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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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# 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:

- produce high yields in response to fertiliser nitrogen
- have a high digestibility when harvested at the appropriate growth stage
- are relatively easy to preserve as silage due to their superior content of sugar
- 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:

- 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.
- 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.
- produce a grass with higher intake characteristics during grazing, resulting in improved or more efficient animal production.
- 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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- Institute of Grassland and Environmental Research (IGER), Wales
- Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden
- Institute of Crop and Grassland Science, Federal Agricultural Research Centre (FAL) Braunschweig, Germany
- 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.

- 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.
- Experiment 2.2 evaluated the effects of varying N fertiliser application rates on perennial ryegrass cultivars with high or normal WSC genotypes.
- 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 $m^2$ 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/$m^2$. 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, 8July, 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 $98^0$C for 16h in an oven with forced air circulation. Samples dried at $60^0$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 $550^0$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, Aberelan 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 Aberelan. 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. Aberelan 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, Aberelan 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 Aberelan. 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 Aberelan 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,Aberelan 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 Aberelan 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[1] 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 |

[1]Fennema, Aberelan and Spelga (i.e. diploids excluding the two cultivars bred for elevated WSC); [2]2001 & 2002; [3]2001

**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 ($N_r$) 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 $N_r$ were sampled and weighed. Measurement data were analysed using a split-plot design. The relationship between the variables measured and both $N_r$ and cultivar were examined by stepwise multiple regression analysis [$y = f(N_r, N_r^2$, cultivar (C), C x $N_r$, C x $N_r^2$)] 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 $N_r$ 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 > Fennama (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 $N_r$ were maintained across harvests and years - there were not significant $CxN_r$, $HxCxN_r$, $CxN_rxY$ or $HxCxN_rxY$ 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.

**References:**

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Teagasc, 1998. Management data for farm planning. Teagasc, Dublin, 202 pages.

**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; [1]Standard 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 | | | | | | | | | | | $HxN_r$ | *** | 3.9 |
| H1 | 234 | 201 | 182 | 188 | 180 | 250 | 226 | 187 | 172 | 173 | HxC | ns | 3.2 |
| H2 | 209 | 169 | 156 | 138 | 137 | 222 | 166 | 154 | 149 | 143 | $CxN_r$ | ns | 2.1 |
| H3 | 212 | 205 | 195 | 192 | 192 | 205 | 207 | 209 | 186 | 197 | $HxCxN_r$ | * | 4.8 |
| H4 | 189 | 152 | 147 | 139 | 142 | 172 | 152 | 153 | 145 | 148 | | | |

**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 | | | | | | | | | | | $HxN_r$ | *** | 4.1 |
| H1 | 91 | 92 | 108 | 124 | 142 | 89 | 106 | 113 | 134 | 154 | HxC | ns | 2.9 |
| H2 | 164 | 174 | 214 | 262 | 275 | 140 | 194 | 229 | 254 | 282 | $CxN_r$ | ns | 2.6 |
| H3 | 126 | 145 | 174 | 188 | 192 | 132 | 142 | 166 | 191 | 204 | $HxCxN_r$ | ns | 5.5 |
| H4 | 162 | 200 | 219 | 226 | 247 | 180 | 203 | 233 | 244 | 248 | | | |

**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 | | | | | | | | | | | $HxN_r$ | *** | 3.8 |
| H1 | 806 | 761 | 759 | 755 | 747 | 807 | 765 | 756 | 753 | 754 | HxC | ns | 2.7 |
| H2 | 822 | 834 | 822 | 823 | 831 | 820 | 829 | 820 | 818 | 809 | $CxN_r$ | ns | 2.5 |
| H3 | 771 | 743 | 771 | 763 | 755 | 766 | 743 | 756 | 753 | 758 | $HxCxN_r$ | ns | 5.1 |
| H4 | 752 | 756 | 775 | 779 | 777 | 778 | 768 | 783 | 778 | 787 | | | |

**Table 2.21** Grass ash 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 | 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 | | | | | | | | | | | $HxN_r$ | ns | 2.6 |
| H1 | 91 | 81 | 84 | 77 | 79 | 73 | 75 | 84 | 80 | 82 | HxC | ns | 2.1 |
| H2 | 114 | 109 | 110 | 104 | 114 | 106 | 111 | 102 | 106 | 107 | $CxN_r$ | ns | 1.4 |
| H3 | 112 | 111 | 109 | 113 | 111 | 111 | 109 | 103 | 110 | 107 | $HxCxN_r$ | ns | 3.2 |
| H4 | 105 | 116 | 108 | 115 | 110 | 106 | 113 | 110 | 111 | 107 | | | |

**Table 2.22** Grass WSC 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 | 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 | | | | | | | | | | | $HxN_r$ | *** | 6.2 |
| H1 | 275 | 247 | 209 | 188 | 169 | 238 | 235 | 196 | 175 | 156 | HxC | ns | 4.2 |
| H2 | 173 | 168 | 132 | 106 | 106 | 185 | 116 | 111 | 110 | 92 | $CxN_r$ | ns | 4.2 |
| H3 | 175 | 161 | 155 | 149 | 157 | 153 | 156 | 162 | 143 | 143 | $HxCxN_r$ | ns | 8.7 |
| H4 | 180 | 145 | 140 | 132 | 137 | 160 | 141 | 134 | 132 | 136 | | | |

**Table 2.23** Grass buffering capacity (mEq/kgDM) 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 | 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 | | | | | | | | | | | $HxN_r$ | * | 10.5 |
| H1 | 188 | 214 | 234 | 270 | 264 | 210 | 225 | 250 | 291 | 277 | HxC | * | 9.4 |
| H2 | 270 | 290 | 309 | 362 | 367 | 267 | 314 | 352 | 367 | 370 | $CxN_r$ | ns | 4.4 |
| H3 | 229 | 265 | 298 | 297 | 312 | 261 | 264 | 276 | 309 | 298 | $HxCxN_r$ | ** | 12.2 |
| H4 | 344 | 316 | 371 | 332 | 351 | 291 | 320 | 354 | 354 | 379 | | | |

**Table 2.24** Grass nitrate concentration (g/kgDM) 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 | 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 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 | 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* |
|---|---|---|---|---|---|---|---|---|---|
| Aberdart | $N_0$ | 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 | 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 $m^2$ 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 (Floranid 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/$m^2$. 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 Fennama. 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 were Aberdart had a higher ($P<0.01$) content than Fennama.

