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Changes in yield and composition of barley, wheat and triticale grains harvested during advancing stages of ripening

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This study involved an evaluation of the changes in grain yield, nutritive value, ensilability and harvesting losses of intensively managed winter cereals harvested during the advancing stages of ripening. Five cereal crops (barley cv. Regina and wheat cv. Madrigal in 2001; barley cv. Regina, wheat cv. Falstaff and triticale cv. Fidelio in 2002) were assessed. Twenty plots per crop were arranged in a randomised complete block design, with five times of harvest (four for barley in 2002) and four replicate blocks per harvest. Dry matter (DM) yields changed relatively little between harvest dates, but fresh yields declined ($P < 0.001$) over time due to the moisture loss associated with ripening. Time-course changes in indices of nutritive value, such as concentrations of crude protein, starch and ash, and organic matter digestibility, were relatively small and did not follow a consistent pattern. Ensilability indices, such as DM and water-soluble carbohydrate concentrations and buffering capacity, indicated that satisfactory fermentations were likely if such crops were ensiled; buffering capacity, generally declining with advancing maturity. Harvesting losses were not clearly related to growth stage at harvest. It is concluded that winter cereal grain (barley, wheat and triticale) DM yields and quality were relatively constant as ripening progressed from DM concentrations of around 550 to >800 g/kg.

Keywords: Cereal grain; ensilability; nutritive value; ripening

Introduction

Irish cereal farmers have traditionally aimed to combine-harvest ripe grain at a dry matter (DM) concentration above 800 g/kg, although wet weather at harvesting can result in values below 750 g/kg. Grain

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harvested at DM concentration above 850 g/kg can be stored without artificial drying (Kaiser, 1999). As DM concentration decreases below this threshold, the duration of safe storage decreases and the requirement for aeration, artificial drying or chemical preservation (e.g., propionic acid treatment) rises progressively if grain is to be stored for an extended period.

Buchanan-Smith, Morris and Smith (2003) and Kaiser (1999) indicated that high-moisture grain harvested at a DM concentration below 750 g/kg can be conserved by a number of methods, including ensilage as rolled grain or as urea-treated whole grain. In recent times, some Irish farmers are using these technologies to conserve high-moisture cereal grains at DM concentrations from above 500 to 760 g/kg (Stacey *et al.*, 2003). These technologies involve the use of silos typically associated with forage storage on livestock farms, and offer the potential to eliminate the need to roll grain at feedout. Other potential advantages include permitting farmers to spread harvesting over a wider time frame, to make some fields available for earlier re-use and to facilitate the operation of secure systems of traceability on livestock farms by using home-produced feedstuffs.

Farmers considering technologies based on harvesting and conserving grains at high moisture concentrations need to know the impact of the stage of ripeness at harvest (DM concentrations from 550 to >800 g/kg) on grain yield, estimated nutritive value, ensilability and harvesting losses. Whereas early research involved the study of changes in the yield and composition of wheat and barley grain (Thatcher, 1915; Harlan, 1920), Loss *et al.* (1989) indicate that the growth pattern of modern varieties differs from that of older varieties. Most of the studies showing the relative stability of grain DM yield and chemical composition of cereal grains after physiological maturity was reached (McLean, 1933; Lang and Holmes, 1969) involved crops with considerably lower yields than are currently common on many Irish farms (DAF, 2005). They also frequently combined a relatively modest number of chemical characteristics together with grain yield. In particular, little information exists on the patterns of change in grain DM yield, estimated nutritive value and ensilability (e.g., water-soluble carbohydrate concentration and buffering capacity) when relatively high and time critical inputs of nutrients, fungicides, insecticides, growth regulators, (Conry and Hogan, 2001) are combined to increase and/or prolong the rate of starch deposition in grain. Furthermore, the humid and frequently wet conditions that prevail in Ireland after physiological maturity is reached mean that the rate of decline in grain moisture concentration can be quite irregular, and slower than in many other countries.

Wheat and barley are the main cereals grown for livestock feed in Ireland, and interest in triticale is increasing among farmers contemplating lower-input systems. However, relatively little information exists on the changes in grain DM yield (including grain loss during harvesting), estimated nutritive value and ensilability during advancing stages of ripening for triticale compared to wheat or barley.

Although shedding losses of cereal grains decline when crops are combine-harvested earlier and at higher moisture concentrations, there can be a reciprocal increase in losses during threshing and separation unless a range of settings on the combine harvester are adjusted appropriately. It is thus essential to also estimate grain loss during harvesting in order to calculate the yield of grain available to harvest.

