Irish Journal of Agricultural and Food Research **47:** 119–134, 2008

Evaluation of *Lolium perenne* L. cv. AberDart and AberDove for silage production

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The objective of this study was to assess the value, for silage production, of intermediate-heading *Lolium perenne* L. cultivars, AberDart and AberDove (diploid), bred for increased water-soluble carbohydrate (WSC) concentrations, relative to four control cultivars (Fennema, AberElan and Spelga (diploid), and Greengold (tetraploid)). Cultivars were evaluated for forage dry matter (DM) yield, ground cover and indirect laboratory measures of nutritional value and ensilability over 3 harvest years within intensive silage-production systems. AberDove was the most desirable diploid for silage production producing on average 316 kg/ha higher (2%) DM yield per annum, having a 10 g/kg higher (1%) dry matter digestibility (DMD) and, based primarily on a 6 g/L higher (19%) concentration of WSC expressed in the aqueous extract (WSC_{AE}), offered the greatest potential to produce well preserved silage. Ensiling AberDart compared to the diploid controls offered a slightly greater probability of producing well preserved silage based on a modest increase of 2 g/L (6%) in WSC_{AE} concentration. The dilemma for silage production is that AberDart, on average produced 558 kg/ha less (4%) DM yield per annum but had a greater (1%) DMD of 6 g/kg than the diploid controls. The tetraploid control had, on average, 13 and 8 g/kg higher (2% and 1%, respectively) DMD than AberDart and AberDove, but at a cost of lower ensilability with lower (6% and 21%, respectively) WSC_{AE} values of 2 and 6 g/L. In its favour, the tetraploid control outyielded AberDart by, on average, 917 kg/ha DM per annum (7%) and produced comparable yields to AberDove. Final ground cover ratings were high (≥ 95%) for all cultivars. Evaluation of nutritional value and ensilability offers further grounds to differentiate and select cultivars for animal production potential.

Keywords: ensilability; nutritional value; perennial ryegrass; water-soluble carbohydrate; yield

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Introduction

Information on cultivar performance and ranking, within the spectrum of variability of a species, is typically provided by governmental agencies, e.g. Department of Agriculture and Food (2007). Several criticisms of these trials have arisen in recent years. Generally, these cultivar evaluation trials have emphasised forage yield and adaptation characteristics. Nutritional value and ensilability are given limited to no consideration. In Ireland, nutritional value and ensilability are not considered to any degree in making cultivar recommendations.

In vitro dry matter digestibility (DMD) provides the best single criterion of the nutritional value of a wide range of forage species and cultivars for ruminants (Wilkins and Humphreys, 2003). Higher DMD may lead to improved animal performance by increasing energy availability, rate of passage and intake (Casler, 2001). Averaged across grass species an increase of 10 g/kg in DMD generally leads to a proportional increase of 0.032 in average daily gain of beef cattle (Casler and Vogel, 1999). Digestibility may be increased in forage grasses by a number of methods including manipulating the relative amounts of soluble and structural carbohydrates (Casler, 2001). Soluble carbohydrates in temperate forage grasses are typically estimated by the water-soluble carbohydrate (WSC) criterion, which is heritable, amenable to selection and highly correlated with DMD (Humphreys, 1989b). Increasing WSC concentration may offer other benefits to the grass plant, relevant herbivores and the environment, such as better tiller survival, sward persistency and initial regrowth following defoliation (Fulkerson and Donaghy, 2001), improved forage ensilability (Buxton and O'Kiely, 2003) and palatability (Ciavarella *et al*., 2000), and lower rumen methane production (Beever, 1993).

Perennial ryegrass (*Lolium perenne* L.) is by far the most important grass species in Ireland, accounting for about 95% of agricultural grass seed sales (Department of Agriculture and Food, 2006, personal communication). A number of perennial ryegrass cultivars bred for elevated concentrations of WSC have been commercially released in north-western Europe. None are recommended for agricultural use in Ireland by the national testing authority (Department of Agriculture and Food, 2007), perhaps because nutritional value and ensilability are not considered in making recommendations. Despite these cultivars producing forage with elevated concentrations of WSC in a number of other countries (Gilliland *et al*., 2002; Orr *et al*., 2003) a strong genotype × environment interaction for the WSC trait (Halling *et al.*, 2005) necessitates evaluation in the target environment to determine the robustness of the expression of the high WSC phenotype.

The objective of this study was to assess the value for silage production of two intermediate-heading perennial ryegrass cultivars, AberDart and AberDove, selected for high concentration of WSC. Criteria for assessment included forage yield, ground cover, and indirect laboratory measures of nutritional value and ensilability.

Materials and Methods

Cultivars

Six intermediate-heading perennial ryegrass cultivars were compared (Table 1). Cultivars AberDart (breeders reference no. Ba11778) and AberDove (breeders reference no. Ba11353) (both diploid) were bred for high concentration of WSC (Humphreys, 1989a). Cultivars Fennema, AberElan and Spelga (hereafter collectively referred to as the diploid controls),

Table 1. Description of the six perennial ryegrass cultivars evaluated

Cultivar	Ploidy	Heading date	Breeder	Country of origin
AberDart	Diploid	27 May	IGER	United Kingdom
AberDove	Diploid	29 May	IGER	United Kingdom
Fennema	Diploid	28 May	Norddeutsche	Germany
AberElan	Diploid	30 May	IGER	United Kingdom
Spelga	Diploid	20 May	DARD	United Kingdom
Greengold	Tetraploid	31 May	Teagasc	Ireland

and Greengold (hereafter referred to as the tetraploid control) were not bred for WSC concentration and may be considered to represent perennial ryegrass cultivars with typical WSC concentration. Spelga and Greengold are recommended for use in Ireland (Department of Agriculture, Fisheries and Food, 2007), allowing a standard of comparison with other cultivars recommended for use in the country.