**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 fermentaion 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 | | 3.1 | | | | 3.2 | | | | 3.3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar & harvest | | Aberdart | | Fennema | | Aberdart | | Fennema | | Aberdart | | Fennema | |
| Dry matter (DM) | U | 130 | (7.2) | 131 | (5.0) | 132 | (5.8) | 126 | (7.7) | 131 | (3.0) | 123 | (2.6) |
| (g/kg) | 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 | U | 488 | (3.7) | 489 | (17.1) | 550 | (3.9) | 558 | (6.9) | 442 | (2.4) | 460 | (8.0) |
| (mEQ/kg DM) | W | 478 | (5.0) | 486 | (11.9) | 513 | (10.3) | 528 | (18.5) | 481 | (13.1) | 522 | (27.4) |
| Nitrates | U | 250 | (0.0) | 250 | (0.0) | 500 | (0.0) | 500 | (0.0) | 342 | (106.0) | 433 | (0.0) |
| (mg/l) | W | 250 | (0.0) | 250 | (0.0) | 500 | (0.0) | 500 | (0.0) | 211 | (0.0) | 333 | (129.0) |
| *In vitro* DM | U | 799 | (4.9) | 800 | (5.2) | 778 | (6.1) | 782 | (8.6) | 786 | (3.3) | 793 | (10.6) |
| digestibility (g/kg) | W | 777 | (6.4) | 776 | (9.8) | 750 | (10.3) | 748 | (10.2) | 703 | (8.9) | 712 | (13.7) |

**Table 2.2**. Silage chemical composition and aerobic stability of Aberdart (aber) and Fennema (fen) swards ensiled unwilted (U) or wilted (W) with various additive treatments in Experiments 3.1, 3.2 and 3.3.

| Additive (A) | | | Noadd | | Add-lo | | Add-hi | | Kofa-lo | | Kofa-hi | | Lbuch | | Lmix | | | | | | | | DxC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | | | aber | fen | aber | fen | aber | fen | aber | fen | aber | fen | aber | fen | aber | fen | D | C | A | CxA | DxC | DxA | xA | s.e. |
| Experiment | | | | | | | | | | | | | | | | | | | | | | | | |
| 3.1 | Lactic acid | U | 51 | 118 | 130 | 128 | 99 | 99 | 87 | 120 | 88 | 93 | 43 | 43 | 146 | 99 | *** | *** | *** | *** | ns | *** | *** | 3.6 |
| | (g/kg DM) | W | 69 | 85 | 60 | 76 | 41 | 55 | 74 | 81 | 68 | 68 | 79 | 90 | 91 | 101 | | | | | | | | |
| | $NH_3$-N | U | 95 | 92 | 93 | 101 | 110 | 117 | 91 | 92 | 85 | 91 | 98 | 113 | 48 | 80 | *** | *** | *** | ** | ns | *** | *** | 2.1 |
| | (g/kg N) | W | 62 | 71 | 64 | 78 | 67 | 83 | 68 | 73 | 70 | 75 | 60 | 68 | 40 | 46 | | | | | | | | |
| | WSC | U | 14 | 15 | 33 | 25 | 44 | 36 | 16 | 20 | 65 | 61 | 15 | 14 | 34 | 16 | *** | *** | *** | * | * | *** | * | 2.2 |
| | (g/kg DM) | W | 57 | 40 | 75 | 62 | 93 | 73 | 63 | 53 | 72 | 69 | 23 | 22 | 48 | 40 | | | | | | | | |
| | pH | U | 4.6 | 4.3 | 4.0 | 4.0 | 4.0 | 4.0 | 4.5 | 4.2 | 4.4 | 4.5 | 4.7 | 4.9 | 3.9 | 4.4 | *** | ns | *** | *** | ns | *** | *** | 0.03 |
| | | W | 4.5 | 4.3 | 4.5 | 4.3 | 4.5 | 4.4 | 4.4 | 4.4 | 4.5 | 4.5 | 4.3 | 4.3 | 4.0 | 4.1 | | | | | | | | |
| | days to TR | U | 8.0 | 5.0 | 6.0 | 6.0 | 5.5 | 7.0 | 6.0 | 6.5 | 3.5 | 4.5 | 5.0 | 4.5 | 3.0 | 4.5 | - | ns | *** | ** | - | - | - | 0.50 |
| | | 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 | 5.0 | 3.5 | - | ns | *** | * | - | - | - | 0.89 |
| | ATR to d5 | U | 4 | 14 | 4 | 2 | 14 | 1 | 4 | 2 | 24 | 14 | 5 | 23 | 33 | 21 | - | ns | ** | ns | - | - | - | 5.6 |
| | (…C) | W | 4 | 2 | 2 | 1 | 1 | 0 | 2 | 1 | 2 | 1 | 2 | 3 | 5 | 18 | - | ns | *** | ** | - | - | - | 1.5 |
| 3.2 | Lactic acid | U | 40 | 12 | 147 | 100 | 116 | 89 | 163 | 102 | 128 | 103 | 23 | 15 | 25 | 10 | *** | *** | *** | *** | *** | *** | *** | 4.7 |
| | (g/kg DM) | W | 12 | 14 | 100 | 12 | 112 | 36 | 104 | 13 | 117 | 29 | 12 | 12 | 14 | 13 | | | | | | | | |
| | $NH_3$-N | U | 163 | 224 | 92 | 116 | 109 | 117 | 74 | 127 | 71 | 73 | 194 | 208 | 175 | 224 | *** | *** | *** | ** | *** | * | ns | 20.9 |
| | (g/kg N) | W | 268 | 619 | 145 | 514 | 137 | 418 | 129 | 482 | 99 | 266 | 211 | 638 | 213 | 654 | | | | | | | | |
| | WSC | U | 5 | 11 | 15 | 14 | 14 | 11 | 12 | 9 | 28 | 21 | 10 | 3 | 6 | 4 | * | *** | *** | *** | ns | *** | ns | 1.3 |
| | (g/kg DM) | W | 5 | 10 | 6 | 6 | 17 | 9 | 8 | 9 | 24 | 10 | 8 | 9 | 8 | 6 | | | | | | | | |
| | pH | 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 | *** | *** | *** | *** | *** | *** | *** | 0.06 |
| | | 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 | | | | | | | | |
| | days to TR | 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 | *** | ** | - | - | - | 0.39 |
| | | 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 | - | *** | *** | *** | - | - | - | 0.27 |
| | ATR to d5 | U | 2 | 2 | 2 | 3 | 12 | 10 | 8 | 2 | 14 | 11 | 2 | 7 | 6 | 2 | - | ns | *** | ns | - | - | - | 2.3 |
| | (…C) | W | 2 | 1 | 4 | 1 | 2 | 1 | 0 | 2 | 1 | 18 | 7 | 1 | 7 | 1 | - | ns | ** | *** | - | - | - | 1.7 |
| 3.3 | Lactic acid | U | 151 | 131 | 132 | 127 | 85 | 81 | 123 | 132 | 112 | 110 | 143 | 110 | 150 | 136 | *** | * | *** | * | ns | * | ns | 4.5 |
| | (g/kg DM) | W | 134 | 121 | 112 | 111 | 99 | 92 | 110 | 121 | 100 | 100 | 127 | 120 | 126 | 123 | | | | | | | | |
| | $NH_3$-N | U | 66 | 79 | 84 | 83 | 111 | 110 | 79 | 77 | 80 | 83 | 69 | 92 | 47 | 73 | *** | ** | *** | *** | *** | *** | ns | 2.3 |
| | (g/kg N) | W | 92 | 96 | 104 | 95 | 116 | 109 | 95 | 91 | 104 | 103 | 91 | 93 | 85 | 92 | | | | | | | | |
| | WSC | U | 13 | 14 | 20 | 15 | 16 | 22 | 17 | 14 | 27 | 18 | 16 | 11 | 22 | 13 | ns | ns | *** | *** | ** | *** | *** | 1.2 |
| | (g/kg DM) | W | 16 | 8 | 20 | 20 | 24 | 32 | 11 | 8 | 10 | 17 | 7 | 7 | 20 | 20 | | | | | | | | |
| | pH | 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 | *** | *** | *** | *** | ** | ** | ns | 0.03 |
| | | W | 4.2 | 4.3 | 4.3 | 4.2 | 4.2 | 4.2 | 4.4 | 4.4 | 4.5 | 4.5 | 4.2 | 4.3 | 4.2 | 4.3 | | | | | | | | |
| | days to TR | U | 2.0 | 4.5 | 2.5 | 2.5 | 4.0 | 3.0 | 2.5 | 2.0 | 2.5 | 4.5 | 2.0 | 2.0 | 2.0 | 2.5 | - | ns | ns | ns | - | - | - | 0.69 |
| | | 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 | - | *** | *** | *** | - | - | - | 0.42 |
| | ATR to d5 | U | 38 | 14 | 23 | 21 | 11 | 19 | 25 | 23 | 19 | 12 | 38 | 36 | 47 | 26 | - | ns | ns | ns | - | - | - | 7.9 |
| | (…C) | W | 6 | 2 | 21 | 2 | 3 | 2 | 34 | 2 | 1 | 2 | 31 | 14 | 72 | 31 | - | *** | *** | *** | - | - | - | 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/kgDM 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 Fennema (FN) swards ensiled unwilted and with various additive treatments in Experiment 3.4.

