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Grazing and ensiling of energy-rich grasses with elevated sugar
contents for the sustainable production of ruminant livestock
(Acronym: SweetGrass)

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CONTENTS

	Page no.
1. Introduction	3
2. Agronomy	4
3. Forage conservation	19
4. Beef production	48
5. Conclusions	58
6. Acknowledgements	60
7. Publications	61

1. INTRODUCTION

Permanent grassland dominates the Irish landscape and for many decades perennial ryegrasses have been the main constituent in seed mixtures for grassland. The main attractions in favour of perennial ryegrass swards are that they:

- x produce high yields in response to fertiliser nitrogen
- x have a high digestibility when harvested at the appropriate growth stage
- x are relatively easy to preserve as silage due to their superior content of sugar
- x persist as permanent swards where favourable management practices prevail

If the phenotype of perennial ryegrass were to be improved, one potentially desirable trait would be an elevated concentration of water-soluble carbohydrates (WSC). This could confer benefits in terms of:

- x further increase the probability of achieving a lactic acid dominant fermentation during ensilage. This could reduce the requirement for traditional acid- or sugar-based additives, improve the likelihood of a positive response from additives based on homofermentative lactic acid bacteria or alternatively eliminate the need for any or the currently available conventional additive. If its effect was to improve silage preservation this should positively impact on dry matter (DM) recovery, improve animal productivity and potential product quality, and reduce N loss to the environment.
- x improve the opportunity to produce silage with an elevated concentration of WSC. In circumstances where little or no supplementary concentrate feedstuffs were offered with silage, higher residual WSC could enhance silage intake and digestion, thereby improving animal productivity and reducing urinary loss of N.
- x produce a grass with higher intake characteristics during grazing, resulting in improved or more efficient animal production.
- X better synchronise or balance the supply of a rapidly fermentable carbon source (e.g. WSC) with soluble N compounds in the rumen of cattle or sheep. This could be important with grazing animals in spring and particularly in autumn when grass N content can be relatively high. Improved synchronisation or balance could potentially improve animal productivity and reduce urinary loss of N.

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- x Institute of Grassland and Environmental Research (IGER), Wales
- x Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden
- x Institute of Crop and Grassland Science, Federal Agricultural Research Centre (FAL) Braunschweig, Germany
- X Norwegian Crop Research Institute (NCRI), Kvithamar Research Centre, N-7500 Stjørdal, Norway

2. AGRONOMY

In this section three studies involving the use of field plots were conducted.

- x Experiment 2.1 examined the yield, persistency and chemical composition of six lines of *Lolium perenne* L., two of which contained a high WSC genotype, managed under a four cut conservation regime during three successive years.
- x Experiment 2.2 evaluated the effects of varying N fertiliser application rates on perennial ryegrass cultivars with high or normal WSC genotypes.
- x Experiment 2.3 quantified the effects of three forms of N fertiliser on the yield and chemical composition of two perennial ryegrass cultivars, managed for silage production.

Experiment 2.1: Yield, persistency and chemical composition of lines of *Lolium perenne* L. selected for high water-soluble carbohydrate concentration

Introduction

Increasing the water-soluble carbohydrate (WSC) concentration of grasses may lead to improved productivity by grazing or silage-fed ruminants. For this reason, efforts have been made to breed cultivars of perennial ryegrass with elevated concentrations of WSC. The scale of improvement in WSC concentration by such cultivars relative to cultivars not deliberately bred for this trait may interact with environmental conditions. The latter could be mediated through differences in factors such as prevailing weather, climatic or soil conditions, or management system. This experiment examined the yield and chemical composition of six lines of *Lolium perenne* L., two of which contained a high WSC genotype, managed under a four cut conservation regime during three successive years.

Materials and Methods

The experiment had six complete replicate blocks, each with six 20 m² plots. Six intermediate perennial ryegrass cultivars (Aberdart and Ba11353: selected for high WSC content; Fennema, Aberelan, Spelga and Greengold: controls) were fully randomised within each block. Greengold is a tetraploid cultivar while the remainder are diploid. Plots were sown by hand on 11 September 2000 at a rate of 4 g seed/m². Compound fertiliser (240g N, 25g P and 100g K per kg) was manually applied to each plot at a rate of 471 kg/ha in mid-March each year and at 392, 313 and 313 kg/ha after harvesting cuts 1 (primary growth), 2 (regrowth 1) and 3 (regrowth 2), respectively. Plots were harvested with a Haldrup plot harvester (at a 5cm stubble height) on 28 May, 9 July, 27 August and 17 Oct. 2001, 28 May, 11 July, 26 August and 14 Oct. 2002, and 27 May, 8 July, 25 August and 15 Oct. 2003. On each harvesting date, sward characteristics such as botanical composition (% *Lolium perenne* L.), disease or damage (% herbage surface discoloured), growth stage (scale of 1-7) and lodging (% crop) were assessed visually. To estimate grass dry matter (DM) concentration, samples were dried at 98°C for 16h in an oven with forced air circulation. Samples dried at 60°C (48h) were milled through a sieve with 1mm diameter pores and were used for assessing *in vitro* DM digestibility (DMD) and organic matter digestibility (OMD) (Tilley and Terry, 1963; with the modification that the final residue was isolated by filtration rather than by centrifugation), neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Goering and van Soest, 1970), ash (muffle furnace at 550°C for 5h), crude protein (total N x 6.25; LECO FP 428 nitrogen analyser – AOAC, 1990), buffering capacity (Playne and McDonald, 1966) and WSC (NIRS – as per IGER). Aqueous sub-samples were used for determining pH and nitrate concentration (Merquant test strips). Data for each harvest were subjected to analysis of variance for a randomised complete block design with the factor being cultivar. The individual treatment means were separated using the least significant difference procedure.

Results and Discussion

Treatment effects are presented in Tables 2.1-2.12.

In 2001 (Tables 2.1-2.4), Ba11353 showed better (P<0.05) early growth (cut 1) than Aberdart and consequently had a higher (P<0.05) overall total dry matter (DM) yield. Ba11353 produced a higher (P<0.05) DM yield than Greengold in the primary growth (cut 1), but the situation was reversed (P<0.05) in regrowth 1 (cut 2). Aberelan was the only control with a lower (P<0.05) total DM yield than Ba11353. In the primary growth, Ba11353 had a higher (P<0.05) *in vitro* organic matter digestibility (OMD) than Aberdart and the diploid controls, but lower (P<0.05) than Greengold. There was no difference (P>0.05) between either Aberdart or the controls and Ba11353 in regrowths 1 and 2 (cuts 2 and 3). Aberelan had the lowest (P<0.05) OMD in regrowth 3 (cut 4). Ba11353 was higher in WSC concentration (P<0.05) than Aberdart or the diploid controls in cuts 1, 3 and 4, than Fennema and Spelga in cut 2 and than the tetraploid Greengold in cuts 1, 2 and 3. Spelga had the lowest (P<0.05) crude protein concentration in cut 1. Ba11353 had a lower (P<0.05) crude protein concentration than

Aberdart in the remaining cuts and was lower ($P<0.05$) than Fennema and Spelga in cut 2, Aberlan and Fennema in cut 3 and all diploid controls in cut 4.

In 2002 (Tables 2.5-2.8), herbage DM yields for the four harvests were in the order cut 1 > cut 3 > cut 4 > cut 2. In cut 1, Aberdart and Ba11353 had lower ($P<0.05$) yields than all cultivars except Aberlan. For cut 2, grass cultivars did not differ in yield ($P>0.05$), while in cut 3 Spelga yielded higher ($P<0.05$) than Aberdart, Ba11353 and Fennema. Ba11353 yielded higher ($P<0.05$) than Fennema in cut 4 but did not differ ($P>0.05$) from the other cultivars. Aberlan had a lower ($P<0.05$) total yield than all cultivars, except Aberdart. Spelga had higher ($P<0.05$) total yields than all cultivars, except the tetraploid Greengold. Greengold had higher ($P<0.05$) total yields than Aberdart. There was no significant harvest X cultivar interaction for DM, WSC, crude protein (CP) or ash. Ba11353 and Fennema had a higher ($P<0.05$) annual average DM concentration than Aberdart and Greengold. Ba11353 had a higher ($P<0.05$) mean annual WSC concentration than all other cultivars, while Aberdart, Fennema, Aberlan and Greengold did not differ ($P>0.05$) from one another. Aberdart had a higher ($P<0.05$) mean annual crude protein value than Ba11353, Spelga and Greengold. Ba11353 was lower ($P<0.05$) than all cultivars except Spelga and Greengold. In cut 1, Aberdart and Ba11353 did not differ in *in vitro* organic matter digestibility (OMD) values ($P>0.05$), and Greengold was higher ($P<0.05$) than all cultivars except Ba11353. There was no difference ($P>0.05$) between any cultivars at cut 2. In cut 3, Ba11353 had higher ($P<0.05$) OMD values than all cultivars. Aberdart did not differ ($P>0.05$) from Fennema, Spelga and Greengold but was higher ($P<0.05$) than Aberlan. In cut 4, Ba11353 did not differ ($P>0.05$) from any cultivar except Greengold which was higher. There was no difference ($P>0.05$) between Aberdart and all other cultivars. In cut 1, Aberdart did not differ ($P>0.05$) in buffering capacity from any cultivar except Aberlan which was higher. Ba11353 did not differ ($P>0.05$) in value from any other cultivar. In cut 2, Aberdart had a higher ($P<0.05$) BC than Ba11353, Aberlan and Greengold, but did not differ ($P>0.05$) from Fennema and Spelga. In cut 3, Ba11353 had a higher ($P<0.05$) value than Fennema, with neither of these differing from any other cultivar. In cut 4, grass cultivars did not differ ($P>0.05$) in buffering capacity values. The persistency of all cultivars was similar. In 2003, overall differences in DM, ash and buffering capacity (Tables 2.9-2.12) were relatively small among diploids. Aberdart and Ba11353 tended to have higher organic matter digestibility (OMD) values in the earlier cuts than Spelga. WSC concentrations among the diploids were (on average) in the order Ba11353 > Aberdart > others. The scale of the differences were relatively small - Ba11353 averaged 2.3%units WSC higher than Fennema while Aberdart averaged 1.4%units WSC higher than Fennema. Greengold (tetraploid), tended to have a lower DM (overall average: 161 vs.171 g/kg) concentration than diploids, tended to have higher OMD values compared to the diploids (overall average: 774 vs.758 g/kg), generally had similar buffering capacity (overall average: 394 vs.397 g/kg) and ash (overall average: 85 vs.87 g/kg) values to the diploids, and had a mean WSC concentration of 192 g/kgDM relative to values of 197 and 188 g/kgDM for Ba11353 and Aberdart, respectively, and of 182 g/kgDM for all diploids.

Conclusions

Dry matter yield averaged across years (2001 and 2002) and cuts tended to be lower with Aberdart than with Spelga or Greengold, while Ba11353 was intermediate (Table 2.13). The mean ranking of WSC concentration (across all years and cuts) was Ba11353 (187 g/kgDM) > Greengold (174 g/kgDM) > Aberdart (167 g/kgDM) > 'other' diploids (158 g/kgDM). There was little effect of grass variety on ash, pH or buffering capacity, while crude protein concentration tended to be higher in Aberdart, Fennema and Aberlan than in Ba11353, Spelga and Greengold. Greengold had a lower DM concentration than the diploid varieties (148 vs. 160 g/kg) while the mean ranking of OMD was Greengold (783 g/kg) > Ba11353 (776 g/kg) > Aberdart (771 g/kg) > 'other' diploids (763 g/kg).

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Table 2.1. Sward characteristics for primary growth (cut 1) of cultivars comparison (Experiment 2.1) in 2001 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	157	155	149	151	152	135	3.6	0.003
DM yield (t/ha)	5281	6008	6076	5409	6487	5354	205.9	0.001
pH	6.5	6.5	6.6	6.5	6.6	6.5	0.04	0.203
C.protein (g/kgDM)	171	166	167	160	146	168	4.2	0.004
Ash (g/kgDM)	98	96	100	97	94	101	2.1	0.266
OMD (g/kg)	742	763	734	728	704	778	4.7	<0.001
ADF (g/kgDM)	270	259	284	283	305	275	2.7	<0.001
NDF (g/kgDM)	484	471	505	504	525	473	4.	<0.001
WSC (g/kgDM)	165	184	148	156	155	165	5.6	0.003
B.capacity (mEq/kgDM)	467	495	485	466	466	514	7.1	<0.001
Nitrate (mg/l)	217	192	250	225	175	175	26.7	0.307
Bot.composition (%)	89	90	92	89	94	91	2.0	0.470
Disease/damage (%)	1.0	4.2	1.2	1.5	1.7	1.2	0.54	0.003
Growth stage (%)	3.4	3.1	3.3	3.1	4.0	2.8	0.05	<0.001
Lodging (%)	25.8	7.7	2.2	5.7	4.8	2.2	3.8	0.001

Table 2.2. Sward characteristics for regrowth 1 (cut 2) of cultivars comparison (Experiment 2.1) in 2001 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	147	151	142	147	141	130	2.2	<0.001
DM yield (t/ha)	3301	3400	3042	3195	3324	3779	117.9	0.005
pH	6.4	6.4	6.4	6.4	6.4	6.4	0.03	0.718
C.protein (g/kgDM)	211	191	220	206	209	194	6.0	0.018
Ash (g/kgDM)	112	113	111	114	114	112	1.8	0.717
OMD (g/kg)	808	800	800	808	792	802	5.3	0.291
ADF (g/kgDM)	241	243	256	245	268	264	4.2	<0.001
NDF (g/kgDM)	439	442	462	451	469	448	4.0	<0.001
WSC (g/kgDM)	161	174	137	161	139	156	5.3	<0.001
B.capacity (mEq/kgDM)	552	569	536	559	547	565	7.9	0.064
Nitrate (mg/l)	500	458	500	500	500	500	17.0	0.438
Bot.composition (%)	97	98	98	97	98	98	0.7	0.833
Disease/damage (%)	0	0	0	0	0	0	-	-
Growth stage (%)	2.5	2.1	2.9	2.5	2.9	2.5	0.07	<0.001
Lodging (%)	0	0	0	0	0	0	-	-

Table 2.3. Sward characteristics for regrowth 2 (cut 3) of cultivars comparison (Experiment 2.1) in 2001 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	154	158	142	151	142	134	4.7	0.013
DM yield (t/ha)	3300	3466	3239	3477	3408	3486	96.7	0.364
pH	6.4	6.3	6.3	6.4	6.3	6.3	0.05	0.394
C.protein (g/kgDM)	213	192	205	211	199	195	4.2	0.007
Ash (g/kgDM)	114	108	112	115	116	118	1.7	0.015
OMD (g/kg)	767	776	779	762	766	786	5.7	0.046
ADF (g/kgDM)	260	262	277	273	288	277	3.1	<0.001
NDF (g/kgDM)	455	449	466	473	468	454	5.9	0.046
WSC (g/kgDM)	138	162	134	126	133	144	4.3	<0.001
B.capacity (mEq/kgDM)	523	499	515	518	509	536	18.0	0.770
Nitrate (mg/l)	501	501	501	501	501	501	-	-
Bot.composition (%)	98	99	97	98	98	98	0.4	0.115
Disease/damage (%)	3	2	2	4	2	2	0.3	<0.001
Growth stage (%)	1.7	1.6	1.8	1.8	1.7	1.7	0.02	<0.001
Lodging (%)	0	0	0	0	0	0	0.1	0.438

Table 2.4. Sward characteristics for regrowth 3 (cut 4) of cultivars comparison (Experiment 2.1) in 2001 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	127	125	121	122	116	114	1.4	<0.001
DM yield (t/ha)	2132	2115	1915	2052	1961	2193	46.2	0.002
pH	6.1	6.0	6.1	6.1	6.0	6.0	0.03	0.032
C.protein (g/kgDM)	286	271	286	280	283	279	2.8	0.007
Ash (g/kgDM)	113	110	117	115	118	112	1.9	0.067
OMD (g/kg)	770	769	772	752	771	778	4.7	0.014
ADF (g/kgDM)	244	247	257	249	272	260	1.7	<0.001
NDF (g/kgDM)	463	449	470	471	472	457	2.6	<0.001
WSC (g/kgDM)	113	130	103	107	91	122	3.0	<0.001
B.capacity (mEq/kgDM)	540	522	511	533	518	512	10.1	0.285
Nitrate (mg/l)	501	501	501	501	501	501	-	-
Bot.composition (%)	98	99	98	99	98	98	0.3	0.341
Disease/damage (%)	1.3	1.3	1.5	2.8	1.3	1.3	0.18	<0.001
Growth stage (%)	1	1	1	1	1	1	-	-
Lodging (%)	0	0	0	0	0	0	-	-

Table 2.5. Sward characteristics for primary growth of cultivars comparison (Experiment 2.1) in 2002 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	144	142	150	146	147	144	4.2	0.827
DM yield (t/ha)	5424	5496	6171	4985	6459	5951	219.8	0.001
C.protein (g/kgDM)	177	175	171	187	165	173	4.1	0.025
Ash (g/kgDM)	81	82	79	89	80	78	3.1	0.174
OMD (g/kg)	710	728	720	721	694	745	9.5	0.019
NDF (g/kgDM)								
WSC (g/kgDM)	180	193	177	178	173	202	5.2	0.004
B.capacity (mEq/kgDM)	324	340	328	355	335	346	8.5	0.151
Bot.composition (%)	93	93	93	93	93	93	-	-
Disease/damage (%)	18	18	18	18	18	18	-	-
Growth stage (%)	4	4	4	4	4	4	-	-
Lodging (%)	75	75	75	75	75	75	-	-

Table 2.6. Sward characteristics for regrowth 1 of cultivars comparison (Experiment 2.1) in 2002 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	166	193	174	168	175	156	6.8	0.018
DM yield (t/ha)	412	577	328	417	508	557	86.8	0.322
C.protein (g/kgDM)	199	179	197	193	183	189	8.3	0.470
Ash (g/kgDM)	93	80	88	92	89	90	2.7	0.024
OMD (g/kg)	847	855	846	845	840	848	5.1	0.528
NDF (g/kgDM)								
WSC (g/kgDM)	182	240	187	190	191	182	11.4	0.011
B.capacity (mEq/kgDM)	386	342	390	361	380	357	9.4	0.009
Bot.composition (%)	99	99	99	99	99	99	-	-
Disease/damage (%)	0.67	0.67	0.50	1.83	0.67	0.50	0.189	<0.001
Growth stage (%)	1	1	1	1	1	1	-	-
Lodging (%)	0	0	0	0	0	0	-	-

Table 2.7. Sward characteristics for regrowth 2 of cultivars comparison (Experiment 2.1) in 2002 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	191	192	204	208	203	183	6.3	0.082
DM yield (t/ha)	3297	3376	3444	3557	3888	3628	115.8	0.019
C.protein (g/kgDM)	174	159	164	170	163	158	3.8	0.043
Ash (g/kgDM)	93	90	87	91	93	88	1.7	0.109
OMD (g/kg)	749	781	735	723	737	756	6.9	0.000
NDF (g/kgDM)								
WSC (g/kgDM)	166	200	166	150	154	176	4.7	<0.001
B.capacity (mEq/kgDM)	337	351	320	334	332	334	6.4	0.065
Bot.composition (%)	96	98	97	97	98	98	0.9	0.264
Disease/damage (%)	7.0	3.0	5.2	7.7	3.8	2.8	0.60	<0.001
Growth stage (%)	233	22	292	300	292	300	9.0	<0.001
Lodging (%)	12	78	9	9	8	11	2.3	<0.001

Table 2.8. Sward characteristics for regrowth 3 of cultivars comparison (Experiment 2.1) in 2002 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	143	144	147	139	138	140	2.3	0.060
DM yield (t/ha)	2283	2461	1981	2096	2219	2315	58.3	<0.001
C.protein (g/kgDM)	230	213	233	235	224	220	5.5	0.071
Ash (g/kgDM)	103	97	101	101	103	94	1.5	0.001
OMD (g/kg)	802	788	806	785	786	810	4.6	0.001
NDF (g/kgDM)								
WSC (g/kgDM)	148	166	143	139	134	171	5.0	<0.001
B.capacity (mEq/kgDM)	397	375	396	392	389	386	7.9	0.418
Bot.composition (%)	99	99	99	99	99	99	0.3	0.761
Disease/damage (%)	1.2	1.3	1.0	2.0	1.0	1.0	0.15	<0.001
Growth stage (%)	1	1	1	1	1	1	-	-
Lodging (%)	0	0	0	0	0	0	-	-

Table 2.9. Sward characteristics for primary growth of cultivars comparison (Experiment 2.1) in 2003 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	189	175	181	176	185	166	9.0	0.530
C.protein (g/kgDM)	115	121	119	128	116	120	4.6	0.463
Ash (g/kgDM)	70	77	72	71	69	72	2.2	0.186
OMD (g/kg)	709	733	706	698	692	743	10.7	0.015
NDF (g/kgDM)								
WSC (g/kgDM)	231	231	211	201	207	227	10.9	0.232
B.capacity (mEq/kgDM)	491	478	467	515	518	519	27.8	0.652
Bot.composition (%)	94	96	91	90	94	92	1.0	0.003
Disease/damage (%)	3.6	3.2	3.5	3.7	3.9	3.0	0.10	<0.001
Growth stage (%)	0	0	0	0	0	0	-	-
Lodging (%)	13.5	10.5	11.0	12.5	11.0	9.5	0.61	0.001

Table 2.10. Sward characteristics for regrowth 1 of cultivars comparison (Experiment 2.1) in 2003 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	151	166	154	152	142	141	12.2	0.704
C.protein (g/kgDM)	209	204	220	212	206	218	5.7	0.265
Ash (g/kgDM)	95	90	92	94	92	93	2.0	0.681
OMD (g/kg)	801	785	784	784	771	784	8.6	0.332
NDF (g/kgDM)								
WSC (g/kgDM)	168	176	153	167	165	163	6.1	0.225
B.capacity (mEq/kgDM)	386	366	380	390	394	372	4.7	0.002
Bot.composition (%)	97	97	96	96	97	97	0.5	0.438
Disease/damage (%)	1.6	1.5	1.6	1.6	1.7	1.5	0.06	0.391
Growth stage (%)	0	0	0	0	0	0	-	-
Lodging (%)	0	0	0	0	0	0	-	-

Table 2.11. Sward characteristics for regrowth 2 of cultivars comparison (Experiment 2.1) in 2003 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	194	200	204	208	198	187	2.8	0.001
C.protein (g/kgDM)	169	155	174	189	167	165	5.8	0.009
Ash (g/kgDM)	91	88	89	88	91	86	1.6	0.181
OMD (g/kg)	753	740	741	733	732	757	4.7	0.003
NDF (g/kgDM)								
WSC (g/kgDM)	192	207	182	187	180	195	3.7	<0.001
B.capacity (mEq/kgDM)	344	348	342	337	341	331	7.1	0.673
Bot.composition (%)	99	99	98	99	99	99	0.2	0.023
Disease/damage (%)	2.8	2.6	2.9	2.9	2.8	2.8	0.04	<0.001
Growth stage (%)	0	0	0	0	0	0	-	-
Lodging (%)	1	1	1	1	1	1	-	-

Table 2.12. Sward characteristics for regrowth 3 of cultivars comparison (Experiment 2.1) in 2003 at Teagasc, Grange

	Aberdart	Ba11353	Fennema	Aberelan	Spelga	Greengold	sem	Sig.(P=)
DM (g/kg)	146	154	150	148	149	148	6.4	0.972
C.protein (g/kgDM)	251	249	264	255	251	245	4.7	0.137
Ash (g/kgDM)	95	92	97	94	97	88	1.5	0.002
OMD (g/kg)	803	799	803	803	801	814	4.9	0.354
NDF (g/kgDM)								
WSC (g/kgDM)	160	175	149	155	146	183	5.7	0.001
B.capacity (mEq/kgDM)	361	373	385	352	371	353	6.4	0.009
Bot.composition (%)	99	99	98	99	99	99	0.3	0.250
Disease/damage (%)	1	1	1	1	1	1	-	-
Growth stage (%)	0	0	0	0	0	0	-	-
Lodging (%)	1	1	1	1	1	1	-	-

Table 2.13. Mean DM yield and chemical composition (averaged across years and cuts) of cultivars comparison (Experiment 2.1) at Teagasc, Grange

	Aberdart	Ba11355	Fennema	Aberelan	Spelga	Greengold	All diploids	Other diploids
DM yield ² (t/ha)	3179	3362	3275	3148	3532	3408	3299	3318
DM g/kg	159	163	160	160	157	148	160	159
pH ³	6.33	6.31	6.36	6.37	6.31	6.30	6.34	6.35
C.protein (g/kgDM)	201	189	202	202	193	194	197	199
Ash (g/kgDM)	96	94	95	97	96	94	96	96
OMD (g/kg)	771	776	769	762	757	783	767	763
B.capacity (mEq/kgDM)	426	421	421	426	425	427	424	424
WSC (g/kgDM)	167	187	157	160	156	174	165	158

¹Fennema, Aberelan and Spelga (i.e. diploids excluding the two cultivars bred for elevated WSC); ²2001 & 2002; ³2001

Experiment 2.2: The influence of varying nitrogen fertiliser application rates on perennial ryegrass selected for high water-soluble carbohydrate concentration and grown for silage production.