This experiment was designed to quantify the patterns of change in grain yield, estimated nutritive value, ensilability and grain loss during harvesting for winter wheat, barley and triticale managed as on Irish commercial cereal farms, and harvested at a succession of stages of ripeness.

Materials and Methods

Experimental design

Field plots were located at Teagasc Oak Park, Carlow (52° 50'N latitude, 6°55'W longitude, 61 m above sea level) on Mortarstown Series Grey-Brown podzolic and Athy-Complex Grey-Brown complex soil type (Conry and Ryan, 1967).

In 2001, plots (20 m × 3 m) of barley (*Hordeum vulgare* L., cv. Regina; sown 18 October 2000; 181 kg/ha inorganic fertiliser N) and wheat (*Triticum aestivum* L., cv. Madrigal; sown 12 January 2001; 136 kg/ha inorganic fertiliser N) were managed as for commercial grain production, using pesticide, herbicide, fungicide and fertiliser inputs appropriate for high yielding crops. Twenty plots for each cereal were arranged in a randomised complete block design with five harvest times (H1 to H5) and four replicate blocks. As the crop approached maturity, grain DM concentration was measured frequently; harvest times were based on target concentrations of 600, 660, 720, 780 and >800 g/kg. Plots were harvested to a stubble height of 6 cm using a plot combine harvester (Deutz Fahr Farmliner 3370, with a 2.4 m cutting width) equipped with a built-in grain collection and weighing system to allow individual plot yield to be determined. Harvested grains from each plot were sub-sampled and stored at −18 °C until subsequent qualitative analysis.

In 2002, plots of barley (32 m × 3 m; cv. Regina; sown 9 October 2001; 150 kg/ha inorganic fertiliser N), wheat (24 m × 3 m; cv. Falstaff; sown 30 October 2001; 224/ha kg inorganic fertiliser N) and a semi-dwarf variety of triticale (40 m × 3 m; X *Triticosecale* Wittmack, cv. Fidelio; sown 26 October 2001; 180 kg/ha inorganic fertiliser N/) were grown. The plots were arranged in a similar design to 2001, with comparable crop husbandry, harvesting and sampling procedures. The one exception was that only four harvest times were feasible for barley due to prevailing weather conditions.

Two estimates of harvest losses were made in each plot. The standing crop was flattened at two random positions. Steel frames (2.4 m × 0.6 m) covered with heavy-duty polyvinyl were placed on top of the flattened crop to allow unrestricted passage for the harvester. Once the combine harvester had passed clear of the frames the chaff and straw on the trays were manually separated and removed, and any grains that had passed through the harvester and onto the frames were collected, weighed and dried. The weight of the recovered grains was used to estimate losses of grain across the entire area of the plot and this added to the weight of grain recorded in the combine hopper to obtain harvestable yield per plot.

Data were obtained daily from a meteorological station located within 200 m of the field plots for the period 1 July to 10 September in both seasons (data recorded as described by Keane, 1986).

Chemical analysis

Sub-samples of grain from each plot were dried at 98 °C for 16 h in an oven with forced air circulation to determine the DM concentration. Sub-samples similarly dried at 40 °C for 48 h were milled (Christy and Norris Ltd.) through a screen with 1 mm holes and used to assess organic matter digestibility (OMD) by a modification (the final residue was isolated by filtering rather than centrifuging) of the Tilley and Terry (1963) technique, crude protein (N × 5.83) using a LECO auto-analyser (AOAC, 1990), ash (following combustion in a muffle furnace at 550 °C for 5 h), starch (Megazyme assay; McCleary, Gibson and Mugford, 1997), water soluble carbohydrate (WSC) (anthrone method; Thomas, 1977), neutral (Van Soest, 1965) and acid (Van Soest, 1963) detergent fibre (barley 2001 and wheat 2001 only) and buffering capacity. The latter was measured by a modification (using a Metrome Automatic Analyser) of the method of Playne and McDonald (1966).

Statistical analysis

The grain yield, harvest loss and composition data for each cereal crop were analysed as a randomised complete block design using the General Linear Model option in Unistat 5.6 (Unistat Ltd., 4 Shirland Mews, London W9 3DY, England), with least significant differences being used to separate individual harvest time effects. The relationship between changes in grain yield, harvest losses, composition, and the number of days from harvest 1 (H1) were examined using the linear and polynomial regression functions in Unistat 5.6.