| Additive (A) | NOadd | | AT-lo | | AT-hi | | MIX-lo | | MIX-hi | | LB | | LP+LL | | Statistical summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | 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 | 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 |

[1]g/kgDM; [2]g/kgN; [3]g silage DM/kg grass DM ensiled; [4]days to temperature rise; [5]accumulated 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 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | sem | C | A | CxA |
| DM (g/kg) | U | 150 | 135 | 150 | 144 | 147 | 133 | 149 | 136 | 143 | 138 | 156 | 148 | 144 | 147 | 155 | 154 | 2.3 | *** | *** | ns |
| | 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 | U | 174 | 25 | 98 | 67 | 122 | 9 | 159 | 23 | 58 | 44 | 87 | 87 | 83 | 91 | 93 | 83 | 10.2 | *** | *** | *** |
| (g/kg DM) | W | 12 | 7 | 78 | 30 | 12 | 6 | 63 | 6 | 108 | 7 | 100 | 63 | 123 | 7 | 96 | 81 | | | | |
| $NH_3N$ | 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 | *** | *** | *** |
| (g/kgDM) | 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 | U | 1 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 4.8 | *** | *** | *** |
| (g/kg DM) | 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 | U | 28 | 169 | 166 | 118 | 31 | 193 | 28 | 193 | 172 | 193 | 35 | 90 | 117 | 36 | 45 | 44 | 13.6 | *** | *** | *** |
| temp rise[2] | 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 | 9 | 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 ($^0$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$^0$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) | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | | Significance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | Ab | Fn | sem | C | A | CxA |
| pH | U[4] | 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[5] | 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 | U | 243 | 605 | 755 | 760 | 278 | 75 | 762 | 737 | 382 | 374 | 547 | 537 | 819 | 686 | 854 | 837 | 19.0 | ** | *** | *** |
| (g/kg FP[1]) | W | 594 | 771 | 667 | 700 | 291 | 512 | 825 | 825 | 646 | 730 | 559 | 636 | 832 | 829 | 843 | 783 | | | | |
| $NH_3N$ | U | 88 | 80 | 100 | 107 | 84 | 143 | 60 | 74 | 94 | 111 | 88 | 96 | 59 | 85 | 67 | 72 | 2.8 | ** | *** | *** |
| (g/kg N) | W | 109 | 76 | 105 | 99 | 106 | 78 | 51 | 58 | 93 | 78 | 90 | 83 | 60 | 70 | 67 | 70 | | | | |
| Butyric acid | 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 |
| (g/kg DM) | 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 | U | 192 | 192 | 192 | 192 | 192 | 192 | 56 | 135 | 192 | 186 | 192 | 192 | 43 | 43 | 57 | 57 | 2.6 | *** | *** | *** |
| temp. rise[2] | W | 96 | 88 | 192 | 192 | 192 | 192 | 55 | 61 | 192 | 109 | 192 | 192 | 66 | 81 | 192 | 192 | | | | |
| ATR to d5[3] | 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 | | | | |

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

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 ($15^0$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 lead 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) |
| *in vitro* 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) | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | statistical summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | 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 | s.e.d. |
| 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 | ns | ns | 13.8 |
| 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 | *** | ns | 0.05 |
| 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 | *** | ns | 2.7 |
| 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 | * | ns | 3.0 |
| 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 | *** | ns | 0.04 |
| 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 | ** | *** | * | 1.6 |
| 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 | 2.2 |
| 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 | 0.08 |
| 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 | *** | * | 1.8 |
| 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 | ns | ns | 1.9 |
| 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 | 3.5 | 3.6 | 3.6 | 3.6 | 3.6 | 3.7 | 3.6 | 3.7 | *** | *** | ns | 0.05 |
| g DM loss/kg DM ensiled | 57 | 58 | 55 | 51 | 51 | 51 | 61 | 57 | 63 | 57 | 61 | 58 | 65 | 56 | 62 | 58 | 64 | 57 | 62 | 58 | 62 | 58 | *** | *** | ns | 2.0 |
| 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 | 1.8 |
| 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 | 3.6 | 3.5 | 3.5 | *** | *** | ns | 0.04 |
| 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 | *** | * | 1.5 |
| 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 | ns | 2.3 |
| 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 | ns | * | 0.37 |
| 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 | ns | * | 3.9 |

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

| Additive (A) | | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | | 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 |
| $NH_3N$ | 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 |
| $NH_3N$ | 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 unwilted (U) and wilted (W) silages in Experiment 3.7

| Additive | | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | C | A | D | CxA | CxD | AxD | CxAxD | s.e.d. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | | | | | | | | |
| DM | Un | 192 | 193 | 190 | 196 | 183 | 196 | 195 | 194 | 194 | 195 | *** | ns | *** | ns | * | ns | ns | 5.9 |
| (g/kg) | W | 340 | 348 | 337 | 354 | 339 | 352 | 341 | 353 | 351 | 351 | | | | | | | | |
| pH | Un | 3.7 | 3.8 | 3.7 | 3.7 | 3.7 | 3.8 | 3.7 | 3.8 | 3.8 | 3.7 | ns | *** | *** | ns | ns | ns | ns | 0.075 |
| | W | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | | | | | | | | |
| Lactic | Un | 86 | 99 | 95 | 102 | 97 | 102 | 88 | 103 | 76 | 111 | * | *** | *** | ns | *** | * | ns | 9.3 |
| (g/kgDM) | W | 59 | 48 | 53 | 58 | 61 | 49 | 63 | 54 | 56 | 55 | | | | | | | | |
| $NH_3N$ | Un | 1.0 | 1.3 | 1.1 | 1.2 | 1.0 | 1.1 | 1.0 | 1.2 | 1 | 1.1 | * | *** | *** | ns | ns | *** | ns | 0.22 |
| (g/kgDM) | W | 0.9 | 0.9 | 0.9 | 1.1 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | | | | | | | | |
| $NH_3N$ | Un | 53.3 | 75.8 | 61.8 | 62.2 | 53.5 | 60.7 | 52.6 | 67.4 | 50.6 | 64.9 | * | *** | ** | ns | ns | *** | ns | 11.52 |
| (g/kg N) | W | 49.6 | 53.5 | 51.5 | 62.7 | 51.4 | 58.2 | 63.3 | 60.4 | 59.2 | 56.1 | | | | | | | | |
| Acetic | Un | 23 | 19 | 20 | 20 | 24 | 19 | 27 | 23 | 33 | 21 | *** | *** | *** | * | *** | *** | ns | 2.4 |
| (g/kgDM) | W | 10 | 11 | 10 | 12 | 11 | 1 | 15 | 14 | 17 | 15 | | | | | | | | |
| Propionic | Un | 1.1 | 1.1 | 0.7 | 0.9 | 0.8 | 1.2 | 1.1 | 1.4 | 1.2 | 1.1 | *** | *** | *** | ns | ns | *** | ns | 0.21 |
| (g/kgDM) | W | 0 | 0.2 | 0 | 0.2 | 0 | 0.2 | 0 | 0.3 | 0 | 0.4 | | | | | | | | |
| Butyric | Un | 0.1 | 3.3 | 1.9 | 0.9 | 0.2 | 1.5 | 0.3 | 0 | 0 | 0.8 | ns | ns | *** | ns | ns | ns | ns | 1.57 |
| (g/kgDM) | W | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | |
| Ethanol | Un | 16 | 11 | 14 | 10 | 15 | 10 | 16 | 12 | 17 | 10 | *** | *** | *** | * | ns | *** | * | 1.6 |
| (g/kgDM) | W | 20 | 10 | 18 | 9 | 18 | 9 | 10 | 8 | 11 | 9 | | | | | | | | |