Experimental design and plot management

The experiment was conducted at the Grange Beef Research Centre (53°30' N, 6°40' W and 83 m above sea level). The field site had been in permanent grass pasture for more than 30 years. The soil type was an imperfectly drained Eutric Gleysol of Ashbourne Series (Finch *et al.*, 1983) and prior to the experiment had a pH of 6.6 and concentrations of P and K of 7.9 and 88 mg/L, respectively. Weather data were recorded on a daily basis at a meteorological station situated within 5 km of the experimental site. The instruments and standards used were described by Fitzgerald and Fitzgerald (2004).

In August 2000 the site was sprayed with glyphosate (1.80 kg/ha) to control existing grasses and broad leaved weeds. The area was then cultivated and, following soil test recommendations, fertiliser P and K was incorporated just before sowing at 4 and 8 kg/ha, respectively. Each cultivar was sown by hand in 2 m × 10 m plots on 11 September 2000. The seeding rate was 30 kg/ha. The six cultivars were arranged in a randomised complete block with six replicates. Weeds were controlled by application of benazolin (0.09 kg/ha), 2,4-DB (0.83 kg/ha), MCPA (0.15 kg/ha), triclopyr acid (0.17 kg/ha) and fluroxypyr acid (0.15 kg/ha) on 18 April 2001.

The aim was to manage swards to produce yields that would be commercially sustainable within intensive silage-production systems in Ireland. Each plot was subjected to an infrequent cutting (conservation) management consisting of four harvests/year for 3 consecutive years beginning in 2001 (Table 2). Plots were harvested to a 5 cm stubble height by a Haldrup plot harvester (J. Haldrup, Lögstör, Denmark). Forage yield was measured on a 1.5 m wide swath harvested from the centre of each plot. At each harvest, a representative sample of *c.* 500 g fresh forage was taken from the centre (1.5 m wide) swath of each plot and stored at –18 °C prior to analysis. Granular compound fertiliser (240 g N, 25 g P and 100 g K per kg) was applied each year in mid-March and immediately after the first three harvests (Table 3). Ground

Table 2. Harvest dates for each year

Harvest	Harvest year		
	2001	2002	2003
1	28 May	28 May	27 May
2	9 July	11 July	8 July
3	22 Aug	26 Aug	25 Aug
4	17 Oct	14 Oct	15 Oct

Table 3. Fertiliser application rates and times

Time	Rate (kg/ha) for		
	N	P	K
Mid-March	113	12	47
After Harvest 1	94	10	39
After Harvest 2	75	8	31
After Harvest 3	75	8	31

cover, defined as ground area covered by crown tissue, was visually rated on all plots on 20 Oct 2003 after the final harvest of the experiment. The final ground cover rating is the single best assessment of long-term persistence (Casler, 1999).

Chemical analysis

Frozen forage samples were thawed and individually chopped through a mincer. Sub-samples were dried in a forced air circulation oven at 98 °C for 16 h for determination of dry matter (DM) concentration. Further chemical analyses were carried out using sub-samples dried at 40 °C for 48 h and milled through a 1 mm screen. DMD was determined using the method of Tilley and Terry (1963) with the modification that the final residue was isolated by filtration rather than by centrifugation. Ash was estimated following complete combustion in a muffle furnace at 550 °C for 5 h. Crude protein (CP) was measured using a LECO FP-428 N analyser (AOAC, 1990). Buffering capacity (BC) and neutral detergent fibre (NDF) analyses were carried out according to the methods of Playne and McDonald (1966) and Van Soest (1967), respectively. Concentrations of WSC were estimated using near infrared spectroscopy (NIR Systems, Perstorp Analytical, Berkshire, UK) as described by Lister and Dhanoa (1998). The concentration of WSC expressed on a DM basis (WSC_{DM}; g/kg DM) was converted to an aqueous phase basis (WSC_{AE}; g/L aqueous extract) by multiplying by DM/(1000 – DM).

Statistical analysis

Data were analyzed by mixed-model analysis of variance (Proc MIXED, SAS Institute Inc., NC, USA; Littell *et al.*, 2006). Cultivars and years were assumed to have fixed effects, while replicates and interactions including replicates were assumed to have random effects. Years were considered fixed as years were sequential with potentially cumulative effects on soil and plant parameters. Repeated measures analysis of each harvest period, with year as the repeated measures factor, identified a number of significant ($P < 0.05$) interactions between year and the cultivar comparisons described below (data not presented). Accordingly, data were reanalysed separately for each harvest-year combination using the randomised complete block model. Five pre-planned nonorthogonal contrasts were used to make comparisons among the six cultivars. Contrasts were chosen based on their intrinsic merit rather than on the concept of orthogonality (Chew, 1976). Contrasts for cultivar comparisons were (i) AberDart *v.* AberDove, (ii) Aberdart *v.* the mean of the diploid controls, (iii) Aberdart *v.* the tetraploid control, (iv) AberDove *v.* the mean of the diploid controls and (v) AberDove *v.* the tetraploid control. For each variable a counting was made of the number of harvest-year combinations that values for AberDart in contrasts (i) to (iii) and AberDove in contrasts (iv) and (v) were statistically, based on the P value of the F test, less ($P < 0.05$), not different ($P > 0.05$) from or greater ($P < 0.05$) than the comparable cultivar(s). An analogous counting was made on the basis of numerical rank irrespective of P value. The coefficient of variation was calculated as the square root of the residual error divided by the overall experimental mean × 100, as an indication of experimental design precision. Yield data for 2003 were not available.