Introduction:

Reducing the total costs of production is a necessary component of most commercial farming businesses. Provision of feed to livestock accounts for at least proportionately 0.75 of direct costs in virtually all beef, dairy and sheep production systems in Ireland (Teagasc, 1998). The logic whereby proportionately 0.91 of the land area used for agricultural purposes is accounted for by grassland (including rough grazing) (Fingleton and Cushion, 1997) is thus reinforced by the reality that ruminants can generally be provided with energy from well-managed home-produced grazed grass more cheaply than from any other feedstuff (O’Kiely *et al.*, 1997a), and that grass silage, for both strategic and economic reasons, provides a significant amount of feed requirements during the winter period when most ruminants need to be accommodated indoors. Although grass silage is a more expensive feedstuff than grazed grass, there is a considerable range in the potential costs of providing animals with energy from either source, and crop yield at harvesting has a major influence on the cost of silage (O’Kiely *et al.*, 1997a).

Many environmental and management factors affect the yield of grass grown for silage production. Because high crop yields are needed at harvesting to make grass silage cost competitive, it is usually necessary to provide the crop with N via fertiliser application, legumes that fix atmospheric N or recycled animal manures. On intensively managed grassland farms, with high yields of grass required for first-cut silage in particular, the main emphasis has been on N fertiliser. Many grass yield response curves to applied fertiliser N have been published (Whitehead, 1995) which show an almost linear increase in herbage yield up to application rates between 250

and 400 kg N/ha year, and beyond which the response declines until the maximum yield is attained. The precise shape of the response curve depends on many factors including soil characteristics, prevailing weather, sward type, harvesting frequency, etc.

Applied N can reduce grass DM and WSC concentrations and increase buffering capacity, the effects being greater with increasing rates of N addition and as the interval between N application and harvesting decreases (O'Kiely *et al.*, 1997). The overall effects of such changes are to produce grass that, when ensiled, makes it more difficult for a successful preservation dominated by lactic acid production to ensue.

Cultivars bred for increased water-soluble carbohydrate (WSC) concentration may thus lead to improvements in grass ensilability, as well as nutritive value. However their response to N fertiliser relative to cultivars of normal WSC genotype is unknown. This experiment evaluated the effects of varying N fertiliser application rates on perennial ryegrass cultivars with high or normal WSC genotypes.

Materials and methods:

The experiment was a split-plot randomised complete block design containing four replicates; each replicate consisting of four main plots providing for successive harvests (21 May (H1), 2 July (H2), 20 Aug. (H3) and 8 Oct. 2001 (H4); 22 May, 7 July, 20 August and 14 October, 2003). Within main plots, 2 cultivars x 5 rates of inorganic N fertiliser (N_f) were fully randomised. The two diploid intermediate perennial ryegrass cultivars (Aberdart: selected for high WSC concentration and Fennema: control) were sown as monoculture plots in Sept. 2000 following full cultivation of a permanent grassland site. The rates of N fertiliser (calcium ammonium nitrate (CAN); 275 g N/kg) were equivalent to 0 (N_0), 40 (N_{40}), 80 (N_{80}), 120 (N_{120}) and 160 (N_{160}) kg N/ha and were applied to sub-plots within H1, H2, H3 and H4 in mid-March and after H1, H2 and H3, as appropriate. The remaining sub-plots received an application of CAN equivalent to 80 kg N/ha. All plots were harvested at each harvest period but only herbage from within main plots fertilised with N_f were sampled and weighed. Measurement data were analysed using a split-plot design. The relationship between the variables measured and both N_f and cultivar were examined by stepwise multiple regression analysis [$y f(N_f, N_f^2, \text{cultivar } (C), C \times N_f, C \times N_f^2)$] for each harvest. The individual treatment means were separated using the least significant difference procedure.

Results and discussion

Treatment means and significant effects are presented in Tables 2.14-2.26. Harvest had an effect ($P < 0.01$ or greater) on the dry matter (DM) yield and chemical composition of the swards and on the cultivar yield response to and apparent recovery of applied N. The N_f had an effect ($P < 0.001$) on all variables measured. In comparison with Fennema, Aberdart had a lower ($P < 0.05$) buffering capacity, pH and concentration of nitrate and crude protein, a higher ($P < 0.05$) concentration of WSC and ash but did not differ ($P > 0.05$) in DMD or DM concentration.

Grass WSC concentrations are given for both 2001 and 2003 in Table 2.22. The WSC values for Aberdart > Fennema (169 vs. 158 g/kg DM) and the WSC values for 2003 were greater than for 2001. H1 had the highest values. Values decreased progressively from N_0 to N_{120} . The differences between cultivars in response to N_f were maintained across harvests and years - there were not significant $C \times N_f$, $H \times C \times N_f$, $C \times N_f \times Y$ or $H \times C \times N_f \times Y$ interactions.

Relatively few interactions occurred for any other variables between cultivar and year, harvest, rate of N fertiliser application or any combination of these factors that included cultivar.

Conclusions:

The absolute differences in WSC concentration between Aberdart and Fennema were sufficiently small as to make the differences in ensilability relatively minor. Varying the rate of N fertiliser applied did not alter the relative differences between cultivars in ensilability indices. Thus, the negative effects of N fertiliser on WSC were similar for the two grasses across a range of conditions.

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Table 2.14 Grass dry matter (DM) yield (t/ha) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdart					Fennema					Statistical summary			
	N rate (N _r)	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e. ¹	
2001														
H1		3.76	4.30	4.59	4.71	4.84	3.87	5.33	5.37	5.25	5.07	H	***	0.067
H2		2.74	3.71	3.93	4.46	4.36	2.39	3.74	3.90	4.00	4.56	N _r	***	0.063
H3		2.61	3.70	3.94	3.94	3.70	2.36	3.54	3.97	4.08	4.15	C	ns	0.040
H4		1.63	2.53	2.76	2.93	2.87	1.79	2.32	2.54	2.60	2.71	HxN _r	ns	0.131
												HxC	***	0.088
												CxN _r	ns	0.089
												HxCxN _r	ns	0.181

*, **, *** denote P<0.05, P<0.01 and P<0.001, respectively; ns denotes not significant; ¹Standard error of the mean

Table 2.15 Response to applied N (kg DM/kg total N applied) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdart					Fennema					Statistical summary			
	N rate (N _r)	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.	
2001														
H1			13.6	10.4	7.9	6.8		36.5	18.8	11.5	7.5	H	ns	
H2			24.4	14.8	14.3	10.1		33.9	18.9	13.4	13.6	N _r	***	1.26
H3			27.3	16.7	11.1	6.8		29.6	20.2	14.4	11.2	C	*	0.89
H4			22.5	14.2	10.9	7.8		13.3	9.4	6.8	5.8	HxN _r	ns	
												HxC	**	2.46
												CxN _r	ns	
												HxCxN _r	ns	

Table 2.16 Apparent recovery of applied N (kgN/kg total N applied) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdart					Fennema					Statistical summary			
	N rate (N _r)	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.	
2001														
H1			498	503	563	461		1059	802	593	443	H	ns	
H2			778	582	756	600		1167	663	677	707	N _r	***	40.2
H3			951	878	693	552		832	862	771	618	C	ns	
H4			917	744	651	472		659	614	527	421	HxN _r	ns	
												HxC	**	63.6
												CxN _r	ns	
												HxCxN _r	ns	

Table 2.17. Overall mean composition of the two grasses, across years, harvests and rate of N fertiliser application (Experiment 2.2).

	Aberdart	Fennema	s.e.	Sig.
Dry matter (g/kg)	165	165	0.9	ns
Crude protein (g/kgDM)	178	181	1.2	*
DMD in vitro (g/kg)	796	797	1.1	ns
Ash (g/kgDM)	106	104	0.6	*
WSC (g/kgDM)	169	158	1.9	***
Buffer capacity (mEq/kgDM)	350	357	2.0	**
pH	5.86	5.94	0.014	***
Nitrate (g/kgDM) ¹	1.31	1.58	0.076	*

Table 2.18 Grass dry matter concentration (g/kg) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdart					Fennema					Statistical summary		
	N rate (N _r)	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001													
H1	194	176	167	155	157	200	181	162	155	138	H	***	2.9
H2	203	169	161	147	142	207	163	160	143	143	N _r	***	1.5
H3	175	144	128	120	111	172	141	119	113	120	C	ns	0.9
H4	116	139	128	124	127	164	138	132	127	127	Y	***	0.9
2003													
H1	234	201	182	188	180	250	226	187	172	173	HxN _r	***	3.9
H2	209	169	156	138	137	222	166	154	149	143	HxC	ns	3.2
H3	212	205	195	192	192	205	207	209	186	197	CxN _r	ns	2.1
H4	189	152	147	139	142	172	152	153	145	148	HxCxN _r	*	4.8

Table 2.19 Grass crude protein concentration (g/kg DM) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdart					Fennema					Statistical summary		
	N rate (N _r)	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001													
H1	121	136	155	188	193	120	138	162	174	180	H	***	2.4
H2	116	138	155	198	211	114	150	154	194	214	N _r	***	1.8
H3	119	148	190	210	233	133	147	187	219	225	C	*	1.2
H4	156	192	228	254	254	159	193	233	262	260	Y	ns	1.1
2003													
H1	91	92	108	124	142	89	106	113	134	154	HxN _r	***	4.1
H2	164	174	214	262	275	140	194	229	254	282	HxC	ns	2.9
H3	126	145	174	188	192	132	142	166	191	204	CxN _r	ns	2.6
H4	162	200	219	226	247	180	203	233	244	248	HxCxN _r	ns	5.5

Table 2.20 Grass in vitro DM digestibility (g/kg) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdart					Fennema					Statistical summary		
	N rate (N _r)	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001													
H1	825	804	806	809	798	829	811	822	805	805	H	***	2.2
H2	828	811	803	804	798	838	811	802	798	791	N _r	***	1.7
H3	819	810	805	807	798	814	813	8.4	804	800	C	ns	1.1
H4	840	821	832	817	816	827	813	832	814	826	Y	***	1.1
2003													
H1	806	761	759	755	747	807	765	756	753	754	HxN _r	***	3.8
H2	822	834	822	823	831	820	829	820	818	809	HxC	ns	2.7
H3	771	743	771	763	755	766	743	756	753	758	CxN _r	ns	2.5
H4	752	756	775	779	777	778	768	783	778	787	HxCxN _r	ns	5.1

Table 2.21 Grass ash concentration (g/kg DM) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C) N rate (N _r)	Aberdart					Fennema					Statistical summary	
	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001												
H1	89	98	100	103	100	93	94	98	101	105	H	*** 1.9
H2	101	106	116	117	122	97	109	105	114	111	N _r	*** 1.0
H3	102	104	113	116	115	107	109	113	115	113	C	* 0.6
H4	109	119	114	119	116	111	111	120	122	116	Y	*** 0.6
2003												
H1	91	81	84	77	79	73	75	84	80	82	HxN _r	ns 2.6
H2	114	109	110	104	114	106	111	102	106	107	HxC	ns 2.1
H3	112	111	109	113	111	111	109	103	110	107	CxN _r	ns 1.4
H4	105	116	108	115	110	106	113	110	111	107	HxCxN _r	ns 3.2

Table 2.22 Grass WSC concentration (g/kg DM) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C) N rate (N _r)	Aberdart					Fennema					Statistical summary	
	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001												
H1	242	214	191	164	164	242	207	179	164	153	H	*** 3.2
H2	240	201	171	147	128	233	168	174	136	132	N _r	*** 3.0
H3	217	185	149	138	127	185	164	141	122	122	C	*** 1.9
H4	202	162	148	137	135	181	154	134	116	123	Y	** 2.0
2003												
H1	275	247	209	188	169	238	235	196	175	156	HxN _r	*** 6.2
H2	173	168	132	106	106	185	116	111	110	92	HxC	ns 4.2
H3	175	161	155	149	157	153	156	162	143	143	CxN _r	ns 4.2
H4	180	145	140	132	137	160	141	134	132	136	HxCxN _r	ns 8.7

Table 2.23 Grass buffering capacity (mEq/kgDM) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C) N rate (N _r)	Aberdart					Fennema					Statistical summary	
	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001												
H1	367	417	429	466	463	384	442	485	473	493	H	* 9.0
H2	286	381	352	441	402	305	361	392	411	400	N _r	*** 3.1
H3	299	367	427	437	438	338	393	421	440	413	C	** 2.0
H4	352	394	457	472	457	360	405	450	465	445	Y	*** 2.6
2003												
H1	188	214	234	270	264	210	225	250	291	277	HxN _r	* 10.5
H2	270	290	309	362	367	267	314	352	367	370	HxC	* 9.4
H3	229	265	298	297	312	261	264	276	309	298	CxN _r	ns 4.4
H4	344	316	371	332	351	291	320	354	354	379	HxCxN _r	** 12.2

Table 2.24 Grass nitrate concentration (g/kgDM) in Aberdart and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C) N rate (N _r)	Aberdart					Fennema					Statistical summary	
	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.
2001												
H1	0	0	0.28	1.72	1.89	0	0.14	0.43	1.93	2.83	H	*** 0.130
H2	0.02	0.08	0.26	2.22	2.68	0	0.46	0.41	1.67	2.67	N _r	*** 0.120
H3	0	0.06	1.90	2.34	3.51	0.08	0.21	2.07	3.94	3.54	C	* 0.076
H4	0.06	.041	2.57	3.11	3.02	0.03	0.94	3.31	3.46	3.45	HxN _r	*** 0.251
											HxC	ns 0.169
											CxN _r	ns 0.169
											HxCxN _r	ns 0.346

Table 2.25 Grass pH in Aberdard and Fennema swards at each harvest (H) (Experiment 2.2).

Cultivar (C)	Aberdard					Fennema					Statistical summary		
	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	N ₀	N ₄₀	N ₈₀	N ₁₂₀	N ₁₆₀	Sig.	s.e.	
2001													
H1	6.1	6.2	6.3	6.4	6.4	6.1	6.2	6.4	6.5	6.6	H	***	0.03
H2	5.8	6.0	6.0	6.2	6.1	5.8	6.0	6.1	6.1	6.0	N _r	***	0.02
H3	5.7	6.0	6.0	6.1	6.1	5.7	6.0	6.1	6.1	6.0	C	***	0.01
H4	5.8	6.0	6.1	6.1	6.1	5.9	6.1	6.1	6.1	6.1	Y	***	0.02
2003											HxN _r	ns	0.05
H1	5.3	5.3	5.4	5.5	5.4	5.2	5.6	5.8	5.7	5.6	HxC	ns	0.03
H2	5.2	5.3	5.6	5.7	5.7	5.3	5.5	5.5	5.8	5.7	CxN _r	ns	0.03
H3	5.6	5.8	5.6	5.9	5.9	5.6	5.8	6.0	6.0	6.0	HxCxN _r	ns	0.06
H4	5.8	6.0	6.1	6.1	6.1	6.0	6.1	6.2	6.2	6.2			

Table 2.26. Effects of grass cultivar and rate of N fertiliser application on grass composition (Experiment 2.2).

		DM g/kg	C.protein g/kgDM	DMD g/kg	Ash g/kgDM	WSC g/kgDM	Buf. cap. mEq/kgDM	pH	Nitrate g/kgDM
Aberdard	N ₀	198	132	808	103	213	292	5.65	0.02
	N ₄₀	169	153	792	105	185	330	5.83	0.13
	N ₈₀	158	180	796	107	162	359	5.87	1.25
	N ₁₂₀	150	206	794	108	145	385	5.99	2.35
	N ₁₆₀	148	218	790	108	140	382	5.97	2.78
Fennema	N ₀	199	133	810	101	197	302	5.69	0.03
	N ₄₀	172	159	794	104	167	340	5.91	0.44
	N ₈₀	159	184	798	104	154	372	6.02	1.55
	N ₁₂₀	149	209	790	107	137	389	6.05	2.75
	N ₁₆₀	147	221	791	106	132	384	6.02	3.12
Cultivar (C)	s.e.	0.9	1.2	1.1	0.6	1.9	2.0	0.014	0.076
	Sig.	ns	*	ns	*	***	**	***	*
Rate of N (N _r)	s.e.	1.5	1.8	1.7	1.0	3.0	3.1	0.021	0.120
	Sig.	***	***	***	***	***	***	***	***
Harvest (H)	s.e.	2.9	2.4	2.2	1.9	3.2	9.0	0.027	0.130
	Sig.	***	***	***	***	***	*	***	***
Year (Y)	s.e.	0.9	1.1	1.1	0.6	2.0	2.6	0.015	
	Sig.	***	ns	***	***	**	***	***	
C x N _r	s.e.	2.1	2.6	2.5	1.4	4.2	4.4	0.030	0.169
	Sig.	ns	ns	ns	ns	ns	ns	ns	ns
C x H	s.e.	3.2	2.9	2.7	2.1	4.2	9.4	0.033	0.169
	Sig.	ns	ns	ns	ns	ns	*	ns	ns
C x Y	s.e.	1.3	1.6	1.5	0.8	2.7	3.2	0.021	
	Sig.	*	ns	ns	ns	ns	ns	*	
N _r x H	s.e.	3.9	4.1	3.8	2.6	6.2	10.5	0.047	0.251
	Sig.	***	***	***	ns	***	*	ns	***
N _r x Y	s.e.	2.0	2.5	2.4	1.3	4.3	5.1	0.032	
	Sig.	ns	*	ns	***	*	***	ns	
H x Y	s.e.	3.1	2.8	2.7	2.1	4.3	10.0	0.035	
	Sig.	***	***	***	***	***	***	***	
C x N _r x H	s.e.	4.8	5.5	5.1	3.2	8.7	12.2	0.063	0.346
	Sig.	*	ns	ns	ns	ns	**	ns	ns
C x N _r x Y	s.e.	2.8	3.5	3.5	1.9	6.1	7.2	0.046	
	Sig.	ns	ns	ns	ns	ns	ns	ns	
C x H x Y	s.e.	3.6	3.6	3.5	2.4	5.7	10.7	0.045	
	Sig.	ns	ns	ns	ns	ns	ns	ns	
N _r x H x Y	s.e.	4.8	5.3	5.1	3.1	8.8	13.3	0.068	
	Sig.	***	***	***	ns	ns	ns	ns	
C x N _r x H x Y	s.e.	6.2	7.3	7.1	4.1	12.3	16.8	0.094	
	Sig.	ns	ns	ns	ns	ns	ns	ns	

Experiment 2.3: The influence of the form of N fertiliser on yield and chemical composition of *Lolium perenne* L. selected for high water-soluble carbohydrate concentration

Introduction

N application increases grass growth leading to higher forage yields at subsequent stages of growth. It can simultaneously modify the nutritive value and ensilability of grass managed for silage production. The availability, form and quantity of plant available N varies among fertilisers. This experiment examined the effects of three forms of N fertiliser on the yield and chemical composition of two perennial ryegrass cultivars, managed for silage production.

Materials and Methods

The experiment had six complete replicate blocks, each with six 20 m² plots. Two intermediate perennial ryegrass cultivars (Aberdart: selected for high water-soluble carbohydrate (WSC) concentration, and Fennema: control) and three N fertiliser treatments (CAN: 275g N/kg, urea: 460 g N/ kg and slow release N (SRN): 210 g isobutylidene diurea N/kg and 30 g urea N/kg (Floramid 32, BASF) plus 115 g urea N/kg) were fully randomised within each block. Plots were sown by hand on 11 September 2000 at a rate of 4 g seed/m². The three N fertiliser treatments were applied at rates equivalent to 115 and 94 kg N/ha on 16 March and 30 May 2001, respectively. All plots received 0.494 kg compound fertiliser (0-7-30 N-P-K) on 16 March 2001 and after each harvest. Plots were harvested using a Haldrup plot harvester on 29 May, 9 July and 27 August 2001. Chemical analyses were carried out according to Mc Namara *et al.* (2002) except for WSC concentration which was estimated using NIRS (as per operated by IGER). Data from each individual harvest were subjected to two-way analysis of variance for a randomised complete block 2x3 factorial design. The individual treatment means were separated using the least significant difference procedure.

