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Intake, growth and feed conversion efficiency of finishing beef cattle offered diets based on triticale, maize or grass silages, or *ad libitum* concentrate

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The intake, growth and feed conversion efficiency of finishing cattle offered whole-crop triticale silage, harvested at different stubble heights, or maize silage, supplemented with different amounts and forms of crude protein, were compared with those of cattle offered grass silage or concentrate *ad libitum*. Ninety-eight continental crossbred steers (mean (s.d.) initial live weight 509 (38.6) kg) were allocated among 7 treatments in a randomized complete-block design: triticale silage from a crop harvested to a 14 (TS-L) or 35 (TS-H) cm high stubble, maize silage supplemented with a low (MS-LS) or high (MS-HS) protein concentrate, or with approximately half of the supplementary crude protein replaced by urea (MS-SU), grass silage (GS) or concentrate offered *ad libitum* (ALC). Each silage was offered *ad libitum* for 134 days, supplemented with 3 kg concentrate per head daily. Carcass gain did not differ ($P>0.05$) between animals on treatments TS-L and TS-H, but the carcass gain associated with TS-L was lower ($P<0.05$) than with GS or MS-HS, and with TS-H compared with MS-HS. Carcass gain was lower ($P<0.05$) for steers on GS compared to MS-HS, there were no differences ($P>0.05$) among the values for MS-LS, MS-HS and MS-SU; the carcass gain associated with ALC was the highest ($P<0.001$). The feed efficiency for carcass gain for the animals on TS-L, TS-H, GS, MS-LS, MS-HS, MS-SU and ALC was 44.1, 48.2, 60.8, 59.3, 68.3, 59.8 and 90.1 (s.e. 4.26) kg/t total DM intake, respectively ($P<0.001$). It is concluded that the ranking on nutritive value was TS<GS<MS<ALC. Elevating the cutting height of triticale conferred little benefit. Half the soybean meal in the barley-based

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supplement to maize silage could be replaced by barley plus urea without a negative effect on animal performance.

Keywords: *ad libitum* concentrate; cattle; grass silage; maize silage; triticale silage

Introduction

Most ruminant production systems in Ireland are based on using grazed grass to provide at least half of an animal's lifetime intake of food (O'Riordan and O'Kiely 1996), and approximately 62% of slaughtered cattle are finished off grazed grass (CSO 2010). Traditionally, the remaining cattle, finished indoors, would have been offered a diet based on home-produced grass silage supplemented with purchased energy-rich concentrate. The increasing cost of harvesting each tonne of grass dry matter (DM) together with variability in grass yield, and in the subsequent animal production response to silage, has led many farmers to consider other dietary options for finishing cattle.

Both maize and small-grain cereals have the potential to provide a large yield of high-nutritive-value whole-crop silage from a single harvest (Keane *et al*. 2003; Stacey *et al*. 2006, 2008), at a time that does not compete with agricultural contractors harvesting grass for silage. Besides the reliability of producing well-preserved silage, these crops will normally produce no effluent. Most published information on whole-crop cereal silage relates to wheat and barley, and the high yields needed to make these crops economically viable in Ireland require considerable management expertise and timeliness of operations to ensure that the high cost of the inputs is fully rewarded. Triticale is an attractive crop for many grassland farmers because of the generally lower expertise and less time-critical access to mechanisation required to produce high yields compared to wheat or barley (Hackett and Burke 2004). When grown optimally, including the appropriate use of a growth regulator, triticale can produce a crop with a high harvest index (Stacey *et al*. 2008). However, since it can grow to over 1.5 m tall if grown without a growth regulator, elevating the cutting height may be one strategy for achieving a high harvest index.

Interest in forage maize has increased during the past two decades mainly due to a combination of earlier maturing varieties, which have a lower total ambient heat unit requirement, and the availability of polythene mulch systems. However, producing maize silage containing *ca.* 300 g starch per kilogram DM may incur an additional supplementary feed cost to compensate for their relatively low crude protein concentration. Soyabean meal has been the most commonly used protein source, but urea can provide some of this crude protein in diets with a high input of readily fermentable carbohydrate (Allen and Kilkenny 1980).

Finishing cattle on *ad libitum* concentrate allows target finished weights to be achieved more quickly and predictably than with forage-based diets, but the economic viability of such systems can be quite variable. Because of the more predictable nature of the nutritional response, a diet based on *ad libitum* concentrate can provide a useful positive reference to which other treatments can be compared.