Results and Discussion

Temperatures during 2001 to 2003 were comparable to the long-term average and followed a similar seasonal pattern (Figure 1). Temperatures gradually began to increase in the spring, reaching a maximum towards the end of July and then declined steadily until the winter. Rainfall during 2001 to 2003, like the long-term average, did not follow a clear seasonal pattern, having no well defined wet or dry seasons (Figure 1). As is the nature of Ireland's climate (Keane and Sheridan, 2004) there were significant weekly and monthly variations in rainfall between years. Weather directly, and indirectly via

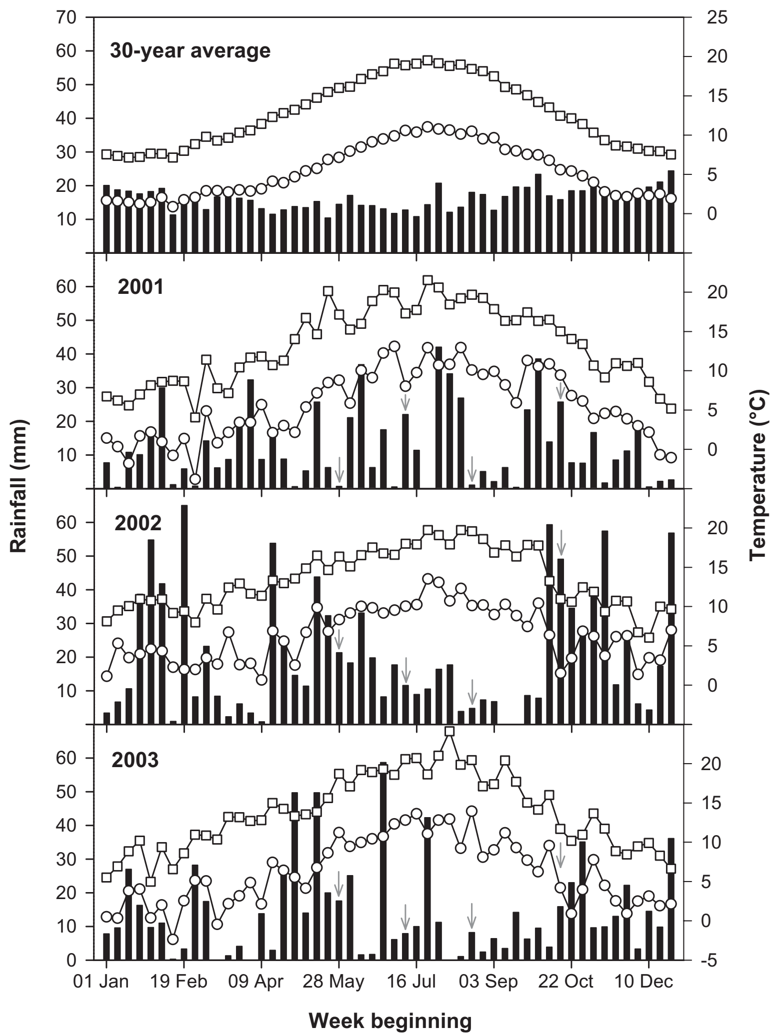

Figure 1. Weekly values for total rainfall (■) and mean minimum (○) and maximum (□) temperatures for 2001 to 2003 and the long-term averages (1971–2000 inclusive) recorded within 5 km of the experimental site. Note 8 days weather is included in weeks beginning 24 December and, during leap years, 12 February. Arrows represent harvest dates.

its effects on soil fertility, pests and diseases, is a major determining factor in the yield and quality of forages (Buxton, 1996; Conaghan *et al.*, 2008).

The combined effects of year-to-year weather and age-of-stand define each year as a separate environment. Cultivar × environment interactions for forage yield and quality measures of each harvest period were a frequent occurrence. The interactions were due to changes with environment in the rank order of cultivars, the magnitude of differences among cultivars or both. Numerous other studies have reported similar inconsistencies across environments for perennial ryegrass (Casler, 1990; Halling *et al.*, 2005; Conaghan *et al.*, 2008). Averaging over environments and ignoring the interaction may be misleading. Accordingly, results for each harvest-year combination are presented separately.

The CV, and the precision with which cultivars could be compared, varied greatly with the trait measured (Table 4). Gomez and Gomez (1984) concluded that the acceptable range of CV for cultivar trials is 6 to 8%. Most measured variables had a mean CV ≤ 8%, the exceptions being yield and WSC_{AE}. Detecting, with high precision, differences among cultivars for yield is very difficult (Conaghan *et al.*, 2008). However, Casler and Undersander (2000) recommended that trial data should not be discarded solely based on the CV as low precision *per se* does not necessarily affect cultivar rankings for yield. The determination of WSC_{AE} involves two measurements, WSC_{DM} and DM concentration, each contributing to error. Because experimental errors from different sources are additive, the high CV for WSC_{AE} may be due to the complexity of a trait determined by two measurements.