Results and Discussion

Treatment effects are presented in Tables 2.27-2.30. The form of N input had no effect ($P>0.05$) on grass dry matter (DM) yields in the primary growth (cut 1) and regrowth 1 (cut 2), but CAN and SRN gave higher ($P<0.05$) yields than urea in regrowth 2 (cut 3). In regrowth 3 (cut 4), SRN gave a higher yield than the other two forms of N. Fennema produced 0.13 (771 kg DM/ha) ($P<0.001$) more DM than Aberdart in the primary growth, but there was no difference ($P>0.05$) in regrowths 1 or 2. In regrowth 3, Aberdart had a higher DM yield than Fennema. Reproductive growth (cut 1) accounted for most of the total yield and consequently, overall, Fennema had 0.05 (599 kg DM/ha) higher total yield than Aberdart. Neither form of N input nor cultivar had any effect ($P>0.05$) on the *in vitro* organic matter digestibility (OMD) of the grass, except in regrowth 3 where Aberdart had a higher OMD than Fennema. Form of N input had no effect ($P>0.05$) on WSC concentration in the primary growth or regrowth 1, but in regrowth 2 and 3 SRN had a lower ($P<0.01$) concentration than CAN or urea. Form of N had no effect on WSC concentration in the primary growth or regrowth 1, while SRN was associated with a lower value than either of the other two forms of N in regrowths 2 or 3. There was no difference ($P>0.05$) between cultivars in WSC concentration in the primary growth, but in regrowths 1, 2 and 3 Aberdart had a higher ($P<0.01$) concentration than Fennema. CAN had the highest ($P<0.01$) crude protein concentration in regrowth 1 and SRN the highest ($P<0.001$) in regrowths 2 and 3. There was an interaction ($P<0.01$) between form of N input and cultivar for crude protein concentration in the primary growth. Fennema had a higher ($P<0.05$) crude protein concentration than Aberdart in regrowth 1, but there was no difference ($P>0.05$) in regrowth 2. Buffering capacity was not affected by form of N in the primary growth or regrowth 1, but in regrowth 2 SRN had the highest buffering capacity while in regrowth 3 SRN and CAN had the higher values. Only in the primary growth did grass cultivar influence buffering capacity, with Fennema having a higher value than Aberdart. SRN was associated with the lowest DM concentration in regrowths 2 and 3, while Aberdart had a higher DM than Fennema in regrowth 2. The only treatment effect on ash concentration was in regrowth 1 where Aberdart had a higher ($P<0.01$) content than Fennema.

Conclusions

Applying a slow release form of N fertiliser to grass grown for first or second cut silage did not alter DM yield, digestibility or ensilability indices, compared to the more conventional fast release forms of N fertiliser. However, it did result in some carryover effects to a subsequent growth. The effects were similar with both grass cultivars.

References

McNamara, K., O'Kiely, P., Whelan, J. Forristal, P.D. and Lenehan, J.J. (2002). Simulated bird damage to the plastic stretch film surrounding baled silage and its effects on conservation characteristics. *Irish Journal of Agricultural and Food Research*, 41 (1): 29-41.

Table 2.27. Chemical composition and yield of primary growth (cut 1) of grasses in Experiment 2.3 (Form of N fertiliser)

	Yield tDM/ha	DM g/kg	pH	Crude protein g/kgDM	Ash g/kgDM	OMD g/kg	B.capacity mEq/kgDM	WSC g/kgDM	NO ₃ g/kgDM
Grass cultivar main effect									
Aberdart	5823	169	6.37	158	99	709	417	154	0.51
Fennema	6594	166	6.38	150	99	711	431	149	0.66
Form of N main effect									
CAN	6183	168	6.42	154	99	708	427	153	0.75
Urea	6230	168	6.38	155	99	710	425	152	0.52
SRN	6213	166	6.34	153	99	713	420	150	0.49
Individual treatment effects									
Ab._CAN	5861	169	6.43	155	100	705	419	157	0.61
Ab._Urea	5750	166	6.37	164	99	710	422	152	0.51
Ab._SRN	5860	170	6.32	154	98	713	411	154	0.43
Fen._CAN	6506	166	6.40	154	98	711	435	149	0.90
Fen._Urea	6710	170	6.38	146	98	710	428	152	0.53
Fen._SRN	6567	162	6.37	152	100	714	429	145	0.55
s.e.m.									
Cultivar	102.7	3.0	0.026	1.4	1.4	3.1	3.7	2.5	0.065
Form of N	125.7	3.7	0.032	1.8	1.7	3.8	4.6	3.1	0.080
Cult. x N	177.8	5.2	0.045	2.5	2.4	5.4	6.4	4.4	0.113
Significance									
Cultivar	<0.001	0.531	0.764	0.002	0.920	0.582	0.017	0.152	0.131
Form of N	0.966	0.950	0.264	0.728	0.949	0.619	0.502	0.754	0.056
Cult. x N	0.648	0.518	0.650	0.004	0.762	0.792	0.622	0.517	0.496

Table 2.28. Chemical composition and yield for regrowth 1 (cut 2) of grasses in Experiment 2.3 (Form of N fertiliser)

	Yield tDM/ha	DM g/kg	pH	Crude protein g/kgDM	Ash g/kgDM	OMD g/kg	B.capacity mEq/kgDM	WSC g/kgDM	NO ₃ - g/kgDM
Grass cultivar main effect									
Aberdart	2902	136	6.27	207	117	806	472	137	2.82
Fennema	2735	134	6.21	221	112	804	470	123	2.91
Form of N main effect									
CAN	2865	132	6.23	228	114	806	476	124	3.02
Urea	2714	137	6.26	213	115	803	474	133	2.90
SRN	2876	136	6.23	200	114	806	462	132	2.67
Individual treatment effects									
Ab._CAN	2952	133	6.23	219	117	809	473	130	3.00
Ab._Urea	2787	139	6.27	206	117	803	474	139	2.84
Ab._SRN	2966	138	6.30	196	116	808	469	143	2.62
Fen._CAN	2779	131	6.22	238	111	803	479	118	3.05
Fen._Urea	2641	136	6.25	221	113	803	475	127	2.95
Fen._SRN	2786	134	6.15	204	112	805	455	122	2.73
s.e.m.									
Cultivar	61.8	1.9	0.020	4.1	1.1	2.5	5.4	3.5	0.163
Form of N	75.7	2.3	0.025	5.0	1.3	3.0	6.7	4.3	0.200
Cult. x N	107.1	3.3	0.035	7.1	1.9	4.3	9.4	6.0	0.283
Significance									
Cultivar	0.069	0.313	0.042	0.027	0.008	0.442	0.759	0.006	0.692
Form of N	0.258	0.263	0.554	0.002	0.936	0.715	0.273	0.289	0.465
Cult. x N	0.986	0.913	0.109	0.727	0.768	0.853	0.546	0.737	0.993

Table 2.29. Chemical composition and yield for regrowth 2 (cut 3) of grasses in Experiment 2.3 (Form of N fertiliser)

	Yield tDM/ha	DM g/kg	pH	Crude protein g/kgDM	Ash g/kgDM	OMD g/kg	B.capacity mEq/kgDM	WSC g/kgDM	NO ₃ - g/kgDM
Grass cultivar main effect									
Aberdart	2889	173	5.88	159	112	796	379	164	0.16
Fennema	2883	166	5.87	157	112	795	373	148	0.63
Form of N main effect									
CAN	2951	172	5.84	156	111	797	371	163	0.37
Urea	2730	176	5.82	150	111	800	361	163	0.25
SRN	2978	162	5.97	169	115	790	397	141	0.58
Individual treatment effects									
Ab._CAN	2955	176	5.83	156	111	801	372	173	0.09
Ab._Urea	2774	179	5.80	150	110	805	367	178	0.04
Ab._SRN	2939	164	6.00	172	116	784	399	141	0.36
Fen._CAN	2946	167	5.85	156	110	793	370	153	0.65
Fen._Urea	2686	172	5.83	151	113	796	355	148	0.46
Fen._SRN	3018	160	5.93	165	114	796	395	142	0.79
s.e.m.									
Cultivar	58.2	1.7	0.021	2.1	1.1	2.9	4.9	3.1	0.136
Form of N	71.3	2.1	0.025	2.6	1.3	3.6	5.9	3.7	0.167
Cult. x N	100.8	2.9	0.036	3.7	1.9	5.1	8.4	5.3	0.236
Significance									
Cultivar	0.944	0.009	0.850	0.562	0.915	0.721	0.408	0.001	0.022
Form of N	0.041	<0.001	0.001	<0.001	0.061	0.132	0.001	<0.001	0.386
Cult. x N	0.713	0.631	0.336	0.527	0.338	0.095	0.825	0.028	0.952

Table 2.30. Chemical composition and yield for regrowth 3 (cut 4) of grasses in Experiment 2.3 (Form of N fertiliser)

	Yield tDM/ha	DM g/kg	pH	Crude protein g/kgDM	Ash g/kgDM	OMD g/kg	B.capacity mEq/kgDM	WSC g/kgDM	NO ₃ - g/kgDM
Grass cultivar main effect									
Aberdart	1475	162	5.72	203	118	790	355	137	0.17
Fennema	1376	163	5.77	202	117	780	364	124	0.51
Form of N main effect									
CAN	1353	166	5.73	201	116	787	362	134	0.30
Urea	1386	164	5.73	199	118	785	345	133	0.35
SRN	1537	157	5.78	209	118	782	371	124	0.37
Individual treatment effects									
Ab._CAN	1410	168	5.70	199	116	790	350	142	0.25
Ab._Urea	1417	162	5.70	200	121	790	339	136	0.08
Ab._SRN	1597	157	5.77	211	117	790	375	133	0.17
Fen._CAN	1296	164	5.77	204	117	785	374	126	0.35
Fen._Urea	1356	167	5.75	197	116	781	350	130	0.61
Fen._SRN	1477	157	5.80	206	119	774	367	115	0.56
s.e.m.									
Cultivar	18.3	1.3	0.019	1.7	0.8	2.5	4.3	1.8	0.116
Form of N	22.4	1.6	0.023	2.1	1.0	3.0	5.2	2.2	0.143
Cult. x N	31.7	2.2	0.033	3.0	1.4	4.2	7.4	3.0	0.202
Significance									
Cultivar	0.001	0.776	0.076	0.754	0.622	0.010	0.147	<0.001	0.049
Form of N	<0.001	0.001	0.182	0.008	0.271	0.432	0.005	0.003	0.940
Cult. x N	0.585	0.149	0.881	0.196	0.051	0.445	0.095	0.115	0.549

3. Forage conservation

In this section nine studies were conducted involving the use of laboratory silos and a specialised aerobic stability assessment facility. In each experiment a grass of elevated (Aberdart) and normal (Fennema) WSC genotype were ensiled. In eight experiments the grasses were ensiled following 0h or 24h wilting (Experiment 3.4 was the exception) and in all experiments an array of contrasting additive treatments was used. The latter were chosen on the basis of their contrasting modes of action and likelihood of restricting WSC metabolism either during ensilage or during post-ensilage exposure to air (i.e. feedout).

Experiments 3.1-3.3 (Experiments 1-3 of 2001). Fermentation and aerobic stability of perennial ryegrass selected for high water-soluble carbohydrate concentration and ensiled unwilted or wilted and with various additive treatments.

Introduction

Ensiling grasses with elevated water-soluble carbohydrate (WSC) concentrations may lead to improvements in silage preservation and nutritive value, but a reduction in aerobic stability. These experiments determined the effects on fermentation and aerobic stability of ensiling perennial ryegrasses, with high or normal WSC genotypes, wilted or unwilted with various additives applied.

Materials and methods

Grass from Aberdart (Aber; selected for high WSC concentration) and Fennema (Fenn; normal WSC concentration) swards were precision-chopped unwilted (22 May (Experiment 3.1), 3 July (Experiment 3.2) and 28 Aug. (Experiment 3.3) or after a 24 h wilt. Six kg (excluding additive) of each grass was ensiled separately in

laboratory silos (> 100 days) with the following additive treatments applied: none (Noadd), Add-SafeR (85% ammonium tetraformate salt) at 3 (Add-lo) or 6 (Add-hi) ml/kg grass, Kofasil Ultra (80 g hexamine, 120 g sodium nitrite, 150 g sodium benzoate, 50 g sodium propionate and 600 g water/kg) at 2.5 (Kofa-lo) or 5 (Kofa-hi) ml/kg grass, *Lactobacillus buchneri* (Lbuch) at 3 ml/kg grass and a *Lactobacillus plantarum* plus *Lactococcus lactis* mixture (Lmix) at 3 ml/kg grass. Three replicate silos were used per treatment combination. Silage aerobic stability was assessed in duplicate for each treatment combination. Chemical composition data and aerobic stability results for each experiment were subjected to analysis of variance for 2 x 2 x 7 and 2 x 7 factorial design, respectively.

Results and discussion

The chemical composition of either unwilted (U) or wilted (W) Aber and Fenn swards at ensiling were quite similar (Table 3.1). Noadd treatments underwent lactic acid fermentation in Experiment 3.1 and 3.3, but clostridial fermentation in Experiment 3.2 (Table 3.2). Aber Noadd silages had ($P<0.05$) a higher and lower pH than their comparable Fenn treatments in Experiments 3.1 and 3.3, respectively. Noadd Aber W silages had ($P<0.05$) higher WSC but less aerobic stability than Fenn Noadd W silages in Experiments 3.1 and 3.3. Wilted Noadd silages had higher ($P<0.05$) WSC than U silages in Experiment 3.1 and overall tended to be more stable. The effects of applying an additive were inconsistent with numerous significant interactions detected. However Add-lo, Add-hi, Kofa-lo and Kofa-hi silages had higher mean WSC concentrations than their comparable controls in Experiment 3.1. Absolute differences in WSC between additive treatments in Experiments 3.2 and 3.3 were modest.

Conclusions

Absolute differences between Aberdart and Fennema silages ensiled with no additives were minimal. Wilting and/or selective additive use modified the fermentation and aerobic stability characteristics.

Table 3.1. Mean (s.d.) chemical composition of unwilted (U) and wilted (W) swards at ensiling in Experiments 3.1, 3.2 and 3.3.

Experiment	Cultivar & harvest	3.1		3.2		3.3	
		Aberdart	Fennema	Aberdart	Fennema	Aberdart	Fennema
Dry matter (DM) (g/kg)	U	130 (7.2)	131 (5.0)	132 (5.8)	126 (7.7)	131 (3.0)	123 (2.6)
	W	379 (5.8)	352 (13.9)	151 (3.8)	140 (3.4)	242 (6.5)	257 (7.9)
WSC (g/kgDM)	U	162 (6.0)	148 (7.9)	147 (7.0)	129 (4.2)	170 (7.0)	155 (2.5)
	W	177 (4.7)	163 (8.9)	106 (4.6)	84 (7.5)	151 (7.4)	137 (3.5)
Buffering capacity (mEQ/kg DM)	U	488 (3.7)	489 (17.1)	550 (3.9)	558 (6.9)	442 (2.4)	460 (8.0)
	W	478 (5.0)	486 (11.9)	513 (10.3)	528 (18.5)	481 (13.1)	522 (27.4)
Nitrates (mg/l)	U	250 (0.0)	250 (0.0)	500 (0.0)	500 (0.0)	342 (106.0)	433 (0.0)
	W	250 (0.0)	250 (0.0)	500 (0.0)	500 (0.0)	211 (0.0)	333 (129.0)
<i>In vitro</i> DM digestibility (g/kg)	U	799 (4.9)	800 (5.2)	778 (6.1)	782 (8.6)	786 (3.3)	793 (10.6)
	W	777 (6.4)	776 (9.8)	750 (10.3)	748 (10.2)	703 (8.9)	712 (13.7)

Table 3.2. Silage chemical composition and aerobic stability of Aberdard (aber) and Fennema (fen) swards ensiled unwilted (U) or wilted (W) with various additive treatments in Experiments 3.1, 3.2 and 3.3.

Experiment	Additive (A) Cultivar (C)	Noadd		Add-lo		Add-hi		Kofa-lo		Kofa-hi		Lbueh		Lmix		D	C	A	CxA	DxC	DxA	DxC	s.e.
		aber	fen	aber	fen	aber	fen	aber	fen	aber	fen	aber	fen	aber	fen								
3.1	U	51	118	130	128	99	99	87	120	88	93	43	43	146	99	***	***	***	***	ns	***	***	3.6
	W	69	85	60	76	41	55	74	81	68	68	79	90	91	101	***	***	***	***	ns	***	***	2.1
	U	95	92	93	101	110	117	91	92	85	91	98	113	48	80	***	***	***	***	ns	***	***	2.2
	W	62	71	64	78	67	83	68	73	70	75	60	68	40	46	***	***	***	*	***	*	***	2.2
	U	14	15	33	25	44	36	16	20	65	61	15	14	34	16	***	***	***	*	***	*	***	0.03
	W	57	40	35	62	93	73	63	53	72	69	23	22	48	40	***	ns	***	***	ns	***	***	0.50
	U	4.6	4.3	4.0	4.0	4.0	4.5	4.4	4.4	4.5	4.4	4.5	4.7	4.9	3.9	4.4	4.1	4.1	4.1	4.1	4.1	4.1	0.89
	W	4.5	4.3	4.5	4.3	4.5	4.4	4.4	4.4	4.5	4.5	4.5	4.5	4.3	4.0	4.1	4.1	4.1	4.1	4.1	4.1	4.1	5.6
	U	8.0	5.0	6.0	6.0	5.5	7.0	6.0	6.5	3.5	4.5	5.0	5.0	4.5	3.0	4.5	-	ns	***	***	-	-	0.42
	W	7.0	10.0	10.0	11.0	13.0	12.5	13.5	12.0	14.0	11.0	15.0	10.5	10.5	5.0	3.5	-	ns	***	ns	-	-	7.9
3.2	U	4	14	4	2	14	1	4	2	24	14	5	23	33	21	-	ns	***	***	-	-	-	1.5
	W	4	2	2	1	1	0	2	1	2	1	2	3	5	18	-	ns	***	***	-	-	-	4.7
	U	40	12	147	100	116	89	163	102	128	103	23	15	25	10	***	***	***	***	***	***	***	1.7
	W	12	14	100	112	112	36	104	13	117	29	12	12	14	13	***	***	***	***	***	*	ns	20.9
	U	163	224	92	116	109	117	74	127	71	73	194	208	175	224	***	***	***	***	***	*	ns	1.3
	W	268	619	145	514	137	418	129	482	99	266	211	638	213	654	*	***	***	***	ns	***	ns	0.06
	U	5	11	15	14	14	11	12	9	28	21	10	3	6	4	-	ns	***	***	***	***	***	0.39
	W	5	10	6	6	17	9	8	9	24	10	8	9	8	6	***	***	***	***	***	***	***	0.27
	U	5.0	5.3	4.0	4.4	4.0	4.2	4.1	4.7	4.3	4.4	5.1	5.3	5.1	5.5	5.3	5.3	5.3	5.3	5.3	5.3	5.3	2.3
	W	5.5	5.4	4.5	5.6	4.1	5.5	4.7	5.9	4.5	6.2	5.5	5.4	5.4	5.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	1.7
3.3	U	6.5	5.5	6.5	5.5	3.0	4.0	4.5	6.5	3.5	3.5	6.0	5.0	5.0	6.0	-	ns	***	***	-	-	-	2.3
	W	6.5	11.0	5.0	7.5	6.0	7.0	6.5	6.5	8.0	4.0	5.0	11.0	5.0	11.0	-	ns	***	ns	-	-	-	1.7
	U	2	2	2	3	12	10	8	2	14	11	2	7	6	2	-	ns	***	***	-	-	-	2.3
	W	2	1	4	1	2	1	0	2	1	18	7	1	7	1	-	ns	***	***	-	-	-	1.7
	U	151	131	132	127	85	81	123	132	112	110	143	110	150	136	***	***	***	*	ns	*	ns	4.5
	W	134	121	111	111	99	92	110	121	100	127	120	126	127	73	***	***	***	***	***	***	***	2.3
	U	66	79	84	83	111	110	79	77	80	83	69	92	47	73	***	***	***	***	***	***	***	1.2
	W	92	96	104	95	116	109	95	91	104	103	91	93	85	92	ns	ns	ns	ns	ns	ns	ns	0.03
	U	13	14	20	15	16	22	17	14	27	18	16	11	22	13	ns	ns	ns	ns	ns	ns	ns	0.69
	W	16	8	20	20	24	32	11	8	10	17	7	7	20	20	***	***	***	***	***	***	***	0.42
days to TR	U	3.9	4.1	3.9	4.0	4.0	4.1	4.2	4.1	4.2	4.2	4.0	4.3	3.9	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	0.69
	W	4.2	4.3	4.2	4.2	4.2	4.2	4.4	4.2	4.4	4.5	4.5	4.2	4.4	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	0.42
	U	2.0	4.5	2.5	2.5	4.0	3.0	2.5	2.0	2.5	2.0	2.0	2.0	2.0	2.5	-	ns	ns	ns	ns	ns	ns	7.9
	W	5.0	8.0	3.0	8.0	7.5	7.0	1.5	9.0	9.0	8.5	2.5	4.5	1.5	2.0	-	ns	ns	ns	ns	ns	ns	2.5
	U	38	14	23	21	11	19	25	23	19	12	38	36	47	26	-	ns	ns	ns	ns	ns	ns	2.5
	W	6	2	21	2	3	2	34	2	1	2	31	14	72	31	-	ns	ns	ns	ns	ns	ns	2.5
	U	6	2	21	2	3	2	34	2	1	2	31	14	72	31	-	ns	ns	ns	ns	ns	ns	2.5
	W	6	2	21	2	3	2	34	2	1	2	31	14	72	31	-	ns	ns	ns	ns	ns	ns	2.5

days to TR = days to temperature rise; ATR to d5 = accumulated temperature rise to day 5; D = dry matter (i.e. unwilted or wilted); s.e. = standard error of the mean for CxA.

Experiment 3.4 (Experiment 4 of 2001): Autumn conservation of perennial ryegrass selected for high water-soluble carbohydrate concentration with different additives applied

Introduction

Ensiling grasses with elevated water-soluble carbohydrate (WSC) concentrations may improve silage preservation and nutritive value, but reduce aerobic stability. This experiment determined the effects of specific additives on the autumn conservation characteristics of perennial ryegrass of high and normal WSC genotype ensiled unwilted in laboratory silos.

Materials and Methods

Grass from Aberdart (AB; selected for high WSC concentration) and Fennema (FN; control) were precision-chop harvested on 31 October. Six kg (excluding additive) of each grass were ensiled separately in laboratory silos for 100 days with the following additive treatments applied: none (NOadd), ammonium tetraformate salt (850 g/kg; Add-SafeR) at 3 (AT-lo) or 6 (AT-hi) ml/kg grass, a mixture of hexamine (80 g/kg), sodium nitrite (120 g/kg), sodium benzoate (150 g/kg), sodium propionate (50 g/kg) and water (600 g/kg) (Kofasil Ultra) at 2.5 (MIX-lo) or 5 (MIX-hi) ml/kg grass, *Lactobacillus buchneri* (LB) at 3 ml/kg grass and a *Lactobacillus plantarum* plus *Lactococcus lactis* mixture (LP+LL) at 3 ml/kg grass. Three replicate silos were used per treatment combination. Silage aerobic stability was assessed in duplicate for each treatment combination. Data were subjected to analysis of variance for a 2 x 7 factorial arrangement with complete randomisation.