Results

Meteorological results data, based on summaries over consecutive 10 or 11 day intervals, are presented in Table 1.

In 2001, the grain DM concentration of barely changed over a 19-day interval from 546 g/kg to 835 g/kg and fresh yield values on successive harvest dates decreased progressively (Table 2). Grain DM yields

Table 1. Mean[1], maximum[2] (Max.) and minimum[2] (Min.) daily values for temperature and rainfall

Year	Date	Temperature (°C)			Rainfall (mm)		
	Interval	*Mean*	*Max.*	*Min.*	*Mean*	*Max.*	*Min.*
		Experimental period					
2001	*July*						
	1–10	14.9	18.3	12.8	0.5	3.3	0.0
	11–20	11.8	13.1	10.1	2.0	8.0	0.0
	21–31	16.2	18.9	14.5	0.1	0.5	0.0
	August						
	1–10	13.7	15.9	12.3	3.7	21.2	0.0
	11–20	15.7	19.2	13.7	3.5	14.0	0.0
	21–31	13.8	15.3	12.3	1.0	3.9	0.0
	September						
	1–10	13.9	16.0	10.9	0.4	2.2	0.0
2002	*July*						
	1–10	12.1	13.4	11.3	2.5	6.9	0.0
	11–20	14.2	17.3	12.3	0.4	2.1	0.0
	21–31	15.6	17.3	13.3	0.9	4.4	0.0
	August						
	1–10	15.1	18.3	11.3	4.3	18.5	0.0
	11–20	15.4	17.4	14.4	1.1	5.2	0.0
	21–31	15.2	17.5	12.3	0.4	1.7	0.0
	September						
	1–10	12.5	14.2	11.2	0.7	2.1	0.0

[1]Mean daily value; [2]maximum and minimum daily average.

Table 2. Grain yield, chemical composition and harvesting losses of five cereal crops over sequential harvests

Crop harvest	Harvest date	Harvestable grain yield		Composition[1]							Harvesting loss of grain DM (kg/ha)
		Fresh (t/ha)	DM (t/ha)	DM (g/kg)	CP (g/kg DM)	Starch g/kg DM	OMD (g/kg)	Ash g/kg DM	BC (mEq/kg DM)	WSC (g/kg DM)	
					Barley in 2001						
H1	6 July	12.5	6.80	546	101	585	844	25.6	107	43	577
H2	9 July	10.8	6.73	631	100	636	843	24.9	102	44	438
H3	12 July	9.8	7.06	724	103	652	839	26.2	102	46	361
H4	18 July	8.7	7.04	818	102	589	846	25.1	92	46	321
H5	25 July	8.0	6.68	835	104	613	846	23.9	88	47	95
s.e.		0.16	0.050	8.7	1.9	14.9	4.7	0.49	3.0	1.0	47.1
Significance		***	***	***		*			**		***
					Barley in 2002						
H1	5 July	11.5	6.26	538	98	573	876	25.8	70	39	248
H2	12 July	8.7	6.19	711	106	554	867	27.8	64	43	256
H3	15 July	7.7	6.32	825	105	558	867	25.1	64	42	557
H4	18 July	6.4	5.48	855	102	566	861	24.4	65	38	162
s.e.		0.17	0.109	3.2	1.6	7.3	3.3	0.99	1.8	0.8	56.9
Significance		***	***	***	*				NS	*	**
					Wheat in 2001						
H1	16 Aug	12.6	7.80	626	112	667	862	18.7	95	50	2
H2	22 Aug	10.6	7.63	726	109	699	870	18.7	82	50	5
H3	23 Aug	9.9	7.76	794	107	689	869	17.1	81	53	6
H4	27 Aug	9.6	7.67	803	105	668	854	18.2	82	54	10
H5	7 Sept	9.3	7.63	822	117	679	879	17.4	82	49	0
s.e.		0.20	0.087	7.0	2.6	9.7	4.6	0.42	2.4	0.6	0.6
Significance		***	NS	***	NS	NS	*	NS	**	***	***
					Wheat in 2002						
H1	6 Aug	16.5	9.53	580	110	638	866	18.7	61	53	48
H2	12 Aug	15.5	10.39	672	112	620	901	29.0	68	54	114
H3	14 Aug	14.7	9.77	664	113	650	889	18.2	63	50	156
H4	19 Aug	12.7	9.95	783	116	711	900	16.2	63	48	199
H5	21 Aug	11.9	9.73	818	113	707	887	15.6	50	54	181
s.e.		0.29	0.164	9.5	1.1	15.0	4.9	2.46	1.9	1.1	43.7
Significance		***	*	***	*	**	**	*	***	*	
					Triticale in 2002						
H1	12 Aug	15.0	8.39	561	98	675	894	20.4	55	64	44
H2	19 Aug	11.9	8.07	681	98	671	891	19.3	76	66	42
H3	21 Aug	10.7	8.07	751	103	665	889	19.4	61	67	37
H4	27 Aug	9.9	8.07	811	100	664	886	19.0	63	68	54
H5	2 Sept	10.0	8.29	826	96	662	881	19.1	65	68	42
s.e.		0.23	0.159	3.6	1.7	5.7	4.7	0.27	1.5	0.8	13.1
Significance		***		***				*	***	*	

