identified in this study.

It is concluded that red clover mixed with perennial ryegrass generally resulted in a higher WSC content but a lower BC and CP content than when in monoculture. The early first harvest date resulted in a higher WSC content and a lower BC and CP content compared to the later first harvest. Crops with Merviot tended to have a higher WSC but a lower CP content than those with Ruttinova. Spring application of inorganic N had little impact on herbage chemical composition.

O'Kiely, P. and Black, A.D.

RMIS No. 5137