Forage yield and quality measures (Tables 5 and 6) were for the most part comparable to the findings of Keating and O'Kiely (2000a) for perennial ryegrass swards managed within a similarly intensive silage-production system for 3 years. The major exception was in 2002 where yields at Harvest 2 were unusually low although the weather over the 6-week growing period before harvesting was not extreme. Given the standard weather conditions in the week after fertiliser application and considering that forage DM yields of 2.11 t/ha have been reported at Grange

Table 4. Average (± s.e.) values for coefficient of variation for measured variables

Variable	CV[1]
Dry matter (DM) yield (kg/ha)	12.4 ± 4.76
Nutritional value indices	
Ash (g/kg DM)	5.2 ± 0.52
In vitro dry matter digestibility (g/kg)	1.7 ± 0.22
Neutral detergent fibre (g/kg DM)	2.5 ± 0.24
Water-soluble carbohydrate (g/kg DM)	8.4 ± 0.74
Crude protein (g/kg DM)	6.3 ± 0.61
Ensilability indices	
Dry matter (g/kg)	7.1 ± 0.91
Buffering capacity (mEq/kg DM)	5.4 ± 0.62
Water-soluble carbohydrate (g/L aqueous extract)	15.0 ± 1.80

[1] The CV was estimated for each harvest-year combination (n = 8 for yield; n = 12 for each index of nutritional value and ensilability) and then averaged across all harvest-year combinations.

Table 5. Least squares means for AberDart and contrast effects for each harvest-year combination

Variable[1]	Harvest/year												Total no. of harvests[2]					
	Harvest 1			Harvest 2			Harvest 3			Harvest 4			F test			Rank		
	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003	–	0	+	–	0	+
	AberDart means																	
Dry matter (DM) yield (kg/ha)	5281	5424	NA[3]	3301	412	NA	3300	3297	NA	2132	2283	NA						
Ash (g/kg DM)	98	81	70	112	93	95	114	93	91	113	103	95						
DMD (g/kg)	757	713	722	827	852	792	784	761	764	790	814	816						
NDF (g/kg DM)	484	522	515	439	454	463	455	504	487	463	446	479						
WSC_{DM} (g/kg DM)	165	180	231	161	182	168	138	166	192	113	148	160						
CP (g/kg DM)	171	177	115	211	199	209	213	174	169	286	230	251						
DM (g/kg)	157	144	189	147	166	151	154	191	194	127	143	146						
BC (mEq/kg DM)	467	324	506	552	386	386	523	337	344	540	397	361						
WSC_{AE} (g/L)	31	31	57	28	37	30	25	39	46	16	25	28						
	AberDart minus AberDove																	
DM yield (kg/ha)	–727*	–72	NA	–99	–165	NA	–166	–79	NA	17	–178*	NA	2	6	0	7	0	1
Ash (g/kg DM)	1	–1	–7*	–2	14**	4	6*	3	3	3	6**	3	1	8	3	3	0	9
DMD (g/kg)	–20**	–18	–24	11	–5	–7	–5	–29**	12	4	13*	7	2	9	1	7	0	5
NDF (g/kg DM)	13*	14	18	–4	23*	–8	5	23***	3	14**	–4	8	0	8	4	3	0	9
WSC_{DM} (g/kg DM)	–19*	–13	0	–13	–58**	–8	–24***	–34***	–15**	–17***	–19**	–15	7	5	0	11	1	0
CP (g/kg DM)	6	2	–6	21*	20	6	22**	16**	14*	15***	18*	2	0	6	6	1	0	11
DM (g/kg)	3	2	15	–4	–27**	–16	–5	–1	–5	2	–2	–8	1	11	0	8	0	4
BC (mEq/kg DM)	–28*	–16	11	–17	43**	20**	25	–14	–5	18	2	–12	1	9	2	6	0	6
WSC_{AE} (g/L)	–3	–1	7	–3	–21**	–5	–6**	–8**	–5*	–2**	–3*	–5	6	6	0	11	0	1

(*Table 5 Continued*)