[1]Dry matter (DM); crude protein (CP); organic matter digestibility (OMD); buffering capacity (BC); water-soluble carbohydrate (WSC).

were higher (P < 0.01) at H3 and H4 than at the other harvests. Starch tended to be highest at H2 and H3, while the values for crude protein, ash, WSC and OMD did not change (P > 0.05) throughout the harvest period. Buffering capacity decreased (P < 0.01) during the 19 day interval. For H1 through to H5, neutral detergent fibre (NDF) concentrations in DM were 223, 218, 225, 226 and 226 (s.e. 3.7; P = 0.47) g/kg, respectively, with corresponding values for acid detergent fibre (ADF) of 62, 61, 61, 63 and 61 (s.e. 1.2; P = 0.56) g/kg.

In 2002, the grain DM concentration of barley increased (P < 0.001) over a 13 day interval from 538 g/kg to 855 g/kg while fresh yields decreased (P < 0.001) correspondingly (Table 2). Grain DM yield was lower at H4 than at the first three harvests whereas crude protein concentration was higher (P < 0.05) at H2 than H1, with H3 and H4 being intermediate. Grain WSC concentrations were higher (P < 0.05) at H2 and H3 compared to H1 and H4. None of the other yield or composition variables in Table 2 were significantly affected (P > 0.05) by harvest date.

In 2001, the grain DM concentration of wheat increased from 626 g/kg to 822 g/kg over a 22-day period while the fresh yield simultaneously decreased (P < 0.001). Neither DM yield, crude protein, starch nor ash concentrations differed across the five harvests. Grain WSC values were higher (P < 0.001) at H3 and H4 than at other harvests. The OMD was lower at H4 than at adjacent harvests, while grain buffering capacity was higher (P < 0.01) at H1 than at subsequent harvests. For H1 through to H5, respectively, the NDF concentrations were in the DM were 160, 154, 156, 153 and 150 (s.e. 2.0; P < 0.05) g/kg, and the corresponding ADF concentrations were 40, 38, 37, 37 and 37 (s.e. 0.3; P < 0.001) g/kg.

The grain DM concentration for wheat in 2002 increased during the 15-day interval from 580 g/kg to 818 g/kg (Table 2) and the fresh yield decreased simultaneously (P < 0.001) (Table 2). The grain DM yield achieved at H2 was higher (P < 0.001) than at H1, H3 or H5, while crude protein concentration was lower (P < 0.05) at H1 than at H4. The OMD was lower at H1 (P < 0.01) and the ash concentration was higher (P < 0.05) at H2 than at the other harvests. Grain WSC values were lower (P < 0.05) at H4 than at H1, H2 or H5. Starch concentration was higher (P < 0.01) at H4 and H5 than at earlier harvests whereas the lowest (P < 0.001) buffering capacity was at H5.

The grain DM concentration of triticale increased at successive harvests during the 21 day interval (Table 2). The fresh yields of triticale grain decreased (P < 0.001) from H1 to H4 and H5. There was no change (P > 0.05) over time in DM yield, crude protein, starch or OMD. Grain WSC values were lower (P < 0.05) at H1 than at the final three harvests. Ash concentration was highest (P < 0.05) at H1 while buffering capacity was lowest (P < 0.001) at H1 and highest at H2.

Harvesting losses of grain DM (kg) per ha were influenced by harvest date for barley in 2001 and 2002, and for wheat in 2001. Values for barley decreased from the highest loss at H1 to the lowest at H5 in 2001. Losses for wheat in 2001 increased (P < 0.001) from H1 to H4 but all were at or under 10 kg/ha, and there was no detectable loss for H5. In 2002 barley losses were higher (P < 0.01) at H3 than at other harvests.