Results and Discussion

The mean (s.d.) composition of AB at ensiling was: dry matter (DM) 107 (0.8) g/kg, DM digestibility 772 (7.9) g/kg, crude protein (CP) 266 (4.7) g/kg DM, WSC 101 (10.0) and buffering capacity 460 (10.3) mEq/kg DM. The corresponding values for FN were 117 (3.0) g/kg, 770 (14.0) g/kg, 257 (4.0) g/kg DM, 96 (3.5) g/kg DM and 428 (11.0) mEq/kg DM. When ensiled with NOadd both cultivars preserved badly (Table 3.3). Both LB and LP+LL failed to improve preservation. Both rates of AT and MIX markedly improved preservation and ($P < 0.05$) silage DM recovery rates relative to NOadd. Silages from MIX-hi had the highest ($P < 0.05$) WSC concentrations. Applying an additive did not improve ($P > 0.05$) aerobic stability (days to TR) for either cultivar relative to their respective NOadd treatments. Ensiling FN with MIX-hi, LB or LP+LL worsened ($P < 0.05$) stability relative to NOadd. Aerobic losses (ATR to d5) relative to NOadd were greater ($P < 0.05$) with AT-lo for AB and with LB and LP+LL for FN. For each additive there were no marked differences between cultivars in preservation, but AB had ($P < 0.05$) lower WSC and higher CP concentrations than FN across all additives. Aerobic stability, aerobic losses and DM recovery rates were similar overall, but there were cultivar differences ($P < 0.05$) depending on additive.

Conclusions

The conservation characteristics of perennial ryegrass of high WSC genotype, ensiled in autumn without wilting or additive application, were similar to the control cultivar. Contrasting additives each had a similar effect on the preservation of both cultivars but altered aerobic stability.

Table 3.3. Silage chemical composition and aerobic stability of Aberdart (AB) and Femema (FN) swards ensiled unwilted and with various additive treatments in Experiment 3.4.

Additive (A) Cultivar (C)	NOadd		AT-lo		AT-hi		MIX-lo		MIX-hi		LB		LP+LL		Statistical summary			
	AB	FN	AB	FN	AB	FN	AB	FN	AB	FN	AB	FN	AB	FN	C	A	CxA	s.e.
DM (g/kg)	149	149	154	151	153	152	155	156	159	153	151	144	146	150	ns	**	*	1.8
WSC ¹	9	12	9	16	10	16	15	12	28	56	11	10	10	22	**	**	ns	4.8
Cp ¹	243	226	259	243	263	251	258	247	255	246	248	222	244	228	**	**	ns	4.1
pH	5.2	5.3	4.6	4.2	4.5	4.3	4.4	4.5	4.2	4.4	5.2	5.4	5.3	5.2	ns	**	ns	0.1
Lactic acid ¹	13	12	61	102	54	65	101	79	101	78	11	11	10	33	ns	**	ns	10.6
Acetic acid ¹	77	81	48	28	32	27	37	49	21	13	77	80	77	55	ns	**	ns	8.1
Propionic acid ¹	9.4	9.7	5.0	2.0	2.8	0.9	3.2	3.8	1.4	0.6	9.0	9.3	9.0	6.0	*	**	ns	0.9
Butyric acid ¹	0	1.7	0	1.8	3.3	2.2	0	0	0	0	6.2	0.9	11.9	*	ns	ns	2.5	
Ammonia-N ²	163	196	128	113	137	138	97	101	87	85	164	205	169	175	ns	**	ns	14.4
Recovery ³	814	811	887	900	913	895	908	893	926	864	821	828	851	853	ns	**	*	11.0
Days to TR ⁴	4.0	4.5	3.0	5.0	3.5	5.0	4.0	4.0	3.0	3.0	4.5	3.0	4.0	3.0	ns	*	**	0.3
ATR to d5 ⁵	12	7	31	8	14	9	15	14	15	16	10	20	10	26	ns	ns	**	3.4

¹g/kg DM; ²g/kg N; ³g silage DM/kg grass DM ensiled; ⁴days to temperature rise; ⁵accumulated temperature rise (°C) to day 5

Experiments 3.5 (Experiment 1 of 2002): The fermentation and aerobic stability of unwilted and wilted perennial ryegrass cultivars ensiled using contrasting additive treatments

Introduction

A high sugar content in grass greatly favours successful ensiling (Lunden Pettersson, Lindgren., 1990.), albeit potentially predisposing the silage to aerobic instability at feedout. The objectives of this experiment were to investigate the effects of additives selected to favour dominance of lactic acid bacteria on the fermentation characteristics and susceptibility to aerobic spoilage of silages produced from grasses (unwilted and wilted) differing in sugar content.

Materials and Methods

Aberdart (Ab) (selected for high water-soluble carbohydrate (WSC) concentration) and Fennema (Fn) (normal WSC concentration) perennial ryegrass swards were precision chopped on 8 August 2002. Grass was ensiled unwilted or after a 24 hour wilt. Units of 6 kg of each grass, both unwilted and wilted, were randomly allocated among eight additive treatments with three replicates per treatment. The treatments were: (1) no additive, (2) Add-SafeR (85% ammonium tetraformate salt) at 6ml/kg grass, (3) *Lactobacillus buchneri* at 3ml/kg grass, (4) Powerstart (*Lactobacillus plantarum* and *Lactococcus lactis*) at 3ml/kg grass, (5) and (6) Kofasil Ultra (80g hexamine, 120g sodium nitrite, 150g sodium benzoate, 50g sodium propionate and 600g water/kg) at 2.5 or 5 ml/kg grass, (7) Powerstart at 3ml/kg plus Kofasil Ultra at 2.5ml/kg and (8) Powerstart at 3ml/kg plus Kofasil Ultra at 5ml/kg. Silos were filled, sealed and stored for > 100 days. When opened silage compositional analyses and aerobic stability measurements were made. These results were subjected to analysis of variance for 2 x 2 x 8 and 2 x 8 factorial arrangement of treatments, respectively.

Results and Discussion

The mean (s.d.) composition of Ab and Fn at ensiling are summarised in Table 3.4. Both unwilted grasses were leafy (high OMD and relatively low NDF and ADF) and very wet, reflecting the prevailing weather conditions. Wilting conditions were bad, with herbage being still quite wet after 24h 'on the ground'. Herbage digestibility decreased and ash concentration increased during this 24h interval. WSC concentrations were much higher and buffering capacities lower in Aberdart compared to Fennema, indicating the former should be easier to preserve as silage. The bad wilting conditions resulted in an elevation in buffering capacity and a reduction in WSC, with the differences between varieties being maintained.

Table 3.4. Chemical composition (mean and s.d.) of grasses at ensiling in Experiment 3.5

	Unwilted				Wilted			
	Aberdart		Fennema		Aberdart		Fennema	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
DM (g/kg)	169	3.9	144	4.0	175	2.1	156	2.1
pH	6.1	0.08	6.1	0.05	6.1	0.05	6.3	0.05
Ash (g/kg DM)	119	3.5	119	3.8	131	6.4	140	8.6
ADF(g/kg DM)	270	11.4	282	6.6	277	16.3	295	11.1
NDF(g/kgDM)	482	4.8	500	8.4	501	21.3	534	18.1
OMD(g/kg)	778	10.3	764	14.2	749	16.8	720	16.8
Buff. cap. (mEq/kgDM)	361	10.6	408	11.6	390	13.9	440	27.2
WSC (g/kgDM)	223	6.2	165	5.2	197	25.6	123	29.6

Table 3.5. Chemical composition and aerobic stability of unwilted (U) and wilted (W) silages in Experiment 3.5

Additive (A)	1		2		3		4		5		6		7		8		sem	C	A	CxA	
	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn					
Cultivar (C)	U	150	135	150	144	147	133	149	136	143	138	156	148	144	147	155	154	2.3	***	***	ns
DM (g/kg)	W	149	137	157	138	149	139	150	135	156	145	165	151	160	138	165	155				
pH	U	3.7	4.7	3.8	4.2	4.0	4.8	3.8	4.8	4.6	4.7	4.3	4.2	4.3	4.2	4.2	4.3	0.12	***	***	*
	W	5.4	5.1	4.2	5.0	5.2	5.1	4.8	5.1	4.3	5.4	4.5	4.9	4.1	5.4	4.5	4.6				
Lactic acid (g/kg DM)	U	174	25	98	67	122	9	159	23	58	44	87	87	83	91	93	83	10.2	***	***	***
	W	12	7	78	30	12	6	63	6	108	7	100	63	123	7	96	81				
NH ₃ -N (g/kg DM)	U	1.6	3.3	3.4	4.7	1.9	3.9	1.4	2.8	2.8	3.3	2.0	2.2	2.2	2.5	2.0	2.5	0.51	***	***	***
	W	5.6	9.4	4.8	10.2	4.5	9.4	3.7	9.6	2.6	6.0	2.8	4.5	2.3	7.9	3.1	3.2				
Butyric acid (g/kg DM)	U	1	0	0	3	0	1	0	0	0	0	0	0	0	2	0	1	4.8	***	***	***
	W	44	44	2	32	25	41	26	44	0	43	0	21	0	58	6	0				
DM recovery ¹	U	922	875	851	840	900	853	897	870	878	868	906	901	887	924	903	931	18.1	ns	***	*
	W	913	854	931	845	930	851	929	888	946	939	979	944	967	876	970	964		***	***	**
Duration to temp rise ²	U	28	169	166	118	31	193	28	193	172	193	35	90	117	36	45	44	13.6	***	***	***
	W	82	193	78	193	125	193	49	193	150	193	152	193	52	193	179	193	16.6	***	***	***
ATR to d5 ³	U	52	2	0	3	41	0	51	0	2	0	39	6	2	28	35	26	2.7	***	***	***
	W	9	0	0	1	1	0	24	1	0	0	1	0	19	0	0	0	3.8	***	**	***

¹ = g silage DM/kg grass DM ensiled ² = hours ³ = accumulated temperature rise to day 5 (°C) s.e.m. = CxA

Unwilted Aberdart underwent a lactic acid dominant fermentation whereas Fennema preserved poorly (but not a butyric fermentation) (Table 3.5). 'Wilting' resulted in a clostridial (high butyric acid and ammonia-N) fermentation with both grasses. Formic acid restricted fermentation with unwilted Aberdart and stimulated a lactic acid dominant fermentation with unwilted Fennema. It also stimulated greater lactic acid production and inhibition of Clostridia with the wilted forages, particularly Aberdart. *L.buchneri* reduced lactic acid concentrations in unwilted silage (particularly Aberdart) but had little impact on wilted silages. Powerstart had relatively minor effects on fermentation, although it did give some improvements with wilted Aberdart. Kofasil Ultra restricted fermentation with unwilted Aberdart, and stimulated a more lactic acid dominant fermentation (thereby inhibiting butyric acid) with unwilted Fennema or wilted Aberdart. The high rate of application was required with the wilted Fennema. There was a modest additive effect of Powerstart and Kofasil Ultra on fermentation. The aerobic stability of unwilted Aberdart was improved by formic acid and to a lesser extent by the low rate of Kofasil Ultra. For other treatments the interaction of standard of preservation and aerobic stability made the effects of additives or variety difficult to interpret.

Conclusions

Aberdart was easier to preserve than Fennema. Add-SafeR was the most effective of the additive treatments.

References

Lunden Pettersson, K., Lindgren, S., 1990. *Grass and Forage Science*. 45 : 223-233.

Experiment 3.6 (Experiment 2 of 2002): Perennial ryegrasses bred for contrasting sugar contents: manipulating fermentation and aerobic stability using wilting and additives

Introduction

Higher concentrations of water-soluble carbohydrate (WSC) in silage offer ruminant nutrition and environmental attractions. Both successful field wilting and alternative silage additives provide the opportunity to manipulate silage WSC by modifying fermentation and/or improving aerobic stability. This experiment evaluated the fermentation and aerobic stability of silages made from perennial ryegrass cultivars of high or normal WSC genotype that differed in field wilting or additive use.

Materials and methods

Aberdart (Ab; bred for high WSC) and Fennema (Fn; normal WSC) perennial ryegrasses were mown on 19 September 2002. Each was precision-chopped and ensiled in laboratory silos (6 kg) after a 0 or 24 h wilt. The additives applied to grass for three silos per treatment were (1) no additive, (2) Add-SafeR (85% ammonium tetraformate salt; Trouw Nutrition UK Ltd.) at 6 ml/kg, (3) *Lactobacillus buchneri*, *L. plantarum* and *Enterococcus faecium* (Pioneer Hi-Bred) at 3 ml/kg, (4) Powerstart (*L. plantarum* and *Lactococcus lactis*; Genus plc) at 3 ml/kg, (5) and (6) Kofasil Ultra (80 g hexamine, 120 g sodium nitrite, 150 g sodium benzoate, 50 g sodium propionate and 600 g water/kg; Addcon Agrar GmbH) at 2.5 or 5 ml/kg, (7) treatments 4 + 5, and (8) treatments 4 + 6. Silos were filled, sealed and stored (15°C) for >100 days. Silage composition (n=3/treatment) and aerobic stability (n=2/treatment) measurements were made and the results subjected to 3-way analysis of variance.

Results

Mean (s.d.) grass composition at ensiling is summarised in Table 3.6. Unwilted grasses were leafy and not unduly wet. Wilting for 24h lead to an 8%unit rise in DM concentration. Aberdart had a slightly higher WSC concentration than Fennema but a relatively similar buffering capacity. Wilting lead to relatively little change in WSC or buffering capacity, although the buffering capacity of Fennema>Aberdart.

Table 3.6. Chemical composition of grasses at ensiling in Experiment 3.6

	Unwilted				Wilted			
	Aberdart		Fennema		Aberdart		Fennema	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
DM (g/kg)	184	14.3	190	27.4	263	59.2	271	32.4
pH	6.3	0.09	6.5	0.08	6.2	0.10	6.4	0.08
Ash (g/kg DM)	108	2.4	106	1.7	105	3.4	103	1.1
ADF(g/kg DM)	248	3.1	250	3.3	248	3.7	237	4.9
NDF(g/kgDM)	473	3.1	480	5.7	475	7.5	466	7.0
OMD(g/kg)	791	10.3	791	8.5	788	8.0	802	8.3
Buff. cap. (mEq/kgDM)	374	22.8	379	7.2	364	23.1	386	7.6
WSC (g/kgDM)	172	6.1	158	11.8	178	11.0	186	5.7

Unwilted and wilted silage DM values were 152 and 199 (s.e. 0.5; $P<0.001$) g/kg, respectively, and cultivar had no significant ($P>0.05$) effect. Wilting increased lactic acid/fermentation products (Table 3.7). Unwilted Fennema underwent a more lactic acid dominant fermentation than Aberdart. Wilting resulted in more lactic acid dominant fermentations. Formic acid favoured dominance by lactic acid in the unwilted silages and restricted fermentation in the wilted silages. *L.buchneri* had relatively little influence on fermentation in unwilted Aberdart, but substantially reduced lactic acid and increased ethanol and acetic acid with Fennema. It increased acetic acid and reduced lactic acid with both wilted silages. Powerstart promoted the dominance of lactic acid within the fermentations in both grasses and at both DM's. Incremental rates of applying Kofasil Ultra promoted a more lactic acid dominant fermentation with unwilted Aberdart. The low rate of application had a greater effect than the high rate with unwilted Fennema. Effects were relatively minor with wilted herbage. Some evidence for additivity of effects occurred when Powerstart and Kofasil Ultra were applied together.

Unwilted silages were very stable when exposed to air. Powerstart increased susceptibility to aerobic deterioration while Add-SafeR, *L.buchneri* and Kofasil Ultra (high) improved stability with wilted silages.

Table 3.7. Chemical composition and aerobic stability of silages in Experiment 3.6

Additive (A) Cultivar (C)		1		2		3		4		5		6		7		8		Significance			
		Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	sem	C	A	CxA
pH	U ¹	4.6	4.2	3.7	3.8	4.5	4.5	3.8	4.0	4.4	4.6	4.1	4.2	3.8	4.1	4.0	4.1	0.05	0.08	***	***
	W ²	4.2	4.0	4.0	4.1	4.5	4.3	3.8	3.9	4.1	4.1	4.2	4.2	3.9	4.0	4.1	4.2				
Lactic acid (g/kg FP ³)	U	243	605	755	760	278	75	762	737	382	374	547	537	819	686	854	837	19.0	**	***	***
	W	594	771	667	700	291	512	825	825	646	730	559	636	832	829	843	783				
NH ₃ N (g/kg N)	U	88	80	100	107	84	143	60	74	94	111	88	96	59	85	67	72	2.8	**	***	***
	W	109	76	105	99	106	78	51	58	93	78	90	83	60	70	67	70				
Butyric acid (g/kg DM)	U	0	0	0	0	0	0.5	0.5	1.0	0	0	1.9	10.0	0	1.4	0	0	1.07	**	***	0.06
	W	10.7	0.5	1.1	0	11.8	3.6	1.0	0	5.5	0	8.1	0	0.4	0	0	1.1				
Duration to temp. rise ⁴	U	192	192	192	192	192	56	135	192	186	192	192	43	43	57	57	2.6	***	***	***	***
	W	96	88	192	192	192	55	61	192	109	192	192	66	81	192	192					
ATR to d5 ⁵	U	3	1	2	1	3	2	30	1	2	2	2	2	33	1	17	1	1.3	***	***	***
	W	12	11	2	1	3	3	46	25	1	6	2	1	26	11	2	1				

¹FP=fermentation products (lactic+VFA+ethanol); ²hours; ³accumulated temp. rise to day 5 (⁰C); ⁴unwilt; ⁵wilt;

sem = CxA

Conclusions

Cultivar had minor effects on ensilability indices, but Fn silages were better preserved. The partial wilt generally promoted a more efficient fermentation but poorer aerobic stability. The most consistent improvement in dominance by lactic acid was from Add-SafeR and Powerstart, but Powerstart silages were prone to aerobic deterioration. Add-SafeR, *L.buchneri* and Kofasil Ultra (high) improved aerobic stability with wilted silages.

Experiment 3.7 (Experiment 1 of 2003): Perennial ryegrasses bred for contrasting sugar contents: manipulating fermentation and aerobic stability of unwilted silage using additives

Introduction

Grass cultivars bred for elevated concentrations of water-soluble carbohydrate (WSC) could have improved silage preservation but possibly disimproved aerobic stability. Additives can be used to manipulate fermentation and thereby increase silage WSC. They can also influence aerobic stability. This experiment evaluated the fermentation and aerobic stability of unwilted silages made from perennial ryegrass cultivars of high or normal WSC genotype that differed in additive use.

Materials and methods

Aberdart (Ab; bred for high WSC) and Fennema (Fn; normal WSC) perennial ryegrasses were mown on 17 June, 2003 and field dried for 0 or 24 hours. Each was precision-chopped and ensiled in laboratory silos (6 kg unwilted herbage and 5 kg wilted herbage/silo). The additives applied to grass, using three silos per treatment, were (1) no additive, (2) and (3) Add-SafeR (85% ammonium tetraformate salt; Trouw Nutrition UK Ltd.) at 3 and 6 ml/kg, (4) Biomax SI (*Lactobacillus plantarum*; Chr. Hansen UK Ltd.) at 5 ml/kg, (5) Biomax SI at 5 ml/kg + potassium sorbate (KSor; 30 g/l) at 5 ml/kg, (6) Biomax SI at 5 ml/kg + sodium benzoate (NaBe; 30 g/l) at 5 ml/kg, and (7), (8) and (9) Bio-Sil (*Lactobacillus plantarum*; Dr. Pieper Technologie- und Produktentwicklung GmbH) at 5 ml/kg alone or with KSor or NaBe at 5 ml/kg, (10) KSor at 5 ml/kg, and (11) NaBe at 5 ml/kg. Silos were filled, sealed and stored (15°C) for >100 days. Silage composition and aerobic stability measurements were made on every silage and the results subjected to 3-way analysis of variance.

Results

Mean (s.d.) grass composition is summarised in Table 3.8. The grass was stemmy and low in protein at harvest time. Unwilted grass was very wet and 24 hour wilting led to a major increase in grass dry matter concentration. Aberdart had a higher WSC concentration and a lower buffering capacity at harvest, compared to Fennema. The effects of wilting were relatively minor. High numbers of lactic acid bacteria were found on the herbage, and wilting increased the numbers enumerated.

Table 3.8. Chemical composition (mean and s.d.) of grasses at ensiling in Experiment 3.7

	Ab (Un)	Fn (Un)	Ab (W)	Fn (W)
Dry matter (DM) (g/kg)	143 (12.6)	141 (12.8)	372 (26.4)	383 (27.4)
<i>in vitro</i> DMD (g/kg)	624 (9.5)	620 (11.1)	630 (13.4)	619 (9.6)
Total nitrogen (g/kg DM)	17 (0.89)	19 (0.7)	18 (0.4)	19 (0.5)
Ash (g/kg DM)	88 (11.5)	95 (7.4)	90 (4.0)	85 (4.0)
WSC (g/kg DM)	180 (4.8)	154 (11.6)	165 (4.8)	144 (4.8)
NDF (g/kg DM)	610 (13)	608 (12.1)	621 (8.8)	645 (6.3)
ADF (g/kg DM)	343 (11.5)	340 (12.8)	347 (5.5)	355 (3.5)
BC (mEq/kg DM)	226 (19.7)	242 (24.4)	208 (11.0)	235 (16.0)
LAB (CFU/g fresh crop)	1,210,000	1,505,000	11,700,000	14,600,000

Silage effluent, chemical composition and aerobic stability data are summarised in Tables 3.9-3.11. Excluding the formic acid treatment, all other treatments had similar rates of decline in pH. All silages were well preserved, showing evidence of high concentrations of lactic acid, intermediate concentrations of acetic acid and ethanol, and low contents of propionic acid, butyric acid and ammonia-N. Wilting restricted the extent of silage fermentation. Formic acid restricted the extent of silage fermentation. Most other additive treatments had relatively modest effects on fermentation. Ethanol concentrations were elevated when formic acid was applied, or when Biosil was applied to wilted Aberdart. Wilting improved aerobic stability (delayed the duration until temperature rise commenced) and restricted aerobic deterioration (reduced the accumulated temperature rise). Formic acid improved aerobic stability (delayed the duration until temperature rise commenced) and restricted aerobic deterioration (reduced the accumulated temperature rise) - none of the other additive treatments did this reliably.