Variable[1]	Harvest/year												Total no. of harvests[2]					
	Harvest 1			Harvest 2			Harvest 3			Harvest 4			F test			Rank		
	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003	–	0	+	–	0	+
Contrast: AberDart minus the mean of the diploid controls (Fennema, AberElan and Spelga)																		
DM yield (kg/ha)	–710**	–448	NA	115	–5	NA	–75	–333*	NA	156**	184*	NA	2	4	2	5	0	3
Ash (g/kg DM)	1	–2	–1	–2	4	2	–1	2	2	–4	1	–1	0	12	0	6	0	6
DMD (g/kg)	17**	–3	10	7	4	–2	–1	16*	16**	4	9	3	0	9	3	3	0	9
NDF (g/kg DM)	–28***	–6	–19	–22***	–6	–9	–15*	–18***	–11*	–8*	–12**	–3	7	5	0	12	0	0
WSC_{DM} (g/kg DM)	12	5	25	15*	–8	6	7	9	9*	13**	9	10	0	9	3	1	0	11
CP (g/kg DM)	14**	3	–5	0	8	–4	8	9	–4	4	0	–6	0	11	1	4	2	6
DM (g/kg)	7	–3	9	4	–6	–5	9	–14	–9*	7***	2	–3	1	10	1	6	0	6
BC (mEq/kg DM)	–5	–15	0	5	9	–2	10	9	4	19	5	–9	0	12	0	4	1	7
WSC_{AE} (g/L)	4*	0	11	3*	–2	0	3	–1	0	3***	2	1	0	9	3	2	3	7
Contrast: AberDart minus the tetraploid control (Greengold)																		
DM yield (kg/ha)	–73	–527	NA	–477**	–145	NA	–186	–331	NA	–62	–32	NA	1	7	0	8	0	0
Ash (g/kg DM)	–3	4	–2	–1	4	2	–4	5	5*	0	8***	7**	0	9	3	4	1	7
DMD (g/kg)	–35***	–35*	–32*	6	0	–6	–18*	–6	–4	–9	–5	–11	4	8	0	10	1	1
NDF (g/kg DM)	11	22*	14	–9	–3	–4	1	–1	–5	6	6	10	0	11	1	5	0	7
WSC_{DM} (g/kg DM)	0	–21**	4	5	0	5	–6	–11	–3	–9*	–23**	–22*	4	8	0	7	2	3
CP (g/kg DM)	4	4	–5	17*	11	–9	18**	16**	4	8	10	7	0	9	3	2	0	10
DM (g/kg)	23***	1	23	17***	10	10	19**	8	7	13***	3	–2	0	8	4	1	0	11
BC (mEq/kg DM)	–47***	–22	–14	–13	28*	14*	–13	4	12	28	12	8	1	9	2	5	0	7
WSC_{AE} (g/L)	5*	–3	11	4*	3	3	3	0	1	1	–3	–4	0	10	2	3	1	8

[1] DMD = *in vitro* dry matter digestibility, NDF = neutral detergent fibre, WSC_{DM} = water-soluble carbohydrate in dry matter, CP = crude protein, BC = buffering capacity, WSC_{AE} = water-soluble carbohydrate relative to aqueous phase.

[2] Symbols –, 0 and + represent the number of harvests that values for AberDart were statistically (F test) or numerically (Rank) less then, not different from, or greater than the comparable cultivar(s), respectively.

[3] Not available.

Table 6. Least square means for AberDove and contrast effects for each harvest-year combination

Variable[1]	Harvest/year												Total no. of harvests[2]					
	Harvest 1			Harvest 2			Harvest 3			Harvest 4			F test			Rank		
	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003	–	0	+	–	0	+
AberDove means																		
Dry matter (DM) yield (kg/ha)	6008	5496	NA[3]	3400	577	NA	3466	3376	NA	2115	2461	NA						
Ash (g/kg DM)	96	82	77	113	80	90	108	90	88	110	97	92						
DMD (g/kg)	777	730	746	816	856	799	789	790	752	787	801	810						
NDF (g/kg DM)	471	508	497	442	431	471	449	481	484	449	450	471						
WSC_{DM} (g/kg DM)	184	193	231	174	240	176	162	200	207	130	166	175						
CP (g/kg DM)	166	175	121	191	179	204	192	159	155	271	213	249						
DM (g/kg)	155	142	175	151	193	166	158	192	200	125	144	154						
BC (mEq/kg DM)	495	340	495	569	342	366	499	351	348	522	396	373						
WSC_{AE} (g/L)	34	32	50	31	58	35	31	48	52	19	28	32						
Contrast: AberDove minus the mean of the diploid controls (Fennema, AberElan and Spelga)																		
DM yield (kg/ha)	18	–376	NA	213	159	NA	91	–254	NA	139*	363***	NA	0	6	2	2	0	6
Ash (g/kg DM)	–1	–1	6*	0	–10**	–2	–6**	0	–1	–7**	–5**	–4*	5	6	1	9	2	1
DMD (g/kg)	37***	14	34*	–4	9	4	4	45***	3	0	–4	–4	3	9	0	3	1	8
NDF (g/kg DM)	–41***	–20**	–36**	–19***	–29***	–2	–20**	–41***	–14**	–22***	–8*	–11	10	2	0	12	0	0
WSC_{DM} (g/kg DM)	31***	17**	25	28***	50***	14	31***	43***	24***	30***	28***	25***	0	2	10	0	0	12
CP (g/kg DM)	8	1	1	–21**	–12	–9	–14**	–7	–19**	–12**	–18*	–8	5	7	0	9	0	3
DM (g/kg)	4	–6	–6	8**	21*	11	13*	–13	–3	5**	3	5	0	8	4	4	0	8
BC (mEq/kg DM)	22*	1	–11	22*	–35**	–22***	–15	22**	8	2	4	4	3	7	2	4	0	8
WSC_{AE} (g/L)	7**	2	3	7***	19***	5	8***	7**	5**	5***	5***	6	0	4	8	0	0	12
AberDove minus the tetraploid control (Greengold)																		
DM yield (kg/ha)	654*	–455	NA	–379*	19	NA	–21	–252	NA	–78	146	NA	1	6	1	5	0	3
Ash (g/kg DM)	–5	4	5	1	–10*	–2	–9***	2	3	–3	2	4	2	10	0	5	0	7
DMD (g/kg)	–15*	–18	–8	–5	4	1	–13	23*	–17*	–12	–18**	–18**	4	7	1	9	0	3
NDF (g/kg DM)	–2	8	–3	–6	–26**	4	–4	–24***	–8	–7	10*	3	2	9	1	8	0	4