Correlations coefficients between grain DM concentration and fresh yield across the times of harvest were barley −0.98 (2001) and −0.98 (2002), wheat −0.84 (2001) and −0.94 (2002) and triticale −0.96. The regression relationships between the yield, composition and harvesting loss variables and the time of harvest are presented in Table 3.

Table 3. Relationship ($y = a+bx+cx^2$) between grain yield, nutritive value, ensilability variables (y) with date of harvest and time of harvest (x; days from first harvest date)

	Parameter estimates (s.e.)							
Dependent variable[a]	Intercept		Linear		Quadratic[c]		R^2	Sig [b]
Barley in 2001								
Fresh yield (t/ha)	12.4	(0.28)	–0.50	(0.080)	0.015	(0.0040)	0.88	***
DM yield (t/ha)	6.7	(0.09)	0.07	(0.024)	–0.004	(0.0012)	0.34	*
DM (g/kg)	542	(12.2)	35.9	(3.43)	–1.08	(0.171)	0.95	***
Crude protein (g/kg DM)	101	(1.3)	0.16	(0.127)			0.08	
Starch (g/kg DM)	606	(17.8)	4.7	(4.97)	–0.258	(0.2485)	0.06	
NDF (g/kg DM)	221	(2.7)	0.32	(0.259)			0.08	
ADF (g/kg DM)	62	(0.9)	–0.01	(0.085)			<0.01	
OMD (g/kg)	842	(3.2)	0.18	(0.303)			0.02	
Ash (g/kg DM)	25.4	(0.43)	0.09	(0.120)	–0.009	(0.0060)	0.33	*
Buffering capacity (mEq/kg DM)	106	(1.9)	–1.02	(0.177)			0.65	***
WSC (g/kg DM)	44	(0.7)	0.15	(0.063)			0.24	*
Harvest loss[d] (kg/ha)	539	(31.5)	–22.6	(3.00)			0.76	***
Barley 2002								
Fresh yield (t/ha)	11.5	(0.14)	–0.39	(0.016)			0.98	***
DM yield (t/ha)	6.2	(0.13)	0.10	(0.046)	–0.012	(0.0036)	0.62	**
DM (g/kg)	541	(9.3)	25.5	(1.05)			0.98	***
Crude protein (g/kg DM)	98	(1.8)	2.0	(0.66)	–0.136	(0.0506)	0.43	*
Starch (g/kg DM)	573	(7.6)	–5.2	(2.72)	0.36	(0.209)	0.23	
OMD (g/kg)	876	(2.9)	–1.10	(0.325)			0.45	**
Ash (g/kg DM)	25.9	(1.23)	0.54	(0.439)	–0.053	(0.0338)	0.20	
Buffering capacity (mEq/kg DM)	70	(1.9)	–1.26	(0.677)	0.071	(0.0521)	0.30	
WSC (g/kg DM)	39	(0.8)	1.20	(0.293)	–0.097	(0.0226)	0.58	**
Harvest loss (kg/ha)	228	(90.3)	52.1	(32.17)	–3.94	(2.477)	0.17	
Wheat 2001								
Fresh yield (t/ha)	12.6	(0.51)	–0.43	(0.110)	0.013	(0.0045)	0.59	***
DM yield (t/ha)	7.8	(0.23)	–0.01	(0.019)			0.01	
DM (g/kg)	626	(11.5)	24.8	(2.46)	–0.72	(0.101)	0.91	***
Crude protein (g/kg DM)	113	(2.3)	–1.35	(0.488)	0.068	(0.0201)	0.46	**
Starch (g/kg DM)	674	(10.3)	2.0	(2.21)	–0.087	(0.0909)	0.05	
NDF (g/kg DM)	159	(1.6)	–0.41	(0.132)			0.35	**
ADF (g/kg DM)	40	(0.6)	–0.36	(0.124)	0.010	(0.0051)	0.49	**
OMD (g/kg)	861	(4.2)	0.57	(0.360)			0.35	
Ash (g/kg DM)	18.5	(0.33)	–0.05	(0.028)			0.16	
Buffering capacity (kg/ha)	94	(2.4)	–2.24	(0.509)	0.08	(0.021)	0.56	***
WSC (g/kg DM)	49	(0.9)	0.66	(0.199)	–0.031	(0.0082)	0.46	**
Harvest loss (kg/ha)	1.0	(0.87)	1.24	(0.187)	–0.058	(0.0077)	0.78	***
Wheat 2002								
Fresh yield (t/ha)	16.5	(0.37)	–0.10	(0.110)	–0.014	(0.0069)	0.86	***
DM yield (t/ha)	9.6	(0.21)	0.13	(0.062)	–0.008	(0.0039)	0.20	
DM (g/kg)	569	(11.3)	16.0	(1.13)			0.92	***
Crude protein (g/kg DM)	111	(1.03)	0.29	(0.103)			0.31	*
Starch (g/kg DM)	634	(15.3)	–3.6	(4.47)	0.62	(0.281)	0.60	***
OMD (g/kg)	867	(5.4)	6.5	(1.59)	–0.338	(0.0997)	0.55	**
Ash (g/kg DM)	19.6	(2.87)	1.29	(0.839)	–0.111	(0.0527)	0.29	
Buffering capacity (kg/ha)	61	(2.3)	1.95	(0.668)	–0.169	(0.0420)	0.61	***
WSC (g/kg DM)	54	(1.7)	–0.55	(0.499)	0.031	(0.0313)	0.07	
Harvest loss (kg/ha)	58	(36.9)	9.7	(3.71)			0.28	