**Table 3.11.** Aerobic stability of unwilted (U) and wilted (W) silages in Experiment 3.7

| Additive | | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | C | A | CxA | s.e.d |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | Ab | Fen | | | | |
| Hrs to TR >2$^0$C | Un | 28 | 25 | 69 | 79 | 94 | 128 | 51 | 25 | 34 | 22 | 27 | 34 | 22 | 38 | 32 | 32 | 25 | 29 | 24 | 25 | 24 | 21 | ns | *** | ns | 20.8 |
| | W | 139 | 165 | 192 | 158 | 192 | 192 | 110 | 145 | 107 | 192 | 129 | 176 | 82 | 109 | 103 | 159 | 78 | 133 | 171 | 124 | 192 | 187 | * | *** | * | 27.9 |
| Hrs to TR >5$^0$C | Un | 30 | 27 | 78 | 90 | 134 | 134 | 59 | 27 | 41 | 25 | 33 | 37 | 23 | 42 | 36 | 37 | 27 | 32 | 28 | 28 | 27 | 23 | ns | *** | ns | 24.4 |
| | W | 170 | 175 | 192 | 165 | 192 | 192 | 159 | 165 | 158 | 192 | 160 | 191 | 110 | 126 | 123 | 181 | 99 | 155 | 180 | 137 | 192 | 191 | ns | *** | ns | 24.2 |
| Max T | Un | 23.2 | 17.3 | 18.7 | 17.6 | 10.8 | 12.6 | 18.2 | 22.2 | 17.7 | 18.2 | 19.1 | 17.5 | 17.5 | 15.7 | 17.4 | 17.3 | 20.3 | 18.1 | 18.6 | 18.4 | 20.1 | 22.7 | ns | ns | ns | 4.09 |
| | W | 5.4 | .9.6 | 0.6 | 4.4 | 2.1 | 0.7 | 8.8 | 6.2 | 8.5 | 0.5 | 6.1 | 4.6 | 13 | 11.4 | 12.2 | 3.6 | 11.7 | 7.6 | 2.5 | 6.8 | 0.5 | 2 | ns | *** | * | 2.9 |
| Hrs to max TR | Un | 37 | 37 | 95 | 110 | 136 | 148 | 86 | 34 | 52 | 32 | 42 | 43 | 34 | 56 | 51 | 45 | 37 | 39 | 37 | 35 | 35 | 29 | ns | *** | ns | 26.7 |
| | W | 181 | 188 | 192 | 175 | 192 | 192 | 192 | 177 | 178 | 192 | 175 | 192 | 167 | 151 | 147 | 190 | 127 | 168 | 184 | 148 | 192 | 192 | ns | * | ns | 19.3 |
| Hrs from TR > 2$^0$C | Un | 13.3 | 15.3 | 26 | 31 | 44 | 31 | 36.3 | 11.3 | 17.7 | 12 | 16.7 | 11 | 15 | 19 | 21.3 | 13.7 | 13.7 | 10.3 | 13.3 | 11.7 | 13 | 10 | ns | ns | ns | 11.6 |
| to temp max | W | 41.3 | 33.5 | 77.7 | 51 | 59.1 | 34.8 | 82 | 32.7 | 71 | 44.7 | 69.5 | 16.3 | 84.7 | 42 | 44.3 | 31.3 | 48.7 | 35 | 39 | 36 | 42.5 | 16.4 | ns | *** | ns | 18.3 |
| Hrs from TR > 5$^0$C | Un | 7.7 | 10 | 17 | 20.3 | 3 | 21.5 | 27.7 | 7 | 10.7 | 7.7 | 9.3 | 6.3 | 10.3 | 13.7 | 15.7 | 8.7 | 10 | 7.3 | 8.7 | 7.3 | 8 | 6 | ns | ns | * | 6.13 |
| to temp max | W | 33 | 19 | 42.4 | 29 | 28.6 | 15.6 | 33 | 19 | 19.7 | 6.2 | 22.5 | 4.1 | 57 | 24.7 | 23.7 | 13.5 | 28 | 19.5 | 13 | 16.5 | 15.6 | 2.1 | ** | * | ns | 12.2 |
| Acc TR to 24hrs | Un | 2.2 | 3.1 | 0.7 | 0.3 | 1.2 | 0.2 | 2.4 | 1.3 | 0.7 | 2.1 | 1.6 | 0.6 | 2.2 | 0.8 | 1.2 | 0.3 | 1.8 | 0.5 | 0.6 | 1 | 1.7 | 2.1 | ns | ns | ns | 1.31 |
| | W | 0.63 | 0.31 | 0.4 | 0.32 | 0.46 | 0.29 | 0.53 | 0.29 | 0.57 | 0.29 | 0.52 | 0.3 | 0.29 | 0.15 | 0.09 | 0.06 | 0.03 | 0.06 | 0.38 | 0.15 | 0.34 | 0.21 | ** | * | ns | 0.19 |
| Acc TR to 48hrs | Un | 12.7 | 12.3 | 1.6 | 0.7 | 7.1 | 0.6 | 11.3 | 13.7 | 5.7 | 13.1 | 11.2 | 7.5 | 14.8 | 5.1 | 9.5 | 7.9 | 13.7 | 10.1 | 12.5 | 13 | 12.9 | 15.4 | ns | * | ns | 4.87 |
| | W | 1.4 | 0.7 | 0.9 | 0.7 | 1 | 0.7 | 1.2 | 0.7 | 1.3 | 0.7 | 1.2 | 0.7 | 0.8 | 0.5 | 0.3 | 0.2 | 0.3 | 0.2 | 0.8 | 0.5 | 0.7 | 0.5 | * | ns | ns | 0.42 |
| Acc TR to 72hrs | Un | 22.6 | 19.5 | 6.7 | 1.3 | 9.9 | 1.3 | 17.5 | 19.6 | 18.2 | 18.4 | 20.9 | 15.6 | 21.6 | 13.6 | 19.2 | 16.6 | 22.5 | 17.5 | 19.7 | 20 | 19.9 | 21 | * | *** | ns | 4.97 |
| | W | 2.2 | 1.1 | 1.3 | 1.2 | 1.5 | 1 | 2 | 1.3 | 2.1 | 1 | 1.9 | 1.1 | 1.7 | 1.2 | 0.7 | 0.3 | 1.1 | 0.6 | 1.1 | 2.8 | 1.1 | 0.8 | ns | ns | ns | 0.94 |
| Acc TR to 96hrs | Un | 29 | 23.8 | 13.3 | 8 | 12.2 | 4.8 | 21.3 | 23.1 | 24.8 | 22 | 26.5 | 18.8 | 25.5 | 20.3 | 26.7 | 21.1 | 26.9 | 21.2 | 23.2 | 24.4 | 24.1 | 24.7 | ns | ** | ns | 6.17 |
| | W | 3.4 | 1.5 | 1.8 | 2 | 1.9 | 1.3 | 3.2 | 2.2 | 3.3 | 1.3 | 3.1 | 1.5 | 4.1 | 3 | 2 | 0.6 | 4.2 | 1.5 | 1.5 | 6.3 | 1.4 | 1.1 | ns | ns | ns | 1.94 |
| Acc TR to 120hrs | Un | 33.8 | 27.4 | 24.3 | 18.6 | 14.3 | 9.4 | 24.6 | 26.5 | 29.2 | 25.8 | 30.6 | 21.7 | 28.5 | 23.8 | 30.9 | 24 | 30.3 | 24.1 | 26.3 | 27.8 | 27.2 | 29.6 | ns | * | ns | 6.98 |
| | W | 5.5 | 2.3 | 2.4 | 4 | 2.6 | 1.9 | 5.4 | 4.2 | 5.4 | 1.9 | 5.3 | 2.3 | 9 | 8.1 | 5.6 | 1.3 | 12.1 | 4.4 | 2.3 | 8.4 | 2 | 1.5 | ns | * | ns | 3.03 |
| Acc TR to 144hrs | Un | 37.8 | 30.9 | 31.8 | 25.3 | 16.3 | 14.1 | 28.9 | 29.8 | 33.3 | 29.7 | 33.9 | 24.5 | 31.3 | 26.5 | 34 | 26.6 | 33.1 | 26.2 | 28.9 | 30.7 | 30.2 | 33.8 | ns | ns | ns | 7.39 |
| | W | 8.6 | 3.4 | 3 | 7.5 | 3 | 2.4 | 8.8 | 7.3 | 9.5 | 2.3 | 9.1 | 3.1 | 17.6 | 15.2 | 12.9 | 2.7 | 20.5 | 8 | 3.5 | 10.4 | 2.4 | 1.7 | * | ** | ns | 4.81 |
| Acc TR to 168hrs | Un | 41.2 | 34.1 | 36.3 | 29.6 | 18.5 | 22.6 | 34.7 | 33.4 | 36.8 | 33.2 | 36.9 | 27.4 | 33.5 | 28.6 | 36.7 | 28.8 | 35.8 | 27.9 | 31.4 | 33.3 | 33.3 | 37.1 | ns | ns | ns | 7.76 |
| | W | 13 | 6 | 3.5 | 11.2 | 3.4 | 2.8 | 13.9 | 11.1 | 15.3 | 2.7 | 12.8 | 4.2 | 27.4 | 20.7 | 20.4 | 5.1 | 26.6 | 11.1 | 5.7 | 13.6 | 2.9 | 2.1 | * | *** | ns | 6.4 |
| Acc TR to 192hrs | Un | 44.5 | 37.6 | 39.8 | 32.7 | 21.7 | 27.3 | 39.4 | 37.1 | 40 | 36.7 | 40 | 30.3 | 36 | 30.8 | 39.3 | 31.2 | 38.6 | 29.7 | 34.1 | 36.4 | 36.6 | 40.1 | ns | ns | ns | 8.38 |
| | W | 17.5 | 13.9 | 4.1 | 14.9 | 3.8 | 3.3 | 21.2 | 15.5 | 20.8 | 3.2 | 16.6 | 7.1 | 38.8 | 29.7 | 29.2 | 8.2 | 36.8 | 16.8 | 7.8 | 18.9 | 3.4 | 3.3 | * | *** | ns | 8.1 |
| Yeast (log 10 | Un | 4.38 | 5.00 | 0 | 0 | 0 | 0 | 5.54 | 5.22 | 3.90 | 5.23 | 4.09 | 4.51 | 5.01 | 3.16 | 4.23 | 4.4 | 4.46 | 4.73 | 5.09 | 5.37 | 4.74 | 5.28 | ns | *** | ns | 0.68 |
| cfu/g silage) | W | 3.03 | 2.34 | 0 | 1.53 | 0 | 0 | 3.44 | 3.10 | 3.33 | 0 | 3.16 | 1.41 | 3.19 | 3.14 | 4.37 | 3.49 | 3.45 | 3.34 | 2.24 | 3.4 | 0 | 0 | ns | *** | ** | 0.76 |

**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 ($15^0$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 24hours 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 eneral, 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) |
| *in vitro* 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) | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | statistical summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | 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 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | | 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 |
| (g/kg DM) | 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 | Un | 118 | 11 | 130 | 112 | 84 | 87 | 117 | 23 | 118 | 11 | 113 | 10 | 88 | 9 |
| (g/kgDM) | W | 146 | 8 | 130 | 110 | 97 | 110 | 144 | 7 | 133 | 10 | 142 | 6 | 133 | 7 |
| $NH_3N$ | 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 |
| (g/kgDM) | 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 |
| $NH_3N$ | Un | 79 | 173 | 83 | 78 | 100 | 88 | 83 | 158 | 82 | 179 | 85 | 192 | 115 | 212 |
| (g/kg N) | W | 83 | 184 | 93 | 106 | 110 | 106 | 79 | 193 | 84 | 183 | 80 | 185 | 81 | 199 |
| Acetic | Un | 46 | 81 | 21 | 23 | 21 | 16 | 46 | 71 | 47 | 75 | 48 | 80 | 53 | 85 |
| (g/kgDM) | W | 31 | 71 | 23 | 28 | 27 | 18 | 31 | 75 | 33 | 75 | 31 | 79 | 34 | 74 |
| Propionic | Un | 2 | 6.6 | 0 | 0 | 0 | 0 | 2.1 | 6 | 1.3 | 5.5 | 2.5 | 7.7 | 4.1 | 9.2 |
| (g/kgDM) | W | 0 | 8.4 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 6.8 | 0 | 8.9 | 0 | 8.9 |
| Butyric | Un | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.3 | 6 | 6.8 |
| (g/kgDM) | W | 0 | 11.3 | 0 | 0 | 0 | 0 | 0 | 9.8 | 2.6 | 3.3 | 0 | 5.8 | 0 | 9.8 |
| Ethanol | 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 |
| (g/kgDM) | 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 Ab | 8 Fen | 9 Ab | 9 Fen | 10 Ab | 10 Fen | 11 Ab | 11 Fen | C | A | D | CxA | CxD | AxD | CxAxD | sed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 147 | 144 | 147 | 140 | 147 | 149 | 145 | 147 | | | | *** | *** | ns | ns | 3.4 |
| | | | | | | | | ** | ** | ** | | | | | |
| | | | | | | | | * | * | * | | | | | |
| 173 | 165 | 177 | 165 | 178 | 164 | 177 | 165 | | | | | | | | |
| 4.3 | 5.4 | 4.3 | 5.5 | 4.3 | 5.4 | 4.2 | 5.4 | | | | *** | *** | ns | ns | 0.09 |
| | | | | | | | | ** | ** | ** | | | | | |
| | | | | | | | | * | * | * | | | | | |
| 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 | | | | | | | | |
| 3.2 | 7.2 | 3.3 | 7.5 | 3 | 6.6 | 2.8 | 6.3 | | | ns | *** | ns | ** | ns | 0.38 |
| | | | | | | | | ** | ** | | | | | | |
| | | | | | | | | * | * | | | | | | |
| 3 | 6.5 | 2.8 | 6.7 | 2.8 | 6.4 | 2.8 | 6.2 | | | | | | | | |
| 93 | 203 | 94 | 212 | 84 | 181 | 81 | 177 | | | ns | *** | * | ** | ns | 11.6 |
| | | | | | | | | ** | ** | | | | | | |
| | | | | | | | | * | * | | | | | | |
| 83 | 195 | 79 | 197 | 79 | 191 | 78 | 181 | | | | | | | | |
| 49 | 80 | 49 | 83 | 47 | 77 | 39 | 74 | | | | *** | *** | *** | ns | 5.2 |
| | | | | | | | | ** | ** | ** | | | | | |
| | | | | | | | | * | * | * | | | | | |
| 33 | 70 | 29 | 72 | 30 | 70 | 31 | 75 | | | | | | | | |
| 1.1 | 6.4 | 0 | 7.7 | 2.2 | 6.5 | 1 | 8.3 | | | ns | *** | *** | ns | ns | 1.33 |
| | | | | | | | | ** | ** | | | | | | |
| | | | | | | | | * | * | | | | | | |
| 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 | | | | | | | | |
| 11.1 | 33.1 | 11.2 | 30.4 | 12.1 | 27.1 | 10.6 | 25.3 | | | | *** | ns | *** | ns | 2.33 |
| | | | | | | | | ** | ** | ** | | | | | |
| | | | | | | | | * | * | * | | | | | |
| 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 | 1 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | statistical summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar (C) | | 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 |
| Hrs to TR >2$^0$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 |
| | 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 | ns | 26 |
| Hrs to TR >5$^0$C | 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 |
| | 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 | ns | 20.6 |
| Max TR | 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 | 12.6 | ns | ** | ns | 3.65 |
| | 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 |
| Hrs to max TR | 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 |
| | W | 180 | 191 | 191 | 191 | 190 | 191 | 191 | 191 | 191 | 191 | 187 | 191 | 191 | 191 | 191 | 191 | 191 | 191 | 190 | 191 | 191 | 191 | ns | ns | ns | 3.47 |
| Hrs from TR > 2$^0$C | 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 | 21.6 |
| to temp max | W | 72 | 34 | 24 | 4 | 46 | -1 | 60 | 13 | 15 | 24 | 46 | 34 | 35 | 15 | 23 | 76 | 23 | 17 | -4 | 19 | 5 | 21 | ns | ns | ns | 30.6 |
| Hrs from TR > 5$^0$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 | 18.9 |
| 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 | 19.2 |
| 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 | 0.36 |
| | 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 | 0.24 |
| 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 | 2.18 |
| | 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 | 0.5 | 1.7 | *** | 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 | 4.51 |
| | 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 | 1.14 |
| 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 | 6.32 |
| | 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 | 2.05 |
| 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 | 8.13 |
| | 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 | 3.33 |
| 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 | * | 9.95 |
| | W | 22.1 | 3.8 | 4.9 | 3.5 | 8.0 | 2.9 | 5.4 | 4.2 | 4.1 | 4.0 | 8.7 | 4.7 | 0.6 | 2.8 | 2.7 | 2.2 | 0.9 | 2.3 | 1.5 | 4.3 | 1.3 | 4.6 | ns | ns | ns | 5.29 |
| 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 | * | 11.35 |
| | 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 | 7.95 |
| 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 | ** | * | 12.24 |
| | 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 | 10.85 |
| Yeast numbers | Un | 2.7 | 1.2 | 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 | 1.4 | 0.9 | ns | ns | ns | 1.24 |
| (log 10 cfu/g silage) | W | 1.9 | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 1.1 | 0.9 | 0.9 | 0 | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | * | ns | ns | 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 herbages. 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 herbages 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$^0$C (16 h; oven with forced-air circulation) for determination of dry matter (DM) content.

~ greater than 100g was dried @ 60$^0$ 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$^0$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$^O$C (16h) for estimation of DM content

~ dried (200g) at 40$^0$ 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 $NH_3$-N.

The remainder of each silage (5kg unwilted silage and 4kg wilted silage) was placed polytheylene-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$^0$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$^0$C above the reference temperature
(b) Duration to temperature rise >5$^0$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$^0$C) to temperature maximum
(f) Duration from temperature rise (>5$^0$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, $NH_3$-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, $NH_3$-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, $NH_3$-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$^0$C above the reference temperature, (b) the duration to temperature rise >5$^0$C above the reference temperature, (c) the duration to maximum temperature, and (d) the duration from temperature rise (>2$^0$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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Tilley, J.M.A. and Terry, R.A. 1963. A two-stage technique for the *in vitro* digestion of forage crops. Journal of the British Grassland Society, 18:104-111.

**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[1]/g) | 6.5 | 0.27 | 6.1 | 0.05 | 6.4 | 0.08 | 6.3 | 0.06 |

[1]colony-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

| 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 |
|---|---|---|---|---|---|---|---|---|
| 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.ºC ^ to 24h | Acc.ºC^ to 48h | Acc.ºC^ to 72h | Acc.ºC^ to 96h | Acc.ºC^ to 120h | Acc.ºC^ to 144h | Acc.ºC^ to 168h | Acc.ºC^ 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

| Wilting | Grass cultivar | Additive | Acc.'C ^ to 24h | Acc.'C ^ to 48h | Acc.'C ^ to 72h | Acc.'C ^ to 96h | Acc.'C ^ to 120h | Acc.'C ^ to 144h | Acc.'C ^ to 168h | Acc.'C ^ 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 unwilted 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.

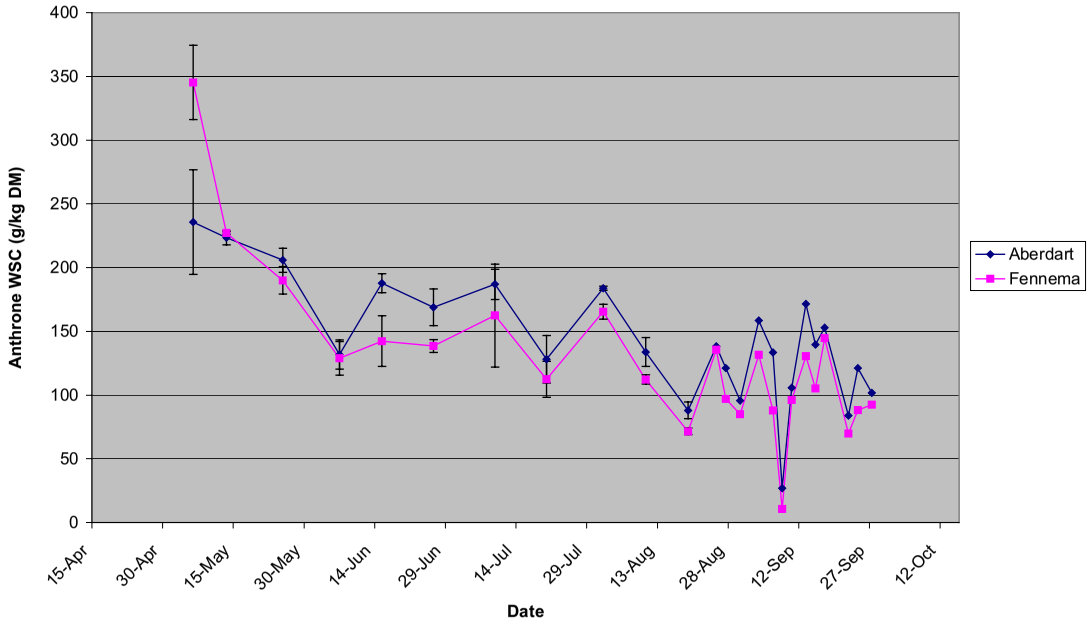
| | Aberdart | Fennema |
|---|---|---|
| Pre-grazing herbage mass (kg DM/ha) | 2570 (561) | 2760 (556) |
| Post-grazing herbage mass (kg DM/ha) | 1110 (206) | 1130 (196) |
| Herbage allowance (kg DM/head/d) | 15.3 (7.11) | 13.7 (5.10) |
| Apparent herbage intake (kg DM/head/d) | 8.7 (5.18) | 8.1 (4.06)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

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 Aberdart perennial ryegrass herbage from 28 April to 30 September 2004 at Grange Research Centre, Ireland in Experiment 4.1.



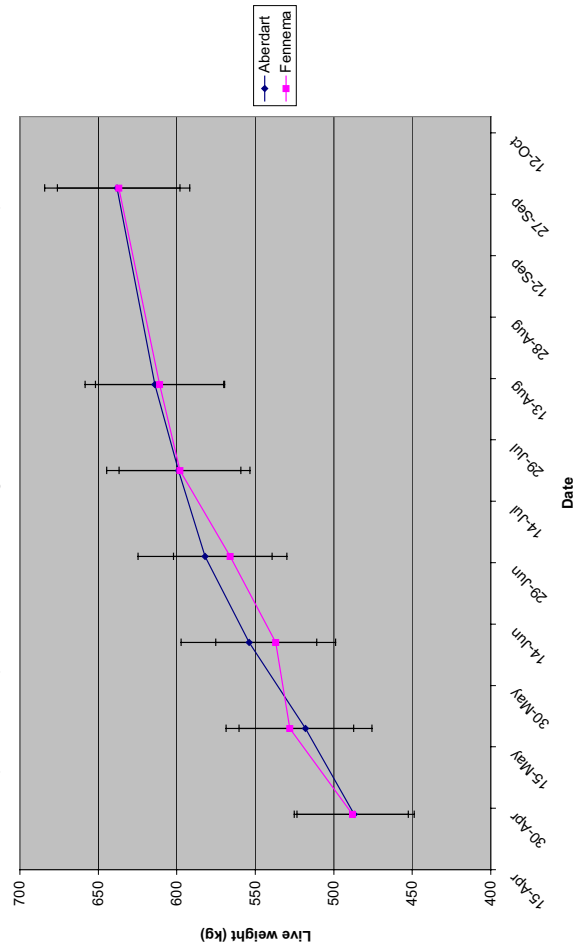



Figure 4.2. Live weight of steers grazing either 'Fennema' or 'Aberdart' perennial ryegrasses from 28 April to 30 September 2004 at Grange Research Centre, Ireland in Experiment 4.1.

**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(s.e. 1.99)X + 421.7(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 (s.e. 2.1)X + 452.9 (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 (s.e. 3.24)X + 125.4(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 O, 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 |
| Faecal 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 (%) | | | | | | | Orthogonal contrasts | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Level of added sucrose (%) | 0 | 3 | 6 | 9 | 12 | s.e.d. | Sig | L | Q | C |
| PD excretion (mmol/day) | | | | | | | | | | |
| Allantoin | 192.0 | 218.7 | 208.0 | 209.3 | 216.9 | 19.72 | NS | NS | NS | NS |
| Uric acid | 4.7 | 4.9 | 4.0 | 4.2 | 3.9 | 0.63 | NS | NS | NS | NS |
| Total | 196.7 | 223.5 | 212.0 | 213.5 | 220.8 | 19.80 | NS | NS | NS | NS |
| 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$^{c}$ | 23.41$^{c}$ | 1.797 | *** | <0.001 | NS | 0.007 |
| Microbial N (g/kg DOMI) | 31.36$^{a}$ | 26.22$^{a}$ | 32.33$^{a}$ | 39.16$^{b}$ | 42.02$^{b}$ | 3.029 | *** | <0.001 | 0.044 | 0.031 |

**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 $60^0$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 $550^0$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 $85^O$C (16h) for estimation of DM content

~ dried (200g) at $40^0$ 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 $NH_3$-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. I*n 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, $NH_3$-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 | Sugar | Liveweight (kg) | | Lwt. gain | Silage DM[1] intake | | Total DM intake | | Feed |
|---|---|---|---|---|---|---|---|---|---|
| kg/day | | Start | Finish | g/d | kg/d | g/kgLwt. | kg/d | g/kgLwt. | efficiency[2] |
| 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 |

[1]Based on 85°C oven DM; [2]g 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.** I*n 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 míle maith agaibh!**

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