(*Table 6 Continued*)

Variable[1]	Harvest/year												Total no. of harvests[2]					
	Harvest 1			Harvest 2			Harvest 3			Harvest 4			F test			Rank		
	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002	2003	–	0	+	–	0	+
WSC_{DM} (g/kg DM)	19*	–9	4	18*	58**	13	18**	24**	12*	8	–5	–7	0	6	6	3	0	9
CP (g/kg DM)	–2	2	1	–4	–10	–15	–4	0	–10	–8	–8	5	0	12	0	8	1	3
DM (g/kg)	20***	–2	9	21***	37***	26**	24***	9	12**	11***	5	6	7	5	0	1	0	11
BC (mEq/kg DM)	–20	–6	–24	4	–15	–6	–37	17	17	11	10	20*	0	11	1	6	0	6
WSC_{AE} (g/L)	8***	–2	4	8***	24***	9*	8***	8*	7**	3***	0	0	8	4	0	1	2	9

[1,2,3] See footnotes to Table 5.

Beef Research Centre for second harvest perennial ryegrass silage swards receiving no applied N (Keating and O'Kiely, 2000b) it does not appear that the low yields were solely a function of high losses of fertiliser N. Visual assessment confirmed that the low yields were not due to lodging or disease (no lodging was recorded and less than 3% of leaf tissue was diseased). Nonetheless, such differences in yield suggest cultivars were subjected to a broad array of environmental conditions allowing a broader environmental inference to be gained as compared to the situation in which environmental conditions remain constant from year to year.

AberDart v. AberDove

Relative differences and rankings between AberDart and AberDove for yield and quality measures were inconsistent across harvest-year combinations (Table 5). For most harvest-year combinations there were no significant differences between cultivars. Of the significant ($P < 0.05$) differences between cultivars the majority favoured AberDove as a superior cultivar for silage production over AberDart. Of the nonsignificant harvest-year combinations, AberDove was typically ranked the more desirable cultivar for silage production. Desirable traits for silage production, which AberDove tended to express more often and to a greater extent than AberDart, include high DM yield (mean increase = 184 kg/ha (6%)), low ash (mean reduction = 3 g/kg (3%)), high DMD (mean increase = 5 g/kg (1%)), low NDF (mean reduction = 9 g/kg DM (2%)), high WSC_{DM} (mean increase = 20 g/kg DM (12%)), high DM (mean increase = 4 g/kg (2%)) and high WSC_{AE} (mean increase = 5 g/L (14%)). Results for BC were ambiguous with both cultivars ranked highest in BC in an equal number of harvest-year combinations and similar overall means (427 *v.* 425 mEq/kg DM). While post-harvest and silo management determine the absolute values of DM, BC and WSC_{AE} necessary to ensure satisfactory preservation, the potential to produce well preserved silage was greater with AberDove compared to AberDart. If well preserved, the higher DMD values at harvest would be reflected in the DMD of the resultant silages (McDonald and Edwards, 1976) and the higher yields of digestible DM would reduce the unit cost of silage for animal production (O'Kiely *et al.*, 1997). Concentration of CP tended to be highest for AberDart (mean 201 *v.* 189 g/kg DM) with the difference significant (P < 0.05 or less) in 6 out of 12 harvest-year combinations. However, selection for high CP concentration is not considered an important grass breeding goal (Smith, Reed and Foot, 1997). The marginally lower CP values for AberDove would not be expected to compromise animal performance on grass silage diets but may help reduce environmental pollution because of lower N excretion (Castillo *et al.*, 2001). Both cultivars persisted well with little difference between AberDart and AberDove in ground cover (95.0% *v.* 96.2%, P < 0.05). To the authors' knowledge, there are no other published comparisons of AberDart with AberDove.

AberDart v. the mean of the diploid controls

Relative differences and, with the exception of NDF concentration, rank between AberDart and the mean of the diploid controls varied across harvest-year combinations (Table 5). Variation in the seasonal distribution of yield was comparable to the findings of the Scottish Agricultural College (2005) with DM yield lowest (P < 0.10 or less) for AberDart at the first harvest by, on average, 579 kg/ha (11%) and highest (P < 0.05 or less) at the final harvest by, on average, 170 kg/ha (8%). AberDart was bred for reduced reproductive growth (Wilkins and Davies, 1994) and this may have contributed to the lower first-harvest yield as reproductive growth accounts for a large proportion of first-harvest silage yield (Wilkins, 1989). Considering that the first harvest accounts for over 70% of the silage harvested in Ireland (Drennan, Carson and Crosse, 2005), this is a serious deficiency in a cultivar considered for silage production. A lower proportion of reproductive tillers would also serve to explain the generally higher ranking of AberDart *v.* the mean of diploid controls for DMD and the consistently lower ranking of AberDart for NDF concentration. Statistically, differences between Aberdart and the mean of the diploid controls in DMD and NDF values were either not significant or in favour (P < 0.05 or less) of AberDart (i.e., high DMD and low NDF). On average, AberDart had 6 g/kg higher (1%) DMD and 13 g/kg DM lower (3%) NDF concentration. Differences between AberDart and the mean of the diploid controls in CP (mean 201 *v.* 198 g/kg DM), DM (mean 159 *v.* 159 g/kg) and BC (mean 427 *v.* 424 mEq/kg DM) values were relatively small and ambiguous. AberDart had the highest (P < 0.05 or less) concentrations of WSC_{DM} and WSC_{AE} at three of the 12 harvest-year combinations. However, AberDart was ranked highest for WSC_{DM} and WSC_{AE} concentration at the majority of harvest-year combinations. A similar pattern was reported by Halling *et al.* (2005) for the WSC_{DM} concentration of AberDart and Fennema across 3 years and eight locations. On average, AberDart had 9 g/kg DM higher (6%) WSC_{DM} and 2 g/L higher (6%) WSC_{AE} concentration than the mean of the diploid controls compared with the average 14 g/kg DM higher (9%) WSC_{DM} concentration of AberDart over Fennema found by Halling *et al.* (2005). Based solely on WSC_{AE} differences, AberDart was of generally higher ensilability than the diploid controls, and although the difference was modest AberDart still offers a slightly greater probability of producing well preserved silage. The findings and predictions of this study are supported by the conservation results of O'Kiely *et al.* (2005) who found that Aberdart, ensiled unwilted and without additive treatment over nine harvest-year combinations, produced satisfactorily preserved silage on seven occasions whereas Fennema produced satisfactorily preserved silage on only five occasions. All cultivars persisted well. Although the Scottish Agricultural College (2005) reported that AberDart had a higher ground cover rating than Fennema, AberElan and Spelga, there was no difference between cultivar comparisons in the present study (95.0% *v.* 95.5%).