(Table 3 Continued)

	Parameter estimates (s.e.)							
Dependent variable[a]	Intercept		Linear		Quadratic[c]		R^2	Sig [b]
			Triticale 2002					
Fresh yield (t/ha)	15.0	(0.26)	–0.60	(0.056)	0.017	(0.0025)	0.93	***
DM yield (t/ha)	8.4	(0.17)	–0.06	(0.035)	0.003	(0.0016)	0.15	
DM (g/kg)	556	(7.8)	25.2	(1.65)	–0.58	(0.074)	0.98	***
Crude protein (g/kg DM)	97	(2.3)	0.70	(0.474)	–0.037	(0.0212)	0.16	
Starch (g/kg DM)	675	(5.4)	–1.03	(1.135)	0.020	(0.0508)	0.16	
OMD (g/kg)	894	(4.3)	–0.50	(0.903)	–0.006	(0.0404)	0.23	
Ash (g/kg DM)	20.4	(0.24)	–0.17	(0.052)	0.005	(0.0023)	0.54	**
Buffering capacity (kg/ha)	58	(3.3)	1.6	(0.70)	–0.065	(0.0311)	0.24	
WSC (g/kg DM)	64	(1.0)	0.32	(0.206)	–0.006	(0.0092)	0.35	*
Harvest loss (kg/ha)	42	(10.4)	0.2	(0.82)			<0.01	

[a]DM= dry matter, NDF= neutral detergent fibre, ADF= acid detergent fibres, OMD=organic matter digestibility, WSC=water soluble carbohydrate.
[b]Error df = 18 and 17 for linear and quadratic relationships, respectively (corresponding df = 14 and 13 for barley 2002).
[c]Where quadratic was not significant the equation was reduced and is in a linear form.
[d]Loss of grain at harvesting (DM basis).
Values within brackets are standard errors.

Grain DM concentration increased linearly ($P < 0.001$) with advancing harvest date in 2002 for barley and wheat, while the increase was quadratic ($P < 0.001$) for barley and wheat in 2001 and for triticale in 2002. Fresh yield decreased linearly ($P < 0.001$) with advancing harvest date for barley in 2002, while the decline was quadratic ($P < 0.001$) for the remaining four crops. For wheat in both 2001 and 2002 and triticale, grain DM yield was not directly related to the date of harvest, whereas for barley there was a quadratic relationship in both years reflecting yield decline for ripe grain.

Grain starch concentration was not significantly related to harvest time ($P > 0.05$), except for wheat in 2002 where the relationship was quadratic ($P < 0.01$) and reflected an initial decline followed by a larger increase in value as harvest date advanced. In the case of crude protein, there was no relationship with harvest time for barley in 2001 or triticale while, there were contrasting quadratic relationships for barley in 2002 ($P < 0.05$) and wheat in 2001 ($P < 0.01$), and a linear increase ($P < 0.05$) for wheat in 2002. Digestibility of the grain was linearly related to date of harvest for barley in 2002 (negative, $P < 0.01$) while the relationship for wheat in 2002 was quadratic ($P < 0.01$). In the latter case, after an initial increase, digestibility declined towards the final harvest. There was no relationship between NDF or ADF and the time of harvest for barley in 2001. The NDF concentration of wheat declined linearly ($P < 0.01$) in 2001 with advancing maturity whereas the quadratic relationship ($P < 0.01$) for ADF indicated a decreasing rate of decline with later harvesting. The decline in ash concentration was quadratic for barley in 2001 ($P < 0.05$) and for triticale ($P < 0.01$). Grain buffering capacity was significantly related to harvest date for three of the five cereal crops. A linear decline was recorded for barley in 2001 ($P < 0.001$) while a quadratic relationship occurred with wheat in 2001 reflecting a large decline between H1 and H3 but with little change thereafter. For wheat in 2002, a quadratic relationship reflected a rise in buffering capacity between H1 and H2, followed by a much larger decline through to H5. Grain WSC content increased ($P < 0.05$) linearly for barley in 2001 and quadratically for triticale, the latter indicating a declining rate of increase as the crop ripened. Quadratic relationships ($P < 0.01$) for barley in 2002 and wheat in 2001 reflected higher values at the intermediate harvests.