The aims in this experiment were to quantify the intake, growth rate and feed efficiency of finishing beef cattle when offered whole-crop triticale silage harvested at different stubble heights or maize silage supplemented with different amounts and forms of crude protein, and

to compare performance on these diets with performance on a grass-silage-based diet or *ad libitum* concentrate.

Materials and Methods

Feed preparation

Winter triticale (×*Triticosecale* Wittmack, cv. Trinidad) was sown near Dunshaughlin, Co. Meath (53°34′N, 6°33′W) on 2 November. It was managed as for commercial grain production using herbicide, fungicide, growth regulator and fertilizer (180 kg inorganic N per hectare) inputs (Hackett and Burke 2004). It was direct-cut precision-chop harvested (Claas Jaguar 900 (Direct Disc 520); Leinster Farm Machines, Duleek, Co. Meath) on 3 August, with alternate blocks harvested at a mean (s.d.) stubble height of 13.8 (2.43) and 34.8 (4.13) cm; referred to as low cut and high cut, respectively. The chopping knife number and feed roller speed on the harvester were calculated to give a nominal chop length of 19 mm, according to the manufacturer's instructions. Stubble height was measured at 175 locations throughout the replicate blocks after each treatment was harvested, using a manual rising-plate meter (Jenquig, Fielding, New Zealand). The low-cut (yield 61 t) and high-cut (yield 54 t) triticale were ensiled, without additive being applied, in separate horizontal, roofed, concrete-walled silos (silage face dimensions (width×height) were: low cut 4.55 m×2.38 m; high cut 4.40 m×2.43 m). Each was sealed beneath 2 layers of black polythene sheeting (0.125 mm; IS 246, 1989), covered in a complete layer of tyres and edged with silt. Silos were filled and sealed on the same day.

Each trailer load of whole-crop triticale was sampled at ensiling and samples were stored at −18 °C prior to being composited, using a bowl-chopper (Müller, MTK 204 Special, Saarbrücken, Germany) to give 6 separate composite samples per treatment. Each composite sample was analysed for DM, organic matter digestibility (OMD), ash, starch, water soluble carbohydrates (WSC), crude protein (CP) and buffering capacity.

Immediately prior to harvesting, a total of 261 triticale tillers were randomly selected throughout the crop, cut at a stubble height of approximately 14 cm and composited into six bundles. Within each bundle, the grain, chaff, top third of the straw and bottom two-thirds of the straw were separated, weighed and analysed for OMD, CP, starch (grain only) and ash.

Whole-crop triticale silage was removed for feeding, starting 299 days after ensiling, using a tractor-mounted shear grab (McHale Farm Machinery Ltd., Kilmaine, Co. Mayo). Each silage was sampled 3 times per week, and samples were stored at −18 °C prior to compositing, on a 3 week basis, to produce a total of 6 composite samples per silage and analysed for DM, OMD, ash, neutral detergent fibre (NDF), acid detergent fibre (ADF), starch, CP, lactic acid, volatile fatty acids (VFA; acetic, propionic and butyric acids), ethanol, WSC, ammonia-N and pH.

Maize (*Zea mays* L., cv. Benicia; FAO 270) was sown under complete-cover plastic mulch near Navan, Co. Meath (53°42′N, 6°39′W), and received the maximum input of animal manure and inorganic N advised by Coulter and Lalor (2008). It was harvested at approximately 65% milk-line on 25 to 26 October using a precision-chop silage harvester (Claas Jaguar 900, with 6 row maize header and maize-corn cracker (1.5 mm roll clearance); Claas, Bury St., Edmonds, UK) at a stubble height of 20 to 25 cm. Harvester settings and operation ensured all grains were fully broken; no silage additive was applied. The crop (290 t) was ensiled as described for triticale using two horizontal, roofed, concrete-walled silos (silage face dimensions: 4.40 m

wide×2.43 m high) and one outdoor silo (silage face dimensions 9.15 m wide×2.75 m high). Sampling of the freshly harvested crop, and subsequent sample processing and chemical analysis, were as described for triticale, with 8 composited whole-crop samples being generated for analysis.

At the time of harvest, 60 individual maize plants (assigned to 6 bundles of 10) were cut at a stubble height of 22 cm. Within each bundle, the cobs and stover were separated, weighed and analysed for starch and OMD, respectively.

Maize silage was removed for feeding, starting 216 days after ensilage, sampled, processed and analysed as described for