Wilting or appropriate additive application may negate the ensilability advantage of AberDart over the diploid controls. Wilting of grass prior to ensiling has been widely adopted and encouraged as a means of aiding silage preservation and management. The additional cost of wilting when making silage is negligible (O'Kiely *et al.*, 1997). Under these circumstances the choice of AberDart over the diploid controls may be considered a trade-off between lower silage yield and higher nutritional value. The optimum cultivar will vary between farms depending on factors such as the stocking rate on the farm, the cost and availability of alternative feedstuffs, the desired level of individual animal performance and the sale value of animal product (O'Kiely *et al.*, 1997).

AberDart v. the tetraploid control

AberDart was consistently ranked lower yielding than the tetraploid control, although the difference was significant ($P < 0.01$) at only one harvest-year combination (Table 5). Overall, the DM yield advantage of the tetraploid control was 229 kg/ha (7%) per harvest. Under a comparable conservation management regime in Northern Ireland AberDart was found to have a similar yield to Greengold at the first harvest but was lower yielding over subsequent harvests (Gilliland, 2007). Relative differences and rankings between AberDart and the tetraploid control in measures of forage quality varied across harvest-year combinations (Table 5). For the majority of harvest-year combinations there were no significant differences between cultivars. Where significant differences ($P < 0.05$ or less) were found AberDart had lower values for DMD and WSC_{DM} and, higher values for CP, DM and WSC_{AE}. Cultivar rankings across all harvest-year combinations supported these trends, with AberDart ranked lowest in DMD and WSC_{DM} and highest in CP, DM and WSC_{AE} at the majority of harvest-year combinations. On average, AberDart had 13 g/kg lower (2%) DMD, 7 g/kg DM lower (4%) WSC_{DM}, 7 g/kg DM higher (4%) CP, 11 g/kg higher (7%) DM and 2 g/L higher (6%) WSC_{AE} values than the tetraploid control. Results for NDF (mean 476 *v.* 472 g/kg DM) and BC (mean 427 mEq/kg DM for both) were ambiguous with neither cultivar demonstrating a clear ascendancy based on the frequency and direction of significant differences and rankings. Taken on the whole, AberDart produced a lower forage yield of generally lower nutritional value but greater ensilability. This was especially evident at the first harvest. Tetraploids tend to have greater digestibility, and by extension nutritive value, than diploids because of lower NDF and higher WSC_{DM} concentrations (Baert and Carlier, 1988) and this usually results in higher animal performance as suggested in the review by Smith *et al.* (2001). Unfortunately for silage production, tetraploids tend to be lower in DM concentration (Baert and Carlier, 1988). In the present study, the higher concentration of WSC_{DM} was insufficient to compensate for the low DM concentration and WSC_{AE} was generally lower for the tetraploid control compared to AberDart. Wilting or appropriate additive application may be necessary to realise the higher yield of digestible DM offered by the tetraploid control in the resultant silages. Although tetraploids generally produce more open swards and in evidence Gilliland (2007) found sward density was significantly greater for AberDart compared to Greengold, no significant difference in ground cover was found between these cultivars in the present study (95.0% *v.* 94.7%).