Harvest loss was linearly and negatively related ($P < 0.001$) to harvest date for barley in 2001, whereas the relationship for wheat in 2001 was quadratic ($P < 0.01$) with the rate of increase declining as harvest date advanced. Relationships were not significant for the other crops.

Discussion

The crop husbandry programme employed used similar amounts and timing of seed variety, fertiliser, herbicide, fungicide and growth regulator (Conry and Hogan, 2001) to those used to produce high yields of harvested grain on commercial farms in Ireland. The harvest schedules adopted encompassed DM concentrations ranging from high moisture grain (Stacey *et al.*, 2003) through to conventionally ripe grain, thus providing the opportunity to quantify the practical effects of stage of ripening at harvest on grain DM yield and composition. The weather conditions prevailing throughout the harvesting periods were within the range experienced at this site over the preceding 29 year period.

Yield and dry matter concentration

The grain DM yields achieved were similar to or better than the mean yields obtained with barley and wheat on Irish farms in the same years (DAF, 2005), or with triticale (Hackett and Burke, 2004). The higher barley DM yield recorded in 2001 than 2002 reflects the pattern recorded nationally (DAF, 2005). In contrast, the lower wheat DM yield in 2001 likely reflects the quite late sowing (Darwinkel, ten Hag and Kuizenga, 1977) of the crop due to wet conditions the previous autumn.

The yields of harvested wheat and triticale grain DM were relatively constant over the harvest dates studied. In contrast, although barley grain DM yield was also constant across most of the DM range studied, the final harvests at grain DM concentrations of 835 and 855 g/kg resulted in proportionate reductions (after correction for harvesting losses) of 0.08 and 0.15, respectively, compared to the mean of the preceding yields. These declines were likely due to the loss of ripe grain following shattering from the ear prior to harvesting (Smith, 1960). Thus it can be concluded that each of the crops had reached physiological maturity (Hanft and Wych, 1982) prior to their first harvest date. That physiological maturity was reached by the stage of the first harvest agrees with Clarke (1983), Jennings and Morton (1963) and McLean (1933).

The high negative correlations between the reduction in fresh grain yield and the increase in grain DM concentration over successive harvest dates are indicative of the extent to which the reduction in fresh yield was due to water disappearance from the grain. Although there was a general, progressive increase in grain DM concentration as crops advanced through to ripeness, there were considerable weather-mediated fluctuations. Thus in 2001, for example, barley DM concentration increased from 631 to 724 g/kg over 3 days (31 g/day), while wheat increased from 794 to 803 g/kg in 4 days (2.3 g/day). The reason for the higher than anticipated DM concentration of the wheat grain at H2 in 2002 is not evident, but may be associated with the elevated ash concentration recorded at that harvest. In general, however, crops of approximate DM concentrations of 538 to 626 g/kg required between 10 and 22 days to ripen to above 800 g/kg, giving mean daily changes of from 16 to 29 g/kg. These compare with daily change rates of 25 g/kg and 14 to 41 g/kg reported by MacGregor, LaBerge and Meredith (1971) and Clarke (1983), respectively. Furthermore, data collected within days (unpublished) showed that similarly large weather-mediated fluctuations in grain DM concentration can occur within a single day. Thus, frequent monitoring of grain DM concentration is required if harvesting at a target DM concentration is to be achieved, and the duration for which this target DM concentration is maintained can be relatively short.

Nutritive value

The *in vitro* digestibility values recorded at the final harvest of barley, wheat and triticale grain were similar to those published by MAFF (1990). Starch concentrations for barley 2001 and barley 2002 were at the upper end (2001) and middle (2002), respectively, of the ranges published for winter barley by MAFF (1990). The higher value for barley in 2001 likely reflects the better growing conditions that resulted in higher DM yields that season (Jenner, Ugalde and Aspinall, 1991). In contrast, the starch concentrations for wheat in 2001 and 2002 were at the middle and the upper end, respectively, of the published ranges for winter wheat (MAFF, 1990). Again, the ranking of the starch concentrations reflects their ranking in DM yield, with the lower yield for wheat in 2001 being explained by the unusually late sowing date (January 2001). The lower starch concentration of wheat in 2002 at H1 to H3 compared to H4 and H5 is surprising, and was not reflected in either a similar profile for OMD or a reverse profile for WSC or crude protein. Triticale had a starch concentration that was at the upper end of the range published by MAFF (1990), reflecting the high harvested grain DM yield (8.3 t/ha). The protein concentration for barley and triticale was at the lower end of the range published by MAFF (1990) while that for wheat was in the middle.

In general, changes among indices of grain nutritive value during the advancing stages of ripening were absent, or at most relatively modest in scale, and did not follow a clear and consistent temporal pattern. This agrees with the data published for wheat and barley by Chanda, Narmada and Singh (1999), Jennings and Morton (1963), MacGregor *et al.* (1971) and Salo (1985).

Ensilability

Grain buffering capacity was low compared to the values normally encountered in forages (McDonald, Henderson and Heron, 1991), and indicates that a smaller quantity of fermentation acids or added acid is required to elicit a given decline in pH if high moisture grains rather than forage were ensiled. This, in turn, would be reflected in a requirement for a lower concentration of fermentable substrate, such as water-soluble carbohydrates. Most of the buffering capacity in herbage has been attributed to anions (organic acid salts, orthophosphates, sulphates, nitrates and chlorides) with a small proportion due to plant protein (McDonald *et al.,* 1991). There was little evidence of a relationship between buffering capacity and protein concentration in the current experiment (correlation coefficients of 0.04, −0.45, 0.29, −0.32 and −0.17 for barley in 2001, barley in 2002, wheat in 2001, wheat in 2002 and triticale, respectively). The general decline in grain buffering capacity with advancing ripeness may reflect a reduction in the metabolic activity (McDonald *et al.,* 1991) of the drying grains, and may correspond to a reduction in the metabolic organic acids that contribute to buffering capacity (Muck, O'Kiely and Wilson, 1991).

Grain WSC concentration was numerically highest in triticale and lowest in barley, and the values recorded were at the upper end of the range reported by MAFF (1990). When used as an index of ensilability, WSC concentration is best expressed on an aqueous phase basis (O'Kiely and Muck, 1998), thereby reflecting the effects of both the water and WSC concentrations of the grain. Thus, in the present study, overall mean values increased from 67 to 251 g/L between the first and final harvests. These values indicate a considerable surplus of WSC above the normal fermentable substrate requirements for ensilage, particularly when cognisance is taken of the low water concentration and buffering capacity of the grain.

Harvesting losses

Grain losses at harvest indicate that the combine harvester as operated did not completely thresh and/or adequately separate grain from straw and chaff. Mean losses recorded were 51, 7 and 5 g/kg for barley, wheat and triticale, respectively, and these compare with Schuler, Radokowski and Kucera (1978) who recorded mean losses of 53 g/kg for barley and 36 g/kg for wheat.

There was no clear and consistent relationship between harvesting loss and stage of ripeness in the current experiment. Even in the case of the two crops of barley where losses were relatively high, only the 2001 crop showed a decline in harvesting loss with advancing ripeness.

The low losses obtained with wheat and triticale show the potential to reduce losses, while the relatively high values recorded with barley indicate that further research is required into the optimal operation of combine harvesters during the harvesting of high moisture grain to minimise losses.

It is concluded that the relatively constant grain DM yield, nutritive value and harvesting losses, together with the favourable indices of ensilability, as grain DM concentration of winter barley, wheat and triticale advanced from approximately 550 to over 800 g/kg, indicate that farmers harvesting grain produced using high input practices under Irish conditions can employ a range of conservation technologies without compromising the yield or quality of the harvested grain. In some cases, crops (e.g., barley) allowed to ripen beyond 813 g/kg may suffer grain loss via shattering prior to harvesting, but the qualities of the grain from these ripe crops are similar to the more moist grains.

Because grain DM concentration increased by an average of 16 to 29 g/kg per day the interval for which grain is at a target DM concentration to harvest can be quite short and grain needs to be monitored at least daily if a target DM concentration is to be achieved at harvest.

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