Table 3.9. Effluent production from unwilted silages in Experiment 3.7

Additive (A) Cultivar (C)	1		2		3		4		5		6		7		8		9		10		11		statistical summary C A CxA s.e.d.
	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	
Day 2																							
g/kg fresh grass	113	135	96	107	119	113	103	110	119	130	118	104	115	121	118	109	103	114	107	116	98	103	ns
pH	4.0	4.0	4.3	4.5	3.9	3.9	4.0	4.0	4.1	4.0	4.1	4.1	4.0	4.0	4.0	4.0	4.1	4.1	4.0	4.1	4.1	4.1	ns
g DM loss/kg DM ensiled	31	30	50	48	52	54	35	31	34	32	34	33	33	31	30	31	34	32	35	33	34	33	ns
Day 9																							
g/kg fresh grass	56	55	54	53	56	54	53	52	54	51	53	51	58	59	59	56	58	57	55	54	56	56	ns
pH	3.8	3.8	4.1	4.1	4.0	4.0	3.8	3.8	3.8	3.8	3.8	3.9	3.7	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.8	ns
g DM loss/kg DM ensiled	52	52	46	44	52	57	54	50	55	53	54	52	53	49	52	49	53	50	55	53	54	53	ns
Day 15																							
g/kg fresh grass	14	16	12	10	5	10	14	18	9	17	14	19	14	21	17	21	14	18	13	19	18	20	ns
pH	3.6	3.8	4.0	3.9	4.2	4.1	3.6	3.8	3.7	3.7	3.6	3.8	3.5	3.6	3.5	3.8	3.5	3.6	3.6	3.7	3.6	3.7	ns
g DM loss/kg DM ensiled	55	55	48	50	43	48	53	55	55	55	55	55	56	53	56	52	57	54	57	54	56	56	ns
Day 24																							
g/kg fresh grass	17	16	17	16	15	11	14	16	15	17	15	18	16	18	16	18	16	18	17	16	17	18	ns
pH	3.7	3.7	3.8	4	4.1	4.1	3.6	3.8	3.6	3.7	3.6	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.7	3.6	3.7	ns
g DM loss/kg DM ensiled	57	58	55	51	51	61	57	63	57	61	58	65	56	62	58	64	57	62	58	62	58	62	ns
Day 50																							
g/kg fresh grass	23	22	23	26	17	21	21	25	21	23	23	26	20	25	20	27	21	25	23	24	24	26	ns
pH	3.6	3.6	3.7	3.8	3.9	4.0	3.5	3.6	3.5	3.6	3.5	3.6	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.6	3.5	ns
g DM loss/kg DM ensiled	61	63	56	56	53	56	63	61	62	62	62	62	66	62	63	63	67	62	63	62	61	63	ns
At opening																							
g/kg fresh grass	26	25	27	28	25	27	26	26	23	26	23	27	20	28	23	24	23	25	24	27	23	29	ns
pH	4.7	3.9	4.0	4.1	4.0	4.1	3.9	4.5	4.4	3.9	4.2	4.6	4.2	3.7	3.6	4.5	4.0	4.3	4.1	3.8	4.3	3.8	ns
g DM loss/kg DM ensiled	54	61	61	55	57	54	63	58	55	59	59	56	61	62	66	54	64	55	62	60	58	61	ns

Table 3.10. Chemical composition and aerobic stability of unwillted (U) and wilted (W) silages in Experiment 3.7

Additive (A) Cultivar (C)	1		2		3		4		5		6		
	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	
DM	Un	186	194	180	187	181	187	190	187	196	191	191	195
(g/kg)	W	346	358	338	346	340	351	344	355	345	349	339	349
pH	Un	3.7	3.8	3.8	3.9	4.2	4.0	3.7	3.9	4.0	3.9	3.8	3.9
	W	4.0	4.0	4.1	4.1	4.2	4.3	4.0	4.0	4.0	4.0	4.0	4.0
Lactic	Un	87	101	76	83	31	48	93	93	57	90	78	92
(g/kgDM)	W	50	57	48	42	27	22	58	53	56	58	64	52
NH ₃ N	Un	1.1	1.2	1.9	2.1	3.1	2.7	1.1	1.3	1.0	1.2	1.0	1.2
(g/kgDM)	W	0.9	1.1	1.3	1.6	1.6	1.4	0.9	1.1	1.0	1.5	1.0	1.0
NH ₃ N	Un	59.3	66.5	103.9	104.9	146	140.1	57.9	72.4	52.2	68.9	56	64.2
(g/kg N)	W	52.2	61.4	74.6	88.3	96	80	66.5	58.5	64.8	89.1	59.4	58.1
Acetic	Un	27	20	19	22	20	16	23	24	40	30	33	28
(g/kgDM)	W	14	14	10	10	6	7	13	12	14	14	16	14
Propionic	Un	1.3	1.4	0.5	0.6	1	0.6	0.9	1.6	1.5	1.6	1.3	1.2
(g/kgDM)	W	0	0.2	0	0.2	0	0.1	0	0	0	0.1	0	0.2
Butyric	Un	2.4	1.6	0.2	0	5.6	0	1	2.3	0.5	0.6	0	0
(g/kgDM)	W	0	0	0	0	0	0	0	0	0	0	0	0
Ethanol	Un	18	13	24	21	24	24	18	14	15	12	17	12
(g/kgDM)	W	11	9	20	15	24	18	12	9	13	7	11	9

Table 3.10 (continued). Chemical composition of unweiled (U) and weiled (W) silages in Experiment 3.7

Additive	7		8		9		9		10		10		11		11		C	A	D	CxA	CXD	AXD	CXAXD	s.e.d.
	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen								
DMI (g/kg)	Un	192	193	190	196	183	196	195	194	194	194	194	195	195	195	195	***	ns	***	ns	*	ns	ns	5.9
pH	Un	3.7	3.8	3.7	3.7	3.7	3.8	3.7	3.8	3.8	3.8	3.8	3.7	3.7	3.7	3.7	ns	***	ns	ns	ns	ns	ns	0.075
Lactic (g/kgDM)	Un	86	99	95	102	97	102	88	103	76	111	111	111	111	111	111	*	***	ns	***	*	ns	ns	9.3
NH ₃ -N (g/kgDM)	Un	1.0	1.3	1.1	1.2	1.0	1.1	1.0	1.1	1.0	1.2	1	1.1	1.1	1.1	1.1	*	***	ns	ns	ns	ns	ns	0.22
NH ₃ -N (g/kgDM)	Un	0.9	0.9	0.9	1.1	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	*	***	**	ns	ns	ns	ns	11.52
Acetic (g/kgDM)	Un	23	19	20	20	24	19	27	23	33	21	21	21	21	21	21	***	***	*	***	***	ns	2.4	
Propionic (g/kgDM)	Un	1.1	1.1	0.7	0.9	0.8	1.2	1.1	1.4	1.2	1.1	1.1	1.1	1.1	1.1	1.1	***	***	ns	ns	ns	ns	0.21	
Butyric (g/kgDM)	Un	0	0.2	0	0.2	0	0.2	0	0.3	0	0.4	0	0.4	0.4	0.4	0.4	ns	ns	ns	ns	ns	ns	1.57	
Ethanol (g/kgDM)	Un	16	11	14	10	15	10	16	12	17	10	10	10	10	10	10	***	***	*	ns	ns	ns	1.6	

Conclusions

For unwilted herbage, the higher WSC and lower buffering capacity for Ab compared to Fn indicate that Ab had better ensilability indices. The higher lactic acid/fermentation products for Fn silage reflects its higher concentration of lactic acid and lower concentration of both acetic acid and ethanol. The formic acid-based additive had the largest impact on fermentation and was the only additive to consistently and significantly improve aerobic stability and reduce aerobic deterioration.

For wilted herbage, the higher WSC and lower buffering capacity of Ab at harvesting gave it an apparent ensilability advantage over Fn. However, preservation was quite similar for both cultivars. The high rate of the formic acid-containing additive had the largest effect on fermentation and improving aerobic stability. The rates of inclusion of sorbate or benzoate salts did not improve aerobic stability under the test conditions prevailing.

Experiment 3.8 (Experiment 2 of 2003): Perennial ryegrasses bred for contrasting sugar contents: manipulating fermentation and aerobic stability of unwilted silage using additives

Materials and methods

Aberdart (Ab; bred for high WSC) and Fennema (Fn; normal WSC) perennial ryegrasses were mown on 22 July, 2003 and field dried for 0 or 24 hours. Each was precision-chopped and ensiled in laboratory silos (6 kg unwilted herbage and 5 kg wilted herbage/silo). The additives applied to grass, using three silos per treatment, were (1) no additive, (2) and (3) Add-SafeR (85% ammonium tetraformate salt; Trouw Nutrition UK Ltd.) at 3 and 6 ml/kg, (4) Biomax SI (*Lactobacillus plantarum*; Chr. Hansen UK Ltd.) at 5 ml/kg, (5) Biomax SI at 5 ml/kg + potassium sorbate (KSor; 30 g/l) at 5 ml/kg, (6) Biomax SI at 5 ml/kg + sodium benzoate (NaBe; 30 g/l) at 5 ml/kg, and (7), (8) and (9) Bio-Sil (*Lactobacillus plantarum*; Dr. Pieper Technologie- und Produktentwicklung GmbH) at 5 ml/kg alone or with KSor or NaBe at 5 ml/kg, (10) KSor at 5 ml/kg, and (11) NaBe at 5 ml/kg. Silos were filled, sealed and stored (15°C) for >100 days. Silage composition and aerobic stability measurements were made on every silage and the results subjected to 3-way analysis of variance.

Results

Mean (s.d.) grass composition is summarised in Table 3.12. Leafy grass of high protein content and digestibility was used. Grass was very wet at harvesting and the extent of wilting achieved in 24 hours was limited (from approx. 12 to 18%DM). Aberdart had a higher WSC concentration and a lower buffering capacity at harvest, compared to Fennema. In general, WSC concentrations were low and buffering capacities were high. Numbers of colony-forming units of lactic acid bacteria were high, and increased during 24h wilting.

Table 3.12. Chemical composition (mean and s.d.) of grasses at ensiling in Experiment 3.8

	Ab (Un)	Fn (Un)	Ab (W)	Fn (W)
Dry matter (DM) (g/kg)	118 (2.0)	124 (4.8)	179(5.5)	177 (2.3)
<i>in vitro</i> DMD (g/kg)	776 (9.2)	769 (10.5)	775 (9.0)	751 (9.5)
Total nitrogen (g/kg DM)	34 (0.6)	38 (0.4)	34 (0.9)	36 (0.6)
Ash (g/kg DM)	119 (4.4)	121 (4.6)	125 (6.6)	127 (6.0)
WSC (g/kg DM)	143 (4.4)	122 (6.3)	134 (8.8)	105 (7.6)
NDF(g/kg DM)	502 (8.7)	506 (11.0)	501 (7.3)	530 (10.5)
ADF(g/kg DM)	250 (4.9)	247 (4.7)	249 (2.5)	253 (5.2)
BC (mEq/kg DM)	504 (21.4)	541 (8.8)	452 (16.8)	471 (20.3)
LAB (CFU/g fresh crop)	1742500	512500	138000000	207000000

The initial rate of pH decline during silage fermentation was markedly influenced by formic acid - other treatments had relatively minor impacts (Table 3.13).

Aberdart underwent an extensive, lactic acid dominant fermentation. In contrast, Fennema underwent an extensive fermentation dominated by acetic acid (Table 3.14). Wilting favoured greater dominance of lactic over acetic acid for silages made using Aberdart, but had relatively little impact with silages made using Fennema. The low rate of application of formic acid improved the dominance of lactic acid in the fermentation of silages made using Aberdart, while the high rate restricted fermentation. When applied to silages made using Fennema, formic acid promoted a lactic acid dominant fermentation. The other additive treatments had relatively little impact on fermentation end-products.

Wilting improved aerobic stability (delayed the duration until temperature rise commenced) and restricted aerobic deterioration (reduced the accumulated temperature rise) (Table 3.15). Silages made using Fennema, having undergone a poorer fermentation, had better aerobic stability (delayed the duration until temperature rise and less aerobic deterioration (reduced the accumulated temperature rise) compared to silages made using Aberdart. Formic acid tended to improve aerobic stability (delayed the duration until temperature rise commenced) and restrict aerobic deterioration (reduced the accumulated temperature rise). The other additive treatments tended to improve aerobic stability and restrict aerobic deterioration for silages made using Aberdart but not for silages made using Fennema.

Table 3.13. Effluent losses from unwilted grasses ensiled in Experiment 3.8

Additive (A) Cultivar (C)	1		2		3		4		5		6		7		8		9		10		11		statistical summary			
	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	C	A	CxA sed	
Day 1																										
g/kg fresh grass	59	24	97	46	136	68	63	10	62	10	56	10	48	21	62	23	55	10	60	13	71	13	***	***	ns	12.5
pH	4.6	4.9	4.4	4.7	3.9	3.9	4.6	4.9	4.6	4.9	4.6	4.8	4.6	4.9	4.6	4.9	4.7	5	4.6	4.9	4.6	4.9	***	***	ns	0.09
g DM loss/kg DM ensiled	30	28	53	48	57	57	29	33	30	17	29	16	31	25	32	28	30	24	32	19	32	19	**	***	ns	6.6
Day 3																										
g/kg fresh grass	109	109	82	90	55	79	113	108	111	108	112	75	126	108	124	91	122	65	129	93	110	102	*	*	ns	18.7
pH	4.2	4.3	4.6	4.5	4.1	4.1	4.2	4.3	4.2	4.4	4.3	4.3	4.2	4.3	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3	***	***	ns	0.05
g DM loss/kg DM ensiled	58	53	64	59	70	67	61	54	62	53	60	56	62	53	60	53	61	53	61	55	63	53	***	***	ns	2.3
Day 7																										
g/kg fresh grass	30	31	29	25	25	28	35	34	36	34	34	29	53	34	30	27	36	22	37	31	34	29	*	*	ns	6.2
pH	4	4.1	4.1	4.1	4.1	4.2	4	4.1	4	4.2	4	4.2	3.8	4.2	3.9	4.1	3.9	4.2	4	4.1	4	4.1	***	***	***	0.05
g DM loss/kg DM ensiled	67	62	58	60	61	64	71	63	71	62	72	66	69	60	68	60	70	58	70	63	72	64	***	***	***	2.5
Day 14																										
g/kg fresh grass	57	29	30	28	25	24	32	29	32	29	31	24	30	25	31	24	28	16	31	26	30	30	***	***	ns	2.9
pH	3.9	4.1	4	4	4.2	4.2	3.9	4.1	3.9	4.2	3.9	4.5	3.9	4.4	3.9	4.4	3.9	4.5	3.9	4.2	3.9	4.2	***	***	***	0.08
g DM loss/kg DM ensiled	70	66	62	65	58	61	71	67	72	66	71	73	71	64	70	63	71	59	72	65	73	65	***	***	***	2.7

Table 3.14. Chemical composition of silages in Experiment 3.8

Additive	1		2		3		4		5		6		7		
	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	Ab	Fn	
DM	Un	148	144	153	158	153	161	150	148	150	150	150	144	150	147
	W	173	163	179	179	178	182	173	163	179	163	172	163	176	164
pH	Un	4.2	5.3	4.0	4.0	4.0	4.0	4.2	5.2	4.3	5.4	4.3	5.4	4.5	5.4
	W	4.2	5.7	4.0	4.3	4.1	4.1	4.1	5.6	4.2	5.6	4.2	5.6	4.2	5.7
Lactic (g/kgDM)	Un	118	11	130	112	84	87	117	23	118	11	113	10	88	9
	W	146	8	130	110	97	110	144	7	133	10	142	6	133	7
NH ₃ N (g/kgDM)	Un	2.8	6.3	3.0	3.1	3.8	3.6	2.9	5.9	2.9	6.3	3	6.9	4	7.5
	W	2.9	6.3	3.4	4.0	4.0	4.0	2.8	6.4	3.0	6.3	2.9	6.4	2.9	6.7
NH ₃ N (g/kg N)	Un	79	173	83	78	100	88	83	158	82	179	85	192	115	212
	W	83	184	93	106	110	106	79	193	84	183	80	185	81	199
Acetic (g/kgDM)	Un	46	81	21	23	21	16	46	71	47	75	48	80	53	85
	W	31	71	23	28	27	18	31	75	33	75	31	79	34	74
Propionic (g/kgDM)	Un	2	6.6	0	0	0	0	2.1	6	1.3	5.5	2.5	7.7	4.1	9.2
	W	0	8.4	0	0	0	0	0	10	0	6.8	0	8.9	0	8.9
Butyric (g/kgDM)	Un	0	0	0	0	0	0	0	0	0	0	0	2.3	6	6.8
	W	0	11.3	0	0	0	0	0	9.8	2.6	3.3	0	5.8	0	9.8
Ethanol (g/kgDM)	Un	11.3	29.2	15.1	10.5	26.2	18.5	11.6	22.3	11.2	28.9	11.5	27.1	12.1	28
	W	10.6	25.7	9.4	6.7	12.4	5.5	9.7	25.2	10.9	26.9	10.4	22.5	9.8	23.5

Table 3.14 (continued). Chemical composition of silages in Experiment 3.8

	8		9		10		11		11		C	A	D	CxA	CXD	AxD	CxAXD	sec
	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen								
147	144	144	147	140	147	149	145	147			**	**	**	***	***	ns	ns	3.4
173	165	177	165	178	164	177	165			*	*	*	*					0.09
4.3	5.4	4.3	5.5	4.3	5.4	4.2	5.4			**	**	**	**	***	***	ns	ns	
4.2	5.7	4.1	5.7	4.2	5.6	4.2	5.6			*	*	*	*					
113	10	119	8	105	12	131	14			**	**	**	**	***	***	ns	ns	10.3
										*	*	*	*					
142	6	140	7	143	10	137	7			**	**	**	ns	***	ns	**	ns	0.38
3.2	7.2	3.3	7.5	3	6.6	2.8	6.3			*	*	*	*					
3	6.5	2.8	6.7	2.8	6.4	2.8	6.2			**	**	**	ns	***	*	**	ns	11.6
93	203	94	212	84	181	81	177			**	**	**						
83	195	79	197	79	191	78	181			*	*	*						
49	80	49	83	47	77	39	74			**	**	**	***	***	***	ns	ns	5.2
										*	*	*	*					
33	70	29	72	30	70	31	75			**	**	**	ns	***	***	ns	ns	1.33
1.1	6.4	0	7.7	2.2	6.5	1	8.3			**	**	**						
0	9.5	0	9.9	0	8.5	0	8.5			*	*	*						
0	0	0	2.2	0	2.3	2.6	7.6			**	**	**	***	***	***	*	*	2.69
										*	*	*	*					
0	16.8	0	13.9	0	15.4	0	7.3			**	**	**	***	ns	***	ns	ns	2.33
11.1	33.1	11.2	30.4	12.1	27.1	10.6	25.3			**	**	**	***	ns	***	ns	ns	
10.3	22.9	8.7	24.1	9	23	9.8	26.2			*	*	*	*					
848	841	850	864	831	881	830	870			**	**	**	ns	*	*	*	*	19.8
										*	*	*	*					
992	926	988	920	981	923	990	917			**	**	**	ns					14.2
										*	*	*	*					

Table 3.15. Aerobic stability of silages in Experiment 3.8

Additive (A)	1		2		3		4		5		6		7		8		9		10		11		statistical summary				
	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen	Ab	Fen		C	A	CxA seed	
Cultivar (C)																											
Hrs to TR >2°C	Un 65	130	67	130	165	174	107	109	93	117	106	135	92	81	141	102	139	105	155	160	118	128	ns	*	ns	35.1	
Hrs to TR >5°C	W 108	157	167	187	144	192	131	178	176	167	141	157	156	176	168	178	168	174	192	172	188	170	ns	*	ns	26	
	Un 77	146	83	167	185	191	130	144	104	129	132	160	154	119	178	113	176	124	192	182	137	163	ns	*	ns	33.4	
Max TR	W 126	177	192	192	158	192	158	189	192	182	152	189	170	182	192	189	183	188	192	183	192	180	ns	**	ns	20.6	
	Un 16.6	15.0	16.5	7.1	4.2	3.7	10.6	8.6	6.4	11.8	8.3	11.8	10.0	14.1	6.6	11.5	6.7	13.8	2.9	6.6	6.8	6.8	12.6	ns	**	ns	3.65
Hrs to max TR	W 23.0	10.2	2.8	1.5	9.1	0.7	12.1	4.4	1.3	8.3	12.6	5.4	9.0	6.2	1.8	4.1	7.3	4.8	0.9	5.7	2.0	7.8	ns	*	ns	5.19	
	Un 136	185	140	192	185	192	185	173	112	151	181	192	185	179	192	129	192	164	192	192	155	192	ns	ns	ns	30.5	
Hrs from TR > 2°C	W 180	191	191	191	190	191	191	191	191	191	191	187	191	191	191	191	191	191	191	191	191	191	ns	**	ns	21.6	
	Un 73	55	73	62	30	18	78	63	19	34	75	57	94	98	77	27	53	58	55	48	37	96	ns	**	ns	30.6	
to temp max	W 72	34	24	4	46	-1	60	13	15	24	46	34	35	15	23	76	23	76	24	39	0	15	18	44	ns	18.9	
Hrs from TR > 5°C	Un 59	39	57	38	0	1	55	29	8	22	74	32	31	60	43	16	24	39	0	15	18	44	ns	**	ns	19.2	
to temp max	W 54	14	-1	-1	33	-1	33	2	-1	14	35	2	21	9	-1	2	8	3	-4	8	-1	11	ns	ns	ns	0.36	
Acc TR to 24hrs	Un 1.5	0.5	0.6	0.6	0.5	0.7	0.6	0.8	0.6	0.8	0.4	0.6	0.2	0.3	0.1	0.2	0.0	0.1	0.1	0.3	0.2	0.2	ns	*	ns	0.24	
	W 0.6	0.9	0.6	1.1	0.3	0.9	0.3	1.2	0.5	1.1	0.2	1.1	0.1	0.8	0.2	0.8	0.1	0.8	0.2	0.8	0.3	1.1	***	ns	ns	2.18	
Acc TR to 48hrs	Un 88.2	1.0	1.6	1.0	0.8	1.0	1.3	1.3	2.5	1.3	0.8	1.1	0.6	0.6	0.4	2.7	0.1	0.2	0.2	0.8	0.4	0.4	ns	ns	ns	4.51	
	W 1.8	1.2	1.2	1.5	0.8	1.2	0.8	1.7	1.1	1.6	0.5	1.5	0.1	1.1	0.4	1.1	0.3	1.0	0.4	1.4	1.3	1.0	ns	***	ns	0.45	
Acc TR to 72hrs	Un 16.6	1.5	4.3	1.4	1.2	1.4	2.4	1.8	6.8	3.1	1.4	1.7	1.5	1.9	0.7	6.0	0.4	0.4	0.4	1.4	1.3	1.0	ns	ns	ns	1.14	
	W 5.4	1.7	1.9	2.0	1.9	1.6	1.5	2.3	1.8	2.1	1.3	2.1	0.1	1.4	0.6	1.3	0.4	1.3	0.7	2.1	0.6	2.4	ns	ns	ns	6.32	
Acc TR to 96hrs	Un 25.6	2.0	10.7	2.0	1.6	1.8	4.6	3.4	11.2	5.1	3.0	2.3	3.7	5.2	1.4	8.9	0.9	2.8	0.6	1.9	3.3	2.5	ns	ns	ns	2.05	
	W 8.4	2.2	2.6	2.4	3.8	2.0	2.2	2.8	2.5	2.6	3.5	2.6	0.1	1.7	0.8	1.6	0.5	1.5	0.9	2.8	0.8	3.0	ns	ns	ns	8.13	
Acc TR to 120hrs	Un 29.9	2.9	20.3	3.2	2.3	2.4	7.0	7.0	16.2	6.4	7.6	3.1	6.9	8.2	2.6	14.8	1.7	7.9	1.4	2.7	4.9	3.6	ns	ns	ns	3.33	
	W 12.9	2.7	3.6	2.9	5.9	2.4	3.3	3.5	3.2	3.2	6.0	3.4	0.2	2.2	1.5	1.8	0.7	1.8	1.2	3.5	1.0	3.7	ns	ns	ns	9.95	
Acc TR to 144hrs	Un 35.4	6.9	34.1	5.4	3.3	3.3	10.8	11.3	23.4	9.1	13.6	5.2	11	12.7	4.8	20.6	3	16.8	2.3	4	6.9	5.6	ns	ns	ns	5.29	
	W 22.1	3.8	4.9	3.5	5.0	2.9	5.4	4.2	4.1	4.0	8.7	4.7	0.6	2.2	2.2	0.9	2.3	1.5	4.3	3	1.5	4.3	ns	*	ns	11.35	
Acc TR to 168hrs	Un 43.1	15.5	47.6	9.2	4.5	4.6	17.3	16.5	30.1	15.2	20.8	10.1	17.2	21.9	8.6	25.6	5.7	28.8	3.4	6.5	10.7	10.6	ns	*	ns	7.95	
	W 36.2	6.1	6.5	4.2	10.8	3.4	10.4	5.4	5.2	5.7	14.4	6.8	3.3	4.5	4.0	2.7	2.0	3.4	1.8	5.7	1.6	6.4	ns	ns	ns	12.24	
Acc TR to 192hrs	Un 54.1	28.1	57.9	15.0	7.3	7.3	26.3	22.8	35.7	24.7	28.4	20.1	26.5	33.7	14.4	32	11.3	36.8	5.6	12	17.5	21.1	ns	**	ns	10.85	
	W 51.7	12.4	8.7	5.3	15.8	3.8	18.9	7.9	6.4	10.6	25.3	10.4	10	8.7	5.8	5.1	6.7	6.2	2.3	9.6	2.6	11.7	ns	*	ns	1.24	
Yeast numbers (log 10 cfu/g silage)	Un 2.7	1.2	0	0	1.2	0	1.8	0.9	0.5	2.6	1.0	1.5	1.1	2.0	1.7	1.4	1.7	0.3	1.2	0	0	0	0	0	0	0	0.98

Experiment 3.9 (Experiment 1 of 2004): Aerobic stability responses of silages made using a homofermentative lactic acid bacterial inoculant to a series of rates of sodium benzoate

Introduction

Achieving and maintaining anaerobiosis is fundamental to the preservation of any moist feedstuff as silage. Once silos are subsequently opened to permit feedout of the silage, the silage face is exposed to air and an array of biological processes that had been inhibited can then commence. The primary initiators of these processes are yeast and they are soon succeeded by moulds and sometimes also by aerobic bacteria.

Silages vary widely in their inherent aerobic stability, with those made using homofermentative lactic acid bacteria (LAB) additives tending to be less stable than comparable silages made without additive. Previous experiments have shown that under similar circumstances, formic acid based additives could improve aerobic stability while the effects of agents that are inhibitory to yeast, such as sodium benzoate and potassium sorbate, were less clearcut. The lack of clarity on the effects of the latter could be related to the rates of application used.

This experiment aimed to quantify the responses by indices of aerobic stability and deterioration of silages made from Aberdart and Fennema, following a 0 or 24h wilt, to the addition of a series of rates of inclusion of sodium benzoate with a *Lactobacillus plantarum* based additive. A formic acid based additive was used as a positive control.

Materials and Methods

Herbage was harvested from plots of both Aberdart and Fennema on 27 (unwilted) and 28 (wilted) May. Each was ensiled in laboratory silos (three per treatment combination), with the following additive treatments applied: (a) no additive, (b) Add SafeR (formic acid based), (c) LAB inoculant alone, (d) LAB inoculant plus benzoate low (200mg/kg), (e) LAB inoculant plus benzoate medium (400 mg/kg) and (f) LAB inoculant plus benzoate high (800 mg/kg).

Add SafeR® is an 85% ammonium tetraformate salt (Interchem Ltd., Cherry Orchard Ind. Est., Dublin) and was applied at 3ml/kg herbage. The LAB inoculant used was BIO-SIL® (Dr. Pieper, Wuthenow, Germany) which contained two strains of *Lactobacillus plantarum* (DSM 8862 and DSM 8866). The contents of a sachet (1g) of BIO-SIL® were added to 5 litres distilled water and applied at 5ml/kg herbage – a new mixture was formulated on successive days for treating the unwilted and wilted herbage. Sodium benzoate (NaBe) (10, 20 and 40g made to 250ml with distilled water) solutions were applied at 5ml/kg herbage, and were used for both the unwilted and wilted herbage treatments. The BIO-SIL® and sodium benzoate were applied separately to the herbage (i.e. they were not mixed before application). Each of the 6 treatments had 10 ml liquid applied per kg herbage. This necessitated 0, 5, 7 or 10 g distilled water being added per kg herbage, depending on whether there was 10, 5, 3 or 0 ml additive already applied (per kg herbage). Unwilted and wilted herbage were treated in units of 7 and 6kg, respectively, with correspondingly 6 and 5kg herbage (excluding weight of additive) being ensiled. Silos were stored at approximately 15°C for 130 days.

Six samples of each grass were taken immediately after chopping (i.e. for both unwilted and wilted herbage), and for each

~ 200g was dried at 98°C (16 h; oven with forced-air circulation) for determination of dry matter (DM) content.

~ greater than 100g was dried @ 60°C (48h; oven with forced-air circulation) and milled (screen with 1mm pores) prior to analysis for *in vitro* DM digestibility (DMD; Tilley and Terry, 1963, with the modification that the final residue was isolated by filtration rather than by centrifugation), neutral detergent fibre (NDF; Goering and van Soest, 1970), acid detergent fibre (ADF; Goering and van Soest, 1970), ash (muffle furnace at 550°C for 5h), buffering capacity (Playne and McDonald, 1966), total N (total N x 6.25; LECO FP 428 nitrogen analyser – AOAC, 1990) and water soluble carbohydrates (WSC; anthrone method).

~ MRS nystatin agar was used to enumerate lactic acid bacteria (Seale *et al.*, 1990).

At silo opening, each silage was weighed and sampled. Subsamples were:

~ dried (200g) at 85°C (16h) for estimation of DM content

~ dried (200g) at 40°C (48h), milled (as for grass) and used for determination of total

~ juice was extracted and assayed for pH, lactic acid, VFA, ethanol, WSC and NH₃-N.

The remainder of each silage (5kg unwilted silage and 4kg wilted silage) was placed polyethylene-lined polystyrene boxes (55cm long x 35cm wide x 19cm high [internal dimensions]; 23mm thick) with lids loosely fitted. These were stored on shelves in an insulated room. In the centre of each shelf, an open-topped plastic container of water was used to (1) obtain a reference temperature and (2) help maintain a high relative humidity in the air (in order to prevent the silage drying). Air temperature was maintained at 20°C by two thermostat-controlled warm-air blowers. These also helped circulate and mix the air in the room. A thermocouple (Eureka Tp 103T) was inserted into the centre of each silage. Similarly, a thermocouple was placed into each container of water. Twin-wire thermocouple cable (Eureka 021212 TTU/BN) was used to connect each thermocouple directly to an Eltek Squirrel data logger (model 1105 of the 1000 series). This 80 channel logger was connected to a dedicated computer (Dell model DHM

Pentium 4 with Windows XP) on which Darca (a downloading and remote control application for MS-Windows; Eltek Ltd.) was installed.

Spreadsheets within Microsoft-Excel were developed to facilitate calculating the following indices:

- (a) Duration to temperature rise $>2^{\circ}\text{C}$ above the reference temperature
- (b) Duration to temperature rise $>5^{\circ}\text{C}$ above the reference temperature
- (c) Maximum temperature rise (to the first major peak)
- (d) Duration to maximum temperature
- (e) Duration from temperature rise ($>2^{\circ}\text{C}$) to temperature maximum
- (f) Duration from temperature rise ($>5^{\circ}\text{C}$) to temperature maximum
- (g) Accumulated temperature rise to day 1 (24 hours)
- (h) Accumulated temperature rise to day 2 (48 hours)
- (i) Accumulated temperature rise to day 3 (72 hours)
- (j) Accumulated temperature rise to day 4 (96 hours)
- (k) Accumulated temperature rise to day 5 (120 hours)
- (l) Accumulated temperature rise to day 6 (144 hours)
- (m) Accumulated temperature rise to day 7 (168 hours)
- (n) Accumulated temperature rise to day 8 (192 hours)

Data were subjected to three-way analysis of variance for a completely randomised design, with the factors being wilting, cultivar and additive. The individual treatment means were separated using the least significant difference procedure.

Results and Discussion

Grass composition at ensiling is summarised in Table 3.16. Wilting for 24h lead to an increase in mean DM content from 219 to 339 g/kg, and both Aberdart and Fennema had similar DM contents at ensiling. Grass was in the inflorescence stage when harvested, but nutritive value (as reflected by the DMD) was still relatively high. Wilting was associated with approximately a 2% unit decline in DMD. In general, Aberdart tended to have higher DMD, WSC and ash values and lower NDF values than Fennema. Both crude protein content and lactic acid bacterial numbers were similar for both grasses.

The silage composition results are summarised in Tables 3.17-3.20. Butyric acid content was below detectable levels in all silages. Wilting was associated with an increase in DM, WSC, pH and propionic acid, and a reduction in crude protein, $\text{NH}_3\text{-N}$, lactic acid, ethanol, acetic acid, fermentation products and L/FP. Relative to Fennema, Aberdart had an elevated crude protein, ethanol and acetic acid content but a lower DM, WSC, $\text{NH}_3\text{-N}$, pH, lactic acid and L/FP. Formic acid (contained ammonia) had the largest effect of all the additive treatments, with an increase in WSC, $\text{NH}_3\text{-N}$ and ethanol, and a reduction in lactic acid, acetic acid and L/FP. Other additives had little effect on silage composition – however, lactic acid bacteria when applied alone decreased the content of WSC in wilted silages.

The silage DM recovery results are summarised in Tables 3.21-3.22. The rate of recovery of ensiled herbage DM as silage DM was higher ($P<0.001$) with wilted (985 g/kg) than unwilted (932 g/kg) herbage. Although there was a significant effect of cultivar ($P<0.01$), the differences between Aberdart (965 g/kg) and Fennema (952 g/kg) were relatively small (and inconsistent). The effects of additives failed to reach statistical significance ($P=0.056$), however both formic acid (949 g/kg) and LAB (948 g/kg) resulted in lower ($P<0.05$) values than when no additive was used (971 g/kg), with the sodium benzoate treatments being intermediate.

The silage aerobic stability results are summarised in 3.21-3.22. The indices of aerobic stability were taken as (a) the duration to temperature rise $>2^{\circ}\text{C}$ above the reference temperature, (b) the duration to temperature rise $>5^{\circ}\text{C}$ above the reference temperature, (c) the duration to maximum temperature, and (d) the duration from temperature rise ($>2^{\circ}\text{C}$) to temperature maximum. Wilted silages were generally more stable than unwilted silages, and there was not a significant effect of cultivar ($P>0.05$). Formic acid consistently improved ($P<0.001$) silage aerobic stability while the LAB inoculant tended to shorten the duration until temperature rise (or maximum) were reached – the LAB thus disimproved aerobic stability. The low rate of addition of sodium benzoate along with LAB tended to restore aerobic stability to being similar to the silage made without additive application.

The silage aerobic deterioration results are summarised in Tables 3.23-3.24. The indices of aerobic deterioration were taken to be the accumulated temperature rises. These suggested that the extent of aerobic deterioration at any time-point was less ($P<0.001$) with wilted than unwilted silages, but that cultivar had no effect ($P>0.05$). Formic acid restricted aerobic deterioration ($P<0.001$) while the LAB inoculant promoted aerobic deterioration. The general trend was for the low rate of inclusion of sodium benzoate with LAB to return aerobic deterioration to the level encountered with the silage made without additive application. The medium and higher rates of addition of sodium benzoate gave no advantage over the low rate of addition – in some cases their effect was less than with the low rate.

Conclusions

In general, all silages were well preserved. The differences in silage composition between the two grasses were relatively small. In contrast, wilting restricted fermentation and increased the content of residual WSC in silage.

Silage fermentation was strongly restricted by formic acid while all other additives had relatively minor effects on fermentation characteristics.

Both Aberdart and Fennema had similar aerobic stability and deterioration characteristics. In general, wilted silages were more stable and underwent less deterioration when exposed to air than unwilted silages. Treatment with a LAB inoculant disimproved aerobic stability and deterioration, and these negative effects were overturned by the co-addition of sodium benzoate at 200mg/kg herbage (i.e. it resulted in similar stability and deterioration to silages made without additive application). Higher rates of addition of sodium benzoate conferred less advantage. In contrast, formic acid application resulted in a major improvement in aerobic stability (i.e. duration of stability extended) and a major restriction in aerobic deterioration (i.e. extent of heat production reduced) compared to silages made without additive application.

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Table 3.16. Chemical and microbiological composition of grasses at ensiling in Experiment 3.9.

	Unwilt				Wilt			
	Aberdart		Fennema		Aberdart		Fennema	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
DM (g/kg)	211	5.9	227	9.9	338	7.7	340	8.2
DMD (g/kg)	748	5.9	723	7.8	725	8.9	707	7.7
Ash (g/kgDM)	84	3.9	84	3.3	95	3.9	105	6.6
NDF (g/kgDM)	523	7.9	527	7.6	547	8.1	563	4.9
ADF (g/kgDM)	283	4.2	282	4.5	289	5.0	296	2.1
C.protein (g/kgDM)	148	8.7	156	4.9	152	3.9	147	5.2
WSC (g/kgDM)	121	11.2	108	7.6	136	5.7	117	7.6
B.capacity (mEq/kgDM)	479	22.9	512	11.3	405	12.9	424	7.1
Lactic acid bacteria (log ₁₀ cfu/g)	6.5	0.27	6.1	0.05	6.4	0.08	6.3	0.06

¹colony-forming units

Table 3.17. Silage chemical composition – main effects and major interactions in Experiment 3.9

Wilting	Grass cultivar	Additive	VCODM (g/kg)	Crude protein (g/kgDM)	WSC (g/kgDM)	NH ₃ -N (g/kgN)
Main effect of wilting						
		Unwilt	209	145	12.6	79
		Wilt	328	137	27.8	55
Main effect of grass cultivar						
		Aberdart	266	144	19.2	63
		Fennema	271	138	21.3	71
Main effect of additive						
		1 (none)	268	140	17.7	65
		2 (Add SafeR)	267	144	39.9	88
		3 (LAB)	266	141	13.7	62
		4 (LAB + NaBe-low)	268	143	15.9	63
		5 (LAB + NaBe-med.)	270	140	16.7	64
		6 (LAB + NaBe-high)	269	139	17.5	60
s.e.m.						
		Wilting	1.0	0.8	0.61	1.2
		Cultivar	1.0	0.8	0.61	1.2
		Additive	1.7	1.3	1.05	2.1
		Wilt x cultivar	1.4	1.1	0.86	1.7
		Wilt x additive	2.4	1.9	1.49	2.9
		Cultivar x additive	2.4	1.9	1.49	2.9
Significance (P=)						
		Wilting	<0.001	<0.001	<0.001	<0.001
		Cultivar	0.001	<0.001	0.018	<0.001
		Additive	0.440	0.070	<0.001	<0.001
		Wilt x cultivar	0.045	<0.001	0.258	0.089
		Wilt x additive	0.840	0.085	0.043	0.057
		Cultivar x additive	0.731	0.926	0.757	0.914

VCODM = volatile-corrected oven dry matter (Porter & Murray, 2001)

Table 3.18. Silage chemical composition – individual treatment effects in Experiment 3.9

Wilting	Grass cultivar	Additive	VCODM (g/kg)	Crude protein (g/kgDM)	WSC (g/kgDM)	NH ₃ -N (g/kgN)
Unwilt	Aberdart	1	209	144	7.4	74
Unwilt	Aberdart	2	208	150	31.1	105
Unwilt	Aberdart	3	204	144	7.0	72
Unwilt	Aberdart	4	208	152	6.6	70
Unwilt	Aberdart	5	210	144	6.8	73
Unwilt	Aberdart	6	206	140	7.7	68
Unwilt	Fennema	1	211	144	10.5	77
Unwilt	Fennema	2	210	150	29.5	110
Unwilt	Fennema	3	209	142	10.5	77
Unwilt	Fennema	4	208	146	12.2	78
Unwilt	Fennema	5	210	142	10.5	76
Unwilt	Fennema	6	211	142	12.1	75
Wilt	Aberdart	1	324	142	26.4	49
Wilt	Aberdart	2	321	144	49.1	61
Wilt	Aberdart	3	319	144	17.8	47
Wilt	Aberdart	4	326	142	21.4	48
Wilt	Aberdart	5	327	140	24.9	48
Wilt	Aberdart	6	324	144	23.9	42
Wilt	Fennema	1	329	131	26.5	59
Wilt	Fennema	2	330	131	49.8	78
Wilt	Fennema	3	330	133	19.5	53
Wilt	Fennema	4	330	131	23.4	57
Wilt	Fennema	5	335	133	24.5	58
Wilt	Fennema	6	336	129	26.4	56
s.e.m.			3.4	2.7	2.10	4.1
Signif. (P=)			0.997	0.524	0.906	0.943

VCODM = volatile-corrected oven dry matter (Porter & Murray, 2001)

Table 3.19. Silage chemical composition – main effects and major interactions in Experiment 3.9

Wilting	Grass cultivar	Additive	pH	Lactic g/kgDM	Ethanol g/kgDM	Acetic g/kgDM	Propionic g/kgDM	Ferment. products g/kgDM	L/FP g/kg
Main effect of wilting									
Unwilt			3.78	129	30	25	0.0	184	699
Wilt			4.02	61	6	21	9.4	97	624
Main effect of grass cultivar									
	Aberdart		3.88	92	20	26	4.3	142	627
	Fennema		3.93	98	16	20	5.1	139	696
Main effect of additive									
		1	3.89	99	17	24	5.7	146	660
		2	3.94	74	23	16	2.8	116	633
		3	3.91	100	17	24	4.8	146	675
		4	3.91	99	17	24	4.1	144	681
		5	3.89	98	18	26	5.5	147	658
		6	3.88	99	17	24	5.5	146	661
s.e.m.									
Wilting			0.010	1.9	0.5	1.1	0.514	2.0	11.5
Cultivar			0.010	1.9	0.5	1.1	0.514	2.0	11.5
Additive			0.018	3.2	0.9	1.9	0.891	3.5	19.9
Wilt x cultivar			0.014	2.6	0.7	1.6	0.727	2.8	16.2
Wilt x additive			0.025	4.5	1.3	2.7	1.260	4.9	28.1
Cultivar x additive			0.025	4.5	1.3	2.7	1.260	4.9	28.1
Significance (P=)									
Wilting			<0.001	<0.001	<0.001	0.017	<0.001	<0.001	<0.001
Cultivar			0.001	0.031	<0.001	0.002	0.273	0.282	<0.001
Additive			0.163	<0.001	<0.001	0.019	0.175	0.000	0.621
Wilt x cultivar			0.702	0.011	<0.001	0.012	0.273	0.014	0.028
Wilt x additive			0.278	0.053	<0.001	0.009	0.175	0.068	0.787
Cultivar x additive			0.391	0.313	0.177	0.559	0.292	0.246	0.833

Table 3.20. Silage chemical composition – individual treatment effects in Experiment 3.9

Wilting	Grass cultivar	Additive	pH	Lactic g/kgDM	Ethanol g/kgDM	Acetic g/kgDM	Propionic g/kgDM	Ferment. products g/kgDM	L/FP g/kg
Unwilt	Aberdart	1	3.73	137	31	37	0.0	205	671
Unwilt	Aberdart	2	3.80	103	40	12	0.0	155	663
Unwilt	Aberdart	3	3.73	135	33	26	0.0	194	697
Unwilt	Aberdart	4	3.73	139	33	23	0.0	195	714
Unwilt	Aberdart	5	3.80	125	36	31	0.0	191	647
Unwilt	Aberdart	6	3.73	138	34	24	0.0	196	703
Unwilt	Fennema	1	3.77	143	21	28	0.0	192	745
Unwilt	Fennema	2	3.83	103	38	14	0.0	155	660
Unwilt	Fennema	3	3.80	138	25	26	0.0	189	732
Unwilt	Fennema	4	3.87	120	25	29	0.0	174	690
Unwilt	Fennema	5	3.80	131	24	25	0.0	181	727
Unwilt	Fennema	6	3.80	134	24	24	0.0	183	735
Wilt	Aberdart	1	4.00	49	11	17	7.4	84	579
Wilt	Aberdart	2	4.03	40	7	19	5.3	72	574
Wilt	Aberdart	3	4.07	59	5	30	11.2	106	561
Wilt	Aberdart	4	3.97	65	5	29	8.8	108	598
Wilt	Aberdart	5	3.97	59	5	28	8.9	102	582
Wilt	Aberdart	6	3.97	53	5	31	10.2	99	530
Wilt	Fennema	1	4.07	67	5	16	15.4	103	643
Wilt	Fennema	2	4.10	51	7	19	5.8	82	633
Wilt	Fennema	3	4.03	66	6	13	7.8	93	709
Wilt	Fennema	4	4.07	70	6	14	7.6	97	721
Wilt	Fennema	5	4.00	77	5	18	13.0	113	677
Wilt	Fennema	6	4.00	71	5	17	11.9	105	676
s.e.m.			0.035	6.4	1.8	3.9	1.782	6.9	39.8
Signif. (P=)			0.706	0.887	0.283	0.098	0.292	0.449	0.700

L = lactic acid; FP = fermentation products

Table 3.21. Silage DM recovery from silo and indices of subsequent aerobic stability – main effects and major interactions in Experiment 3.9

Wilting	Grass cultivar	Additive	DM recovery (g/kg)	Hrs. to 'C'>2°C (A)	Hrs. to 'C'>5°C (B)	Max. °C rise	Hrs. to max. °C rise (C)	Hrs. from A to C
Main effect of wilting								
	Unwilt		932	30	37	22	58	31
	Wilt		985	45	64	14	95	53
Main effect of grass cultivar								
	Aberdart		965	36	50	16	74	42
	Fennema		952	39	51	21	79	42
Main effect of additive								
		1	971	34	49	15	76	43
		2	949	74	96	13	124	51
		3	948	28	33	31	57	36
		4	962	36	50	17	77	44
		5	962	25	35	18	58	38
		6	960	30	41	16	65	40
s.e.m								
	Wilting		3.2	2.5	2.9	3.2	3.4	1.6
	Cultivar		3.2	2.5	2.9	3.2	3.4	1.6
	Additive		5.6	4.3	5.0	5.5	5.8	2.8
	Wilt x cultivar		4.6	3.5	4.1	4.5	4.8	2.3
	Wilt x additive		7.9	6.1	7.1	7.8	8.3	3.9
	Cultivar x additive		7.9	6.1	7.1	7.8	8.3	3.9
Significance (P=)								
	Wilting		<0.001	<0.001	<0.001	0.071	<0.001	<0.001
	Cultivar		0.007	0.422	0.725	0.297	0.310	0.779
	Additive		0.056	<0.001	<0.001	0.221	<0.001	0.007
	Wilt x cultivar		<0.001	0.862	0.714	0.441	0.781	0.195
	Wilt x additive		0.795	<0.001	<0.001	0.380	<0.001	0.029
	Cultivar x additive		0.516	0.108	0.020	0.477	0.050	0.132

Table 3.22. Silage DM recovery from silos and subsequent aerobic stability – individual treatment effects in Experiment 3.9

Wilt	Grass cultivar	Additive	DM recovery (g/kg)	Hrs. to °C>2°C (A)	Hrs. to °C>5°C (B)	Max. °C rise	Hrs. to max. °C rise (C)	Hrs. from A to C
Unwilt	Aberdart	1	964	34	47	18	70	36
Unwilt	Aberdart	2	953	45	56	15	75	30
Unwilt	Aberdart	3	952	27	33	21	52	28
Unwilt	Aberdart	4	966	22	27	21	43	24
Unwilt	Aberdart	5	947	24	28	19	50	31
Unwilt	Aberdart	6	952	23	23	16	39	25
Unwilt	Fennema	1	916	25	37	16	61	36
Unwilt	Fennema	2	898	45	52	15	77	34
Unwilt	Fennema	3	903	23	27	74	48	30
Unwilt	Fennema	4	906	46	58	15	84	41
Unwilt	Fennema	5	918	24	24	20	45	28
Unwilt	Fennema	6	909	25	34	19	51	26
Wilt	Aberdart	1	992	40	61	14	92	52
Wilt	Aberdart	2	973	113	161	8	189	76
Wilt	Aberdart	3	953	27	27	16	54	42
Wilt	Aberdart	4	979	26	48	14	75	50
Wilt	Aberdart	5	976	26	41	17	66	47
Wilt	Aberdart	6	975	29	47	13	81	59
Wilt	Fennema	1	1011	37	51	12	82	49
Wilt	Fennema	2	973	93	115	13	156	63
Wilt	Fennema	3	985	34	46	15	74	44
Wilt	Fennema	4	997	50	67	18	106	63
Wilt	Fennema	5	1007	25	46	16	71	46
Wilt	Fennema	6	1003	42	58	15	89	47
s.e.m.			11.2	8.6	10.0	11.0	11.7	5.5
Signif. (P=)			0.956	0.802	0.266	0.349	0.612	0.802

Table 3.23. Silage aerobic deterioration after silo opening – main effects and major interactions in Experiment 3.9

Wilting	Grass cultivar	Additive	Acc. ^o C [^] to 24h	Acc. ^o C [^] to 48h	Acc. ^o C [^] to 72h	Acc. ^o C [^] to 96h	Acc. ^o C [^] to 120h	Acc. ^o C [^] to 144h	Acc. ^o C [^] to 168h	Acc. ^o C [^] to 192h
Main effect of wilting										
Unwilt			1.10	10.2	21.7	32.3	42.6	53.0	64.4	76.1
Wilt			1.11	4.6	13.3	23.4	32.8	42.2	53.3	68.0
Main effect of grass cultivar										
	Aberdart		1.28	7.9	18.2	29.0	38.7	48.3	58.3	69.5
	Fennema		0.94	6.9	16.7	26.8	36.6	46.9	59.4	74.7
Main effect of additive										
	1		0.77	5.4	15.5	26.5	37.8	48.4	59.9	74.0
	2		0.47	2.2	6.4	13.1	19.2	26.4	33.1	38.6
	3		1.82	11.0	23.8	35.6	46.4	57.8	71.5	87.7
	4		1.00	7.3	17.2	27.3	37.1	47.0	59.2	73.6
	5		1.37	10.2	23.5	35.1	45.4	55.9	68.6	83.6
	6		1.22	8.2	18.5	29.6	40.2	50.0	60.8	75.0
s.e.m.										
Wilting			0.139	0.77	1.25	1.38	1.46	1.70	2.15	2.71
Cultivar			0.139	0.77	1.25	1.38	1.46	1.70	2.15	2.71
Additive			0.241	1.33	2.17	2.39	2.52	2.95	3.72	4.70
Wilt x cultivar			0.197	1.08	1.77	1.95	2.06	2.41	3.04	3.83
Wilt x additive			0.341	1.88	3.07	3.38	3.57	4.18	5.26	6.64
Cultivar x additive			0.341	1.88	3.07	3.38	3.57	4.18	5.26	6.64
Significance (P=)										
Wilting			0.950	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.040
Cultivar			0.093	0.378	0.392	0.262	0.311	0.573	0.739	0.178
Additive			0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Wilt x cultivar			0.277	0.691	0.476	0.449	0.432	0.537	0.740	0.978
Wilt x additive			0.454	0.252	0.839	0.168	0.036	0.067	0.341	0.695
Cultivar x additive			0.175	0.401	0.494	0.569	0.526	0.457	0.565	0.802

Table 3.24. Silage aerobic deterioration after silo opening – individual treatment effects in Experiment 3.9

Wilt	Grass cultivar	Additive	Acc.°C	Acc.°C	Acc.°C	Acc.°C	Acc.°C	Acc.°C	Acc.°C	Acc.°C
			^ to 24h	^ to 48h	^ to 72h	^ to 96h	^ to 120h	^ to 144h	^ to 168h	^ to 192h
Unwilt	Aberdart	1	0.47	6.2	17.9	29.3	41.0	50.7	59.9	70.0
Unwilt	Aberdart	2	0.30	1.8	10.1	22.5	31.1	40.2	45.8	48.2
Unwilt	Aberdart	3	1.29	11.5	23.4	34.6	44.7	55.5	68.3	80.6
Unwilt	Aberdart	4	1.25	15.0	27.4	37.6	47.9	59.8	73.4	86.7
Unwilt	Aberdart	5	1.46	13.5	26.9	38.8	49.4	59.8	71.0	82.1
Unwilt	Aberdart	6	2.20	15.0	25.0	33.6	42.5	51.5	61.6	73.1
Unwilt	Fennema	1	0.69	7.2	22.0	33.2	44.2	56.0	69.9	86.7
Unwilt	Fennema	2	0.75	5.2	12.5	23.9	32.9	40.0	44.7	47.5
Unwilt	Fennema	3	1.61	14.7	29.3	40.1	50.8	62.7	77.4	93.7
Unwilt	Fennema	4	0.77	5.8	12.0	20.8	31.5	40.4	49.9	61.4
Unwilt	Fennema	5	1.73	16.6	29.4	39.5	50.4	64.4	82.2	97.0
Unwilt	Fennema	6	0.70	10.2	24.0	34.3	44.2	54.8	68.1	86.4
Wilt	Aberdart	1	0.72	2.7	9.0	21.5	33.6	44.3	55.3	70.0
Wilt	Aberdart	2	0.53	1.2	1.8	3.1	5.4	8.7	13.9	21.0
Wilt	Aberdart	3	3.44	12.5	26.9	39.6	51.4	63.9	77.8	94.3
Wilt	Aberdart	4	0.96	4.1	14.8	27.1	37.1	46.2	55.7	66.2
Wilt	Aberdart	5	1.37	6.2	20.5	33.1	43.1	51.7	61.3	74.4
Wilt	Aberdart	6	1.32	4.9	15.2	27.1	37.6	47.0	56.1	66.9
Wilt	Fennema	1	1.21	5.7	13.2	22.2	32.2	42.7	54.5	69.2
Wilt	Fennema	2	0.29	0.7	1.1	2.7	7.6	16.7	27.8	37.4
Wilt	Fennema	3	0.93	5.3	15.6	28.1	38.8	49.0	62.6	82.3
Wilt	Fennema	4	1.00	4.4	14.4	23.9	32.0	41.7	57.9	80.3
Wilt	Fennema	5	0.93	4.4	17.2	29.2	38.8	47.7	59.9	80.7
Wilt	Fennema	6	0.67	2.7	9.8	23.3	36.4	46.7	57.4	73.7
s.e.m.			0.107	0.14	0.22	0.40	0.48	0.31	0.18	0.17
Signif. (P=)			0.107	0.144	0.221	0.403	0.475	0.312	0.183	0.167

4. BEEF PRODUCTION

In this section, three large-scale animal production experiments were conducted using beef cattle:

Experiment 4.1 assessed the performance of finishing steers grazing either Fennema (normal WSC) or Aberdart (bred for elevated concentration of WSC) perennial ryegrass.

Experiment 4.2 quantified the intake, growth, digestion, N retention and microbial protein production of growing cattle when zero-grazed grass was fortified with a series of incremental rates of sugar.

Experiment 4.3 quantified the intake, growth and digestibility of cattle offered unwillted silage fortified with a series of incremental rates of sugar, either unsupplemented or supplemented with conventional concentrates.

Experiment 4.1. Performance of steers grazing ryegrass genotypes bred for normal or elevated concentrations of water soluble carbohydrate

Introduction

Grasses differing in their concentration of water soluble carbohydrates (WSC) could differ in the voluntary intakes they stimulate, in the growth and productivity of the animals grazing them and in the losses of nitrogenous materials via urine. This experiment aimed to assess the performance of steers grazing either 'Fennema' (normal WSC) or 'Aberdart' (bred for elevated concentration of WSC) perennial ryegrass.

Materials and methods

Swards (seven plots of Fennema and seven of Aberdart; total area 28 ha) were sown in September 2001, cut for silage and subsequently grazed in 2002, and cut for silage and 'zero-grazed' in 2003. In March 2004, four plots of each cultivar were fenced and prepared for grazing; the remaining three plots of each cultivar were used for silage early in the season, and were available to be brought into the grazing rotation later in the season, as required. Each plot was divided into sub-plots (paddocks) to facilitate optimal grazing management.

One group of 30-31 continental crossbred steers (mean initial liveweight 487 (s.e. 36.9) kg) was rotationally grazed on each cultivar from 28 April to 29 September, 2004. Each group was moved to a new paddock (usually on the same day) once swards had been grazed to a compressed height, measured using a rising plate meter, of about 6 cm. Steers were weighed unfasted at the start of the experiment, at 21 to 28-day intervals and on the day before slaughter on 29 September. Herbage mass was measured immediately before and after grazing each paddock using the rising plate meter. The plate meter was calibrated against herbage mass by cutting four strips (1.5 m x 5 m) to 5 cm height immediately before grazing in each paddock using a Haldrup forage harvester. Linear calibration equations were established for each month by regression between compressed sward height and herbage mass. Apparent herbage intake was estimated as the difference between pre- and post-grazing herbage masses per head per day. The freshly cut herbage from each strip was weighed and sampled. One 100 g sub-sample was dried at 98°C (16 h) for DM determination. A second 200 g sub-sample was dried at 60°C (48 h) and ground through a mill with a 1-mm screen. The milled samples were mixed and bulked into composites of each cultivar for determination of WSC, OMD/DMD, CP and ash concentrations.

Results and Discussion

Mean (s.d.) grass composition throughout the grazing season is shown in Table 4.1 – Figure 4.1 displays the seasonal profile of grass WSC concentration.

Table 4.1. Chemical composition of grass on offer throughout the grazing season in Experiment 4.1

Cultivar	Aberdart		Fennema	
	Mean	s.d.	Mean	s.d.
CP (g/kgDM)	189	27.8	187	32.0
Ash (g/kgDM)	99	14.1	96	10.7
WSC (g/kgDM)	151	49.2	139	68.7
OMD (g/kg)	767	41.8	758	50.5
DMD (g/kg)	761	138.1	750	138.7

There was no difference in the performance of steers grazing either Aberdart or Fennema ryegrass swards (Table 4.2) – Figure 4.2 shows the seasonal profile of animal liveweight. Pre- and post-grazing herbage mass, herbage allowance and apparent herbage intake were generally similar between the two treatments (Table 4.3 – intakes are based on the average of the group of cattle rather than on individual animal estimates, thereby preventing statistical contrasts of treatments).

Table 4.2. Performance of steers grazing either Aberdart or Fennema perennial ryegrass swards from 28 April to 29 September, 2004 in Experiment 4.1

	Aberdart	Fennema	s.e.d.	P
Final live weight (kg)	639	637	10.9	NS
Liveweight gain (kg/d)	1.01	0.98	0.038	NS
Carcass weight (kg)	337	336	6.2	NS

NS = not significant.

Table 4.3. Mean (s.d.) herbage mass, herbage allowance and apparent herbage intake for steers grazing either Aberdart or Fennema perennial ryegrass swards from 28 April to 29 September, 2004 in Experiment 4.1.

	Aberdart	Fennema
Pre-grazing herbage mass (kg DM/ha)	2570 (561)	2760 (556)
Post-grazing herbage mass (kg DM/ha)	1110 (206)	1130 (196)
Herbage allowance (kg DM/head/d)	15.3 (7.11)	13.7 (5.10)
Apparent herbage intake (kg DM/head/d)	8.7 (5.18)	8.1 (4.06)

s.d. in parentheses.

Conclusions

Sward productivity and the performance of grazing steers were similar for mono-culture swards of Aberdart and Fennema perennial ryegrass.

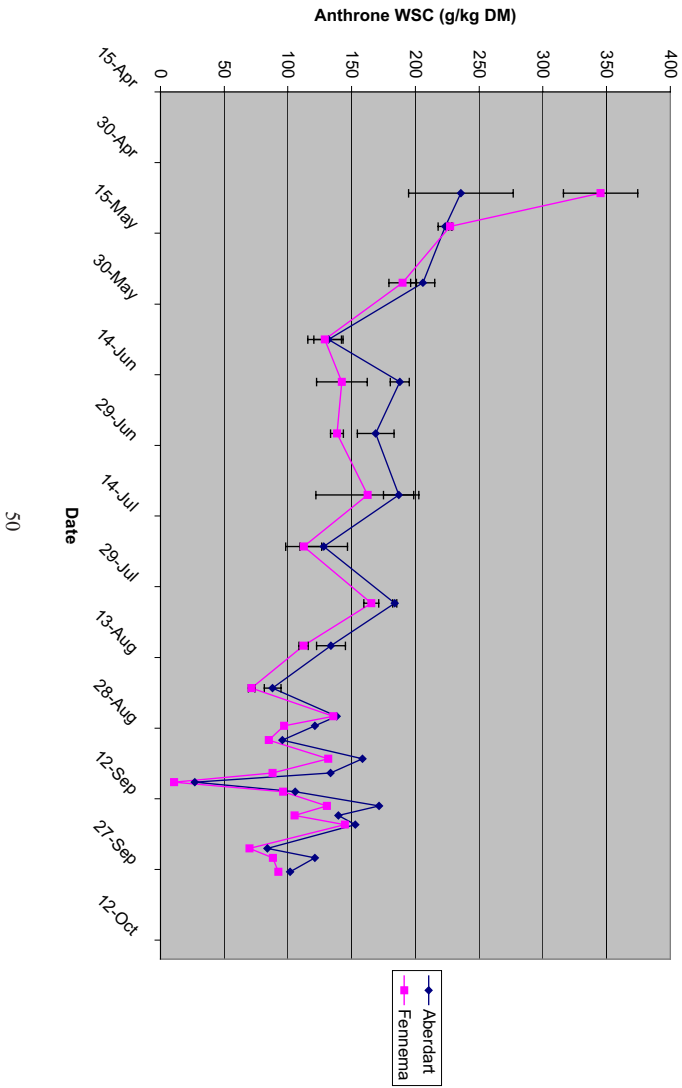
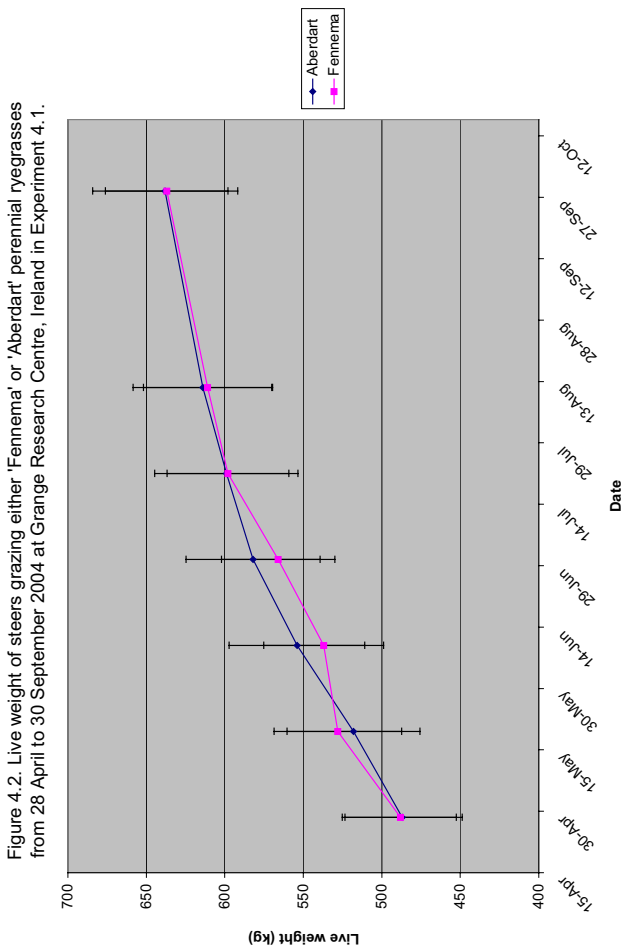


Figure 4.1. Concentration of water soluble carbohydrates (WSC) in Fennema and Aberdard perennial ryegrass herbage from 28 April to 30 September 2004 at Grange Research Centre, Ireland in Experiment 4.1.



Experiment 4.2: Intake, digestibility, growth and N metabolism by growing steers offered zero-grazed grass supplemented with a series of rates of sucrose

Introduction

Rumen metabolism of carbohydrate and nitrogenous compounds can be asynchronous in grazing cattle at some stages of the year. This has the potential to restrict animal production and lead to elevated excretion of urinary nitrogen. These in turn would have negative economic and environmental implications. Increasing the concentration of water soluble carbohydrates (WSC) in grass might better align the kinetics of carbohydrate and nitrogen metabolism in the rumen, leading to potentially improved growth rates and reduced excretion of urinary N by beef cattle. The purpose of this experiment was to be a proof-of-concept study, aimed at quantifying the intake, growth, digestion and N metabolism of beef cattle offered grasses differing only in sugar content. This was done by mimicking the sugar concentrations that could occur if comparable grasses of very contrasting sugar concentration existed and were offered to growing cattle.

Materials and Methods

The approach used was to increase the sugar concentration of zero-grazed grass by adding supplementary sugar in a step-wise series of doses. Grass was zero-grazed because it facilitated accurate measurement of grass intakes and of faecal and urinary outputs, permitted accurate supplementation with a series of rates of added sucrose and eliminated potentially confounding effects of sward supply, structural characteristics etc.

Grass was harvested daily from July until October, 2003 and offered to steers through Calan gates. The treatments are as follows:

- A mixture of Fennema and Aberdart alone
- A mixture of Fennema and Aberdart + 3% WSC
- A mixture of Fennema and Aberdart + 6% WSC
- A mixture of Fennema and Aberdart + 9% WSC
- A mixture of Fennema and Aberdart +12% WSC

Sucrose was mixed with grass each day, and was added on a DM basis (i.e. +3% = +30g sucrose/kg grass DM).

Results and Discussion

There were 15 individually-fed Charolais crossbred steers per treatment. Intakes, liveweight gains and urinary and faecal outputs were recorded. Results are summarised in Tables 4.4-4.7.

Total (i.e. grass and added WSC) animal daily dry matter intakes (DMI) and daily liveweight gains (LWG) for the five treatments are presented in Table 4.5. Cattle offered zero-grazed grass with incremental levels of supplemental WSC had an increase in intake to the first increment (30g/kg grass DM) of WSC, but not thereafter. Orthogonal contrasts showed a positive ($P=0.007$) linear relationship between DMI (kg/d) and level of added WSC. A positive linear trend ($P=0.002$) existed between increasing WSC addition (X) (g/kg grass DM) and DMI (Y) (g/kg bodyweight) and this relationship is best described by the equation:

$$Y = 0.014(\text{s.e. } 0.0044)X + 18.65(\text{s.e. } 0.324), R = 0.33, P = 0.002.$$

There was no significant effect ($P>0.05$) of increasing WSC content on liveweight gain, but relative to the control (no added WSC), increasing levels of WSC tended ($P=0.054$) to increase liveweight gain. A positive linear trend ($P=0.027$) existed between LWG and increasing levels of WSC.

As sucrose addition increased there was a significant increase ($P<0.05$) in the faecal excretion of nitrogen and this was coupled with an inverse significant reduction of urinary nitrogen excretion. As a consequence, there were no significant ($P>0.05$) effects of sucrose level on total loss of nitrogen in grams per day, or in grams of nitrogen retained per day. However, there is a decreasing linear trend ($P=0.052$) of total N loss as level of sucrose increases, and an increasing linear trend ($P=0.085$) in nitrogen retained in grams per day, as level of sucrose increases.

Total faecal N output by cattle given the 12% and 9% levels of sucrose was higher ($P<0.05$) than with the 0% (ie control) and 6% levels. Faecal N output from cattle given the 3% did not differ ($P>0.05$) from any of the other sucrose levels. Faecal N output and increasing levels of sucrose showed a significant positive linear relationship ($P=0.006$).

The urinary N output by the cattle given 0% sucrose did not differ ($P>0.05$) from cattle given the 3% level, but was significantly higher ($P<0.05$) than all other levels. Urinary N output for the 12% sucrose level was lower ($P<0.05$) than the 0 and 3% levels, but did not differ ($P>0.05$) from the 6 and 9% levels. The fraction of N excreted in the urine decreased linearly ($P<0.001$) with increasing level of sucrose.

The partitioning of N excretion between the faeces and the urine (Y) (ie the ratio of faecal N excretion to urinary N excretion) increased as sucrose level (X) increased. The ratio increased in a linear fashion and the equation that represents this increase is as follows:

$$Y = 0.046(\text{s.e. } 0.0072)X + 0.927(\text{s.e. } 0.0532), R = 0.7, P < 0.001.$$

The amount of N excreted in the faeces in relation to N intake showed a significant ($P=0.03$) increasing linear response in favour of increasing sucrose level. Urinary N excretion did differ significantly ($P<0.05$) between the

levels and decreased linearly ($P < 0.001$) as level of sucrose increased. The amount of N excreted in the faeces in relation to N intake (Y) and sucrose level (X) can be expressed as a linear equation of :

$$Y = 4.5(\text{s.e. } 1.99)X + 421.7(\text{s.e. } 14.6), R = 0.32, P = 0.03.$$

Nitrogen excreted in the urine as a proportion of nitrogen intake did not differ ($P > 0.05$) between levels 12, 9 and 6%, but 12 and 9% were lower ($P < 0.05$) than 0 and 3%, with 6% being lower ($P < 0.05$) than 0% but not different ($P > 0.05$) from any other level. Nitrogen excreted in the urine as a proportion of nitrogen intake (Y) and sucrose level (X) can be expressed as a linear equation of :

$$Y = -11.05(\text{s.e. } 2.1)X + 452.9(\text{s.e. } 15.4), R = -0.64, P < 0.001.$$

There was no significant ($P > 0.05$) treatment effect on total N retained, when expressed as a proportion of total N intake (Y), but a positive linear trend ($P = 0.054$) existed as level of sucrose (X) increased and this can be described by the equation:

$$Y = 6.54(\text{s.e. } 3.24)X + 125.4(\text{s.e. } 23.8), R = 0.26, P = 0.054.$$

Increasing levels of sucrose did not alter ($P > 0.05$) total purine derivative excretion, nor the individual components of the purine derivatives. Microbial N supply (g/day) was not altered ($P > 0.05$) by sucrose addition. However, when microbial N supply is expressed as grams per kilogram of N intake and digestible organic matter intake, significant ($P < 0.05$) treatment effects do occur.

Microbial N (g/kg DM intake) supply for the 0% sucrose did not differ ($P > 0.05$) from the 3 and 6% levels. Cattle on 12 and 9% added sucrose had a higher microbial N supply than cattle on the 0 and 3% levels, and cattle on 6% sucrose had higher ($P < 0.05$) supplies than those on 3% sucrose, but did not differ ($P > 0.05$) from any of the other levels.

The microbial N supply, expressed as g/kg DOMI of animals given the 0, 3 and 6% levels did not differ ($P > 0.05$) from each other but were significantly ($P < 0.05$) lower than the 9 and 12% levels.

Microbial N supply, expressed as g/kg of N and g/kg of DOMI intake increased linearly ($P < 0.001$), and cubically ($P = 0.007$) and linearly ($P < 0.001$), quadratically ($P = 0.044$) and cubically ($P = 0.031$) respectively, with regard to increasing sucrose level.

Table 4.4. Mean (s.d.) composition of grass offered (zero-grazed) in Experiment 4.2

Dry matter (g/kg)	203 (30.9)
in vitro DMD (g/kg)	687 (50.2)
in vitro OMD (g/kg)	709 (45.9)
Ash (g/kgDM)	148 (36.1)
Crude protein (g/kgDM)	160 (27.4)
NDF (g/kgDM)	495 (19.1)
ADF (g/kgDM)	259 (17.3)
WSC (g/kgDM)	148 (24.8)

Table 4.5. Intake and growth rate of steers offered (zero-grazed) grass with incremental rates of addition of sucrose in Experiment 4.2

Level of added sucrose (%)	0	3	6	9	12	s.e.d.
Grass DM intake (kg/day)	6.63	7.08	6.91	7.36	7.33	0.207
Liveweight gain (kg/day)	0.77	0.94	0.84	0.95	0.95	0.073

Table 4.6. Digestibility and N-retention by steers offered (zero-grazed) grass with incremental rates of addition of sucrose in Experiment 4.2

	Level of added sucrose (%)											
	0	3	6	9	12	s.e.d.	Sig.	L	Q	C		
DDMI (kg)	7.23	7.44	7.33	7.91	7.94	0.373	NS	0.03	NS	NS		
N intake (g/day)	166	166.5	162.5	170.1	160.4	11.04	NS	NS	NS	NS		
Daily N intake (g/kg BW)	0.42	0.42	0.42	0.42	0.41	0.025	NS	NS	NS	NS		
Digestibility co-efficients (g/kg)												
Dry matter	626	627	660	634	636	18.3	NS	NS	NS	NS		
Organic matter	720	723	744	729	732	13.1	NS	NS	NS	NS		
ADF	656	645	669	638	631	24.2	NS	NS	NS	NS		
NDF	733	723	739	716	707	19.3	NS	NS	NS	NS		
DOMD (g/kg DM)	581	593	612	602	601	17.0	NS	NS	NS	NS		
N loss (g/day)												
Faeces	70.1 ^b	73.4 ^{ab}	67.7 ^b	76.8 ^a	78.2 ^a	2.98	**	0.006	NS	NS		
Urine	76.8 ^a	68.9 ^{ab}	61.6 ^{bc}	59.2 ^{bc}	52.7 ^c	6.57	**	<0.001	NS	NS		
Total	146.9	142.3	129.3	136	130.8	8.5	NS	0.052	NS	NS		
N retained	19.1	24.2	33.2	34.1	29.6	7.78	NS	0.085	NS	NS		
Daily N retained (g/kg BW)	0.05	0.06	0.08	0.08	0.07	0.019	NS	0.074	NS	NS		
Facecal N : urinary N	0.94 ^a	1.09 ^{ab}	1.15 ^{bc}	1.34 ^{cd}	1.51 ^d	0.100	***	<0.001	NS	NS		
N loss(g/kg N intake)												
Faeces	427	447	427	453	491	26.8	NS	0.03	NS	NS		
Urine	460 ^c	417 ^{bc}	380 ^{ab}	347 ^a	330 ^a	29.1	***	<0.001	NS	NS		
Retained	113	137	193	201	179	44.1	NS	0.054	NS	NS		

Table 4.7. Estimated microbial protein production by steers offered (zero-grazed) grass with incremental rates of addition of sucrose in Experiment 4.2

Level of added sucrose (%)	Level of added sucrose (%)											
	0	3	6	9	12	s.e.d.	Sig.	L	Q	C		
PD excretion (mmol/day ³)	192.0	218.7	208.0	209.3	216.9	19.72	NS	NS	NS	NS		
Allantoin	4.7	4.9	4.0	4.2	3.9	0.63	NS	NS	NS	NS		
Uric acid	196.7	223.5	212.0	213.5	220.8	19.80	NS	NS	NS	NS		
Total												
Microbial N (g/day)	139.1	162.1	152.4	152.6	159.6	16.68	NS	NS	NS	NS		
Microbial N (g/kg DM intake)	18.39 ^{ab}	15.66 ^a	20.47 ^{bc}	23.97 ^b	23.41 ^c	1.797	***	<0.001	NS	0.007		
Microbial N (g/kg DOMD)	31.36 ^a	26.22 ^a	32.33 ^a	39.16 ^b	42.02 ^b	3.029	***	<0.001	0.044	0.031		

Orthogonal contrasts

Experiment 4.3: Intake, digestibility and growth by growing steers offered unwilted grass silage supplemented with a series of rates of sucrose

Introduction

Among the changes that occur during silage fermentation are a reduction in the content of WSC (being replaced by fermentation products such as lactic acid, acetic acid, butyric acid, ethanol, etc.) and an increase in the proportion of crude protein present as breakdown products of protein. (e.g. peptides, amino acids, ammonia-N, etc.). There is thus a likelihood that the metabolism of silage carbohydrate and nitrogenous compounds in the rumen may be asynchronous, leading to their sub-optimal conversion to animal product. Thus, it could be hypothesised that fortifying unwilted (extensively fermented) grass silage with readily digestible carbohydrate could improve the efficiency of rumen metabolism and result in improved animal productivity and reduced losses of urinary N. The supply of readily digestible carbohydrate could be increased (1) by ensiling grasses of elevated WSC content and/or modifying silage fermentation in order to increase the content of residual WSC in silage and/or restricting aerobic deterioration to protect WSC from catabolism during silage feedout, or (2) by supplementing animals with highly digestible carbohydrate-rich concentrate feeds such as barley, wheat, maize, citrus pulp, molassed beet pulp, etc. In the present study, grass silage fortified with a range of rates of addition of sucrose was offered to growing beef cattle as the sole dietary source or with supplementary concentrates. It was a proof-of-concept study, aimed at mimicking the sugar concentrations that could occur in silage if grasses of very contrasting sugar concentration existed and were preserved optimally.

Materials and Methods

In late May, 2003, grass was precision-chop harvested without wilting, and ensiled in roofed, horizontal silos. At the end of June 2004 silage was offered to growing beef cattle with the following treatments:

1. silage (*ad libitum*) + 0 kg concentrates/head/day
2. silage + 3% sucrose (*ad libitum*) + 0 kg concentrates/head/day
3. silage + 6% sucrose (*ad libitum*) + 0 kg concentrates/head/day
4. silage + 9% sucrose (*ad libitum*) + 0 kg concentrates/head/day
5. silage (*ad libitum*) + 3kg concentrates head/day
6. silage + 3% sucrose (*ad libitum*) + 3kg concentrates head/day
7. silage + 6% sucrose (*ad libitum*) + 3kg concentrates head/day
8. silage + 9% sucrose (*ad libitum*) + 3kg concentrates head/day

Sucrose was mixed with fresh silage each day, and was added on a DM basis (i.e. +3% = +30g sucrose/kg silage DM).

Twelve Continental-crossbred growing steers (mean (s.d.) starting liveweight 376 (25.4) kg) were allocated to these eight diets in a randomised complete block design. On a daily basis each animal was individually offered (through Calan gates) fresh silage *ad libitum* (at 1.15 times intake) for 109 days. Drinking water was also offered *ad libitum*. Animals offered supplementary concentrates (800g rolled barley, 140g soyabean meal, 50g molasses and 20g mineral/vitamin mix per kg) each received their daily allocation in a single feed every morning. Animals not receiving supplementary concentrates received 60g min./vit. mixture dusted onto their fresh silage each day. Starting and final liveweights were the mean of weighings on two consecutive days.

Contemporaneously, a group of twelve Continental-crossbred steers (mean (s.d.) liveweight 343 (23.7) kg) were used to determine the digestibility of silage fortified with 0, 4.5 or 9% sucrose, alone or with supplementary concentrates. This was conducted on two separate occasions (two runs).

Samples of grass dried at 60°C (48h) were milled through a sieve with 1mm diameter pores and were used for assessing *in vitro* DM digestibility (DMD) and organic matter digestibility (OMD) (Tilley and Terry, 1963; with the modification that the final residue was isolated by filtration rather than by centrifugation), neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Goering and van Soest, 1970), ash (muffle furnace at 550°C for 5h), crude protein (total N x 6.25; LECO FP 428 nitrogen analyser – AOAC, 1990), buffering capacity (Playne and McDonald, 1966) and WSC (anthrone method).

Silage samples were taken three times per week and composited each fortnight. Each composite sample was:

~ dried (200g) at 85°C (16h) for estimation of DM content

~ dried (200g) at 40°C (48h), milled (as for grass) and used for determination of crude protein, WSC, buffering capacity and *in vitro* DM digestibility (DMD).

~ juice was extracted and assayed for pH, lactic acid, VFA, ethanol, WSC and NH₃-N.

Feed intake, animal growth rate and feed efficiency data were subjected to analysis of variance with the effects of concentrate supplementation, sucrose fortification, concentrates x sucrose and block being included in the model. *In vivo* dietary digestibility were subjected to analysis of variance with the effects of concentrate supplementation, sucrose fortification, concentrates x sucrose and run being included in the model. The individual treatment means were separated using the least significant difference procedure.

Results and Discussion

The mean (s.d.) composition of the grass at ensiling was crude protein 110 (9.3) g/kgDM, ash 78 (8.3) g/kgDM, NDF 598 (17.3) g/kgDM, ADF 324 (10.7) g/kgDM, WSC 163 (20.3) g/kgDM and buffering capacity 279 (16.2) mEq/kgDM. The mean (s.d.) composition of silage at feedout was DM 176 (12.3) g/kg, *in vitro* DMD 630 (22.2) g/kg, crude protein 121 (6.6) g/kgDM, buffering capacity 730 (46.5) mEq/kgDM, WSC 7 (1.3) g/kgDM, NH₃-N 126 (15.2) g/kgN and lactic acid 120 (14.5) g/kgDM.

Supplementation with concentrates increased (P>0.001) final liveweight, liveweight gain, total DM intake and the liveweight gain produced per unit total DM intake (Table 4.8). Supplementation correspondingly reduced (P<0.001) silage DM intake. In contrast, fortifying silage with added sucrose did not alter (P>0.05) intake, liveweight gain or feed efficiency. There was a trend (P=0.083) for the 3% and 6% rates of fortification with sucrose to increase DM intake when expressed relative to mean liveweight. No interaction was evident (P>0.05) between supplementation with concentrates and fortification with sucrose.

Table 4.8 Feed intake, animal growth rate and feed efficiency for main effects and individual treatment effects in Experiment 4.3

Meals kg/day	Sugar	Liveweight (kg)		Lwt. gain g/d	Silage DM ¹ intake		Total DM intake		Feed efficiency ²
		Start	Finish		kg/d	g/kgLwt.	kg/d	g/kgLwt.	
Main effects of supplementary meals									
0		377.8	405.8	257	5.54	14.2	5.60	14.3	45.0
3		374.5	476.3	934	5.00	11.8	7.52	17.7	125.6
Main effects of level of sugar fortification									
	None	380.6	443.7	579	5.15	12.6	6.44	15.6	85.8
	3%	375.5	438.4	577	5.35	13.2	6.64	16.2	80.8
	6%	373.9	440.3	609	5.44	13.4	6.73	16.5	84.7
	9%	374.6	441.8	616	5.14	12.7	6.43	15.7	89.9
Individual treatment effects (meals x sugar)									
0	None	382.4	408.2	237	5.51	14.0	5.57	14.1	41.3
0	3%	373.5	398.0	225	5.59	14.5	5.65	14.7	39.6
0	6%	380.8	407.6	247	5.68	14.4	5.74	14.6	42.9
0	9%	374.5	409.2	318	5.39	13.7	5.45	13.9	56.3
3	None	378.8	479.2	921	4.80	11.2	7.32	17.1	130.3
3	3%	377.6	478.9	929	5.10	11.9	7.62	17.8	122.1
3	6%	367.0	472.9	972	5.20	12.4	7.72	18.4	126.4
3	9%	374.8	474.4	914	4.90	11.6	7.42	17.5	123.5
Standard error of the mean									
Meals		1.57	2.77	20.7	0.088	0.20	0.088	0.20	3.54
	Sugar	2.22	3.92	29.2	0.124	0.28	0.124	0.28	5.00
Meals	Sugar	3.14	5.55	41.3	0.176	0.40	0.176	0.40	7.07
Significance (P=)									
Meals		0.149	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Sugar	0.141	0.808	0.696	0.245	0.106	0.245	0.083	0.644
Meals	Sugar	0.034	0.455	0.420	0.898	0.746	0.898	0.650	0.461

¹Based on 85°C oven DM; ²g liveweight gain per kg total DM intake

These results suggest that in this experiment with a forage of relatively high fibre content and low protein content that animal growth was more limited by energy intake (and hence the large response to +3kg concentrates per head daily) than by the ratio of residual WSC to crude protein (reflected in the absence of a response to fortification with sucrose).

In vivo dietary DM digestibility was increased (P<0.01) by supplementation with concentrates but was not altered (P>0.05) by fortification of silage with sucrose (Table 4.9). No interaction was evident (P>0.05) between supplementation with concentrates and fortification with sucrose.

Table 4.9. *In vivo* dietary digestibility for main effects and individual treatment effects in Experiment 4.3

	Meals	Sugar	DM digestibility
	kg/day		g/kg
Main effects of supplementary meals			
	0		670
	3		711
Main effects of level of sugar fortification			
		0%	694
		4.5%	692
		9.0%	693
Individual treatment effects (meals x sugar)			
	0	0%	673
	0	4.5%	676
	0	9%	653
	3	0%	711
	3	4.5%	708
	3	9%	714
Standard error of the mean			
	Meals		8.1
		Sugar	10.0
	Meals	Sugar	14.1
Significance (P=)			
	Meals		0.002
		Sugar	0.857
	Meals	Sugar	0.629

Conclusions

Fortifying the unwilted grass silage offered to growing steers with sucrose in the current experiment did not alter any of the intake, digestion, growth or feed efficiency variables examined. The effects of fortification with sucrose did not interact with those of concentrate supplementation.

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5. CONCLUSIONS

Grass WSC

Grasses were sown in autumn 2000 and plots harvested throughout 2001-2003. A wide range of weather conditions prevailed during the many grass growths and at the times of harvesting. Aberdart had been recommended as a diploid, intermediate, perennial ryegrass bred for elevated concentrations of water soluble carbohydrates (WSC) while Fennema was considered a comparable ryegrass not selected for elevated WSC. In one experiment, additional treatments included another 'high sugar' diploid ryegrass (Ba11353) and a tetraploid ryegrass (Greengold - not selected for elevated WSC).

Across the three experiments, Aberdart had an average of 11g more WSC per kg DM than Fennema (i.e. an additional one percentage unit more) (Table 5.1). This was a relatively modest increase, and considerably less than originally anticipated. In contrast, the scale of benefit was larger with Ba11353. The tetraploid cultivar Greengold had a WSC content between Aberdart and Ba11353.

Table 5.1. Overall mean concentrations of water-soluble carbohydrates (g/kgDM) in grass

Experiment	Year(s)	Aberdart	Fennema	Ba11353	Greengold
Cultivar comparisons (Exp. 2.1)	2001,2002,2003	167	157	187	174
Rates of N fertiliser (Exp. 2.2)	2001,2003	169	157	-	-
Forms of N fertiliser (Exp. 2.3)	2001	148	136	-	-

It should be noted that most farmers sowing grass seeds use a mixture of cultivars. Thus, the likely magnitude of impact of 'high sugar' cultivars on sward WSC content would logically be diminished compared to when grown in monoculture. In addition, where farmers want swards with an elevated content of WSC, inclusion of tetraploid cultivars in the seed mixture may be helpful.

Ensilage

Grass was ensiled at a range of growth stages (from very leafy to stemmy) and under many different environmental conditions. Grass ensilability across the nine harvests varied from 'difficult' to 'easy' and the prevailing wilting conditions extended from 'no drying' to 'rapid drying'. Untreated, unwilted silages underwent a range of fermentations, from lactic acid dominant to highly clostridial.

Across nine direct comparisons with unwilted grass, Aberdart had a slightly higher WSC content and a slightly lower buffering capacity compared to Fennema (Table 5.2). This resulted in a marginally better average standard of resultant silage preservation (Table 5.2) – overall, seven of the Aberdart silages and five of the Fennema silages could be judged to have preserved satisfactorily when no additive was used (see Table 5.2).

The success of wilting depended on the rate and extent of drying achieved. Wilting could thus improve, disimprove or restrict fermentation depending on the characteristics of the crop at mowing and the subsequent prevailing weather conditions. Wilted silages therefore tended to have only traces of WSC if the crops were ensiled under very difficult conditions or alternatively high WSC values if they were ensiled following rapid and extensive wilting. Wilting usually improved aerobic stability.

Formic acid clearly had the greatest beneficial effect of all the additives evaluated. It promoted a lactic acid fermentation if the silage made without additive preserved poorly while it restricted fermentation and increased the content of residual WSC if the silage made without additive was well preserved. It generally improved aerobic stability.

Kofasil Ultra influenced fermentation in a similar direction to formic acid but did not have beneficial effects on aerobic stability.

Homofermentative lactic acid bacteria had no measurable benefit on silage fermentation when 'untreated silage' was badly preserved. They were capable of improving fermentation when the 'untreated silage' had a borderline standard of preservation. Effects on fermentation (i.e. residual WSC) when the 'untreated silage' was excellently preserved could be beneficial, but not consistently. In the latter situation, homofermentative lactic acid bacteria tended to create aerobically less stable silages.

Heterofermentative lactic acid bacteria had no beneficial effect on fermentation and the effects on aerobic stability were far from consistent.

Inclusion of sodium benzoate or potassium sorbate did not confer benefits initially. In a final experiment sodium benzoate overcame the negative effects of homofermentative lactic acid bacteria on aerobic stability (i.e. returned it to a similar status to silage made without additive).

Table 5.2 shows the relative effects of the two grasses on preservation of unwilted grass across nine direct comparisons. Aberdart tended to have a superior standard of silage preservation compared to Fennema and this is clearly a desirable trend. Whereas some of this effect can be attributed to the higher content of WSC in Aberdart, the lower buffering capacity of Aberdart also contributed (additively).

Table 5.2. Overall preservation of unwilted silages made using Aberdart and Fennema (average of nine direct comparisons)

	Aberdart	Fennema
Grass sugars (g/kgDM)	158	137
Buffering capacity (mEq/kgDM)	419	446
Silage		
pH	4.29	4.53
Lactic acid (g/kgDM)	89	72
Butyric acid (g/kgDM)	0.4	1.3
Ammonia-N (g/kgN)	93	122
DM recovery (%)	90	91
Good preservation	7/9	5/9

Beef production

The two grasses Aberdart and Fennema presumably differ from one another in a number of traits, one of which is WSC content. Where an area of large field-scale replicated plots was sown to each grass (14ha/cultivar), the mean WSC content of Aberdart and Fennema throughout a 154 day grazing duration was 151 and 139 g/kgDM, respectively. This 12 g difference in WSC/kgDM (i.e. 1.2% units difference) (allied to whatever other differences existed between these two cultivars) was insufficient to create any measurable difference in the growth rate of steers (30 per treatment) throughout this extended duration. This was under conditions where the animal growth potential and standard of grazing management were sufficiently good to support an overall liveweight gain by these beef steers of 1.0 kg/day.

In contrast, when (zero-grazed) grass was fortified with a series of rates of added sucrose, DM intake increased from 6.63 to 7.17 (mean of four rates of fortification) kg/day and liveweight gain from 0.77 to 0.92 (mean of four rates of fortification) kg/day. The difference in intake between the unfortified and fortified groups is equal to the intake of added sugar, indicating that the intake of grass DM *per se* was unchanged. The resultant 0.15 kg liveweight gain response per day was of a substantial magnitude, and was greater than might be expected solely from an "energy supplement". This suggests that increasing the WSC content of grass can improve the growth rate of beef cattle, provided that the scale of elevation in grass WSC content is sufficiently large. Furthermore, the results presented in this report indicate that increasing grass WSC content partitions the excretion of N by beef cattle more towards faeces and less towards urine. This change should be beneficial environmentally in terms of reducing the loss of excreted N that reaches ground-water via nitrate.

The precise elevation in grass WSC required to stimulate a measurable response in forage intake, animal growth or the partitioning of N excretion between urine and faeces may be difficult to specify. The target threshold increase may vary depending on factors such as the concentration and form of WSC in "non selected" ryegrasses (and their contribution to the total herbage DM intake from a sward), the concentration and form of protein and possibly other constituents in a sward, the level and type of animal production occurring and the attribute (e.g. intake, liveweight gain, ratio of excreted faecal N to excreted urinary N, etc.) being considered.

The crude protein in extensively fermented unwilted grass silage is normally much more soluble than in the original grass and the content of rapidly digestible carbohydrate is correspondingly low. Thus, it was hypothesised that fortifying such a silage with added sucrose would counteract this apparent imbalance. In farm practice, however, Irish beef farmers do not offer silage to cattle intended to grow at commercial growth rates without supplementing with some form of energy concentrate. The latter, besides providing additional energy to the cattle, also provide a mechanism to counteract the apparent imbalance outlined above. The large magnitude of the liveweight gain response to supplementary concentrates in Experiment 4.3 was not surprising. However, the absence of an interaction between supplementary concentrates and added sugar was surprising. Overall, the results suggest that in this experiment with a forage of relatively high fibre content and low protein content that animal growth was more limited by energy intake (and hence the large response to +3kg concentrates per head daily) than by the ratio of residual WSC to crude protein (reflected in the absence of a response to fortification with sucrose).

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Go raibh mile maith agaibh!

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