AberDove v. the mean of the diploid controls

AberDove produced a higher ($P < 0.05$ or less) DM yield than the mean of the diploid controls at the final harvest with an average advantage of 251 kg/ha (12%). Differences in DM yield at the earlier harvests were not significant although AberDove was ranked highest yielding at most harvest-year combinations (Table 6) with on average 25 kg/ha higher (1%) yield. Under a frequent cutting management, Orr, Martyn and Clements. (2001) found AberDove ranked highest in mean annual yield over 2 years relative to Fennema, AberElan and Spelga, although, similar to this study, rankings were not consistent across years. Relative differences between cultivar comparisons in measures of quality were inconsistent across harvest-year combinations (Table 6). For the majority of harvest-year combinations AberDove had significantly lower ($P < 0.05$ or less) concentrations of NDF ($P < 0.05$ or less) and higher ($P < 0.05$ or less) concentrations of WSC_{DM} and WSC_{AE} than the mean of the diploid controls. At all harvest-year combinations AberDove was ranked lowest in NDF concentration and highest in WSC_{DM} and WSC_{AE} concentration with a mean 22 g/kg DM lower (5%) NDF, 29 g/kg DM higher (18%) WSC_{DM} and 6 g/L higher (21%) WSC_{AE} concentrations than the mean of the diploid controls. Significant differences ($P < 0.05$) between cultivars for DMD, DM and CP values were only detected at three to five harvest-year combinations. Where significant differences occurred, AberDove had the highest DMD and DM values and lowest CP values. Cultivar rankings followed a similar trend with AberDove ranked highest for DMD and DM values and lowest for CP concentration at the majority of harvest-year combinations. Averaged over all harvest-year combinations AberDove had 11 g/kg higher (1%) DMD, 4 g/kg higher (2%) DM and 9 g/kg DM lower (5%) CP concentration. Under a frequent cutting management, Orr *et al.* (2001, 2003) found a similar pattern among AberDove, Fennema, AberElan and Spelga in digestibility, CP and WSC_{DM} values across 10 harvest-year combinations. In contrast there was no definitive trend among cultivars in BC (mean 425 *v.* 424 mEq/kg DM). AberDove and the mean of the diploid controls had the highest ($P < 0.05$ or less) BC at 3 and 2 harvest-year combinations, respectively. Absolute differences between AberDove and the mean of the diploid controls in BC at the nonsignificant harvest-year combinations were modest. All cultivars showed good persistency producing dense swards, although ground cover was marginally higher for AberDove compared to the mean of the diploid controls (96.2% *v.* 95.5%, $P < 0.05$). Taken on the whole the results favour AberDove as a more desirable cultivar for silage production than the diploid controls, offering generally a higher yield of more digestible forage with greater potential to produce satisfactorily preserved silage.

AberDove v. the tetraploid control

Differences between cultivars in yield were ambiguous with neither cultivar demonstrating a clear ascendancy. Statistically there were no differences between cultivars in yield at the majority (six out of eight) of harvest-year combinations. Furthermore, cultivar rankings at any harvest date were, with the exception of Harvest 3, inconsistent across years. For the majority of harvest-year combinations AberDove was ranked lowest in DMD and NDF although most differences were not significant. Averaged over all harvest-year combinations AberDove had 8 g/kg lower (1%) DMD and 5 g/kg DM lower (1%) NDF concentrations. AberDove had the highest ($P < 0.01$ or less) concentration of WSC_{DM} at six out of 12 harvest-year combinations and was ranked highest at an additional three harvest-year combinations. Overall, the advantage of AberDove in WSC_{DM} concentration was 13 g/kg DM (7%). Absolute differences between cultivars in CP concentration were relatively small (mean 189 *v.* 194 g/kg DM) and nonsignificant for all harvest-year combinations. Concentrations of DM and WSC_{AE} were highest ($P < 0.05$ or less) for AberDove at the majority of harvest-year combinations and cultivar rankings followed a similar trend. On average, AberDove had 15 g/kg higher (10%) DM and 6 g/L higher (21%) WSC_{AE} values. There were no significant differences between cultivars in BC at 11 out of 12 harvest-year combinations and cultivar rankings were inconsistent with both cultivars ranked highest in BC in an equal number of harvest-year combinations. Overall, the absolute difference between cultivars in BC was small (425 *v.* 427 mEq/kg DM). Both cultivars persisted well producing similarly dense swards with no difference between AberDove and the tetraploid control in ground cover (96.2 *v.* 94.7%, $P > 0.05$). Taken on the whole, cultivars were distinguishable only on the basis of forage nutritional value and ensilability, with AberDove generally of lower nutritional value but greater ensilability than the tetraploid control. In order to ensure a comparable standard of preservation and realise the higher DMD offered by the tetraploid control in the resultant silages wilting or appropriate additive application may be necessary. To the authors' knowledge, there are no published comparisons of AberDove with Greengold.

Conclusions

Of the perennial ryegrass cultivars evaluated AberDove was the most desirable diploid for silage production producing generally a higher yield of more digestible forage, and based primarily on higher WSC_{AE} concentration, offered the greatest potential to produce well preserved silage. Ensiling AberDart *v.* the diploid controls offered a slightly greater probability of producing well preserved silage based on a modest increase in WSC_{AE} concentration. The dilemma when considering AberDart for silage production was the generally lower DM yield but greater digestibility compared with the diploid controls. The tetraploid control produced forage of typically greater digestibility than AberDart or AberDove but at a cost of lower ensilability. In its favour, the tetraploid control generally outyielded AberDart and produced comparable yields to AberDove. Final ground cover ratings were high for all cultivars. Evaluation of nutritional value and ensilability offers further grounds to differentiate and select cultivars for animal production potential.

Acknowledgements

The authors thank Messrs. J. Hamill and J. Marron for technical support, the Grange farm staff (and in particular Mr. J. Lynch) for plot management, the

Grange laboratory staff for chemical analyses and Prof. M.D. Casler for statistical advice. A Teagasc Walsh Fellowship, awarded to P. Conaghan and H. Howard, and the European Commission under the Fifth Framework Programme (QLK5-CT-2001-0498) supported this research.

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Received 18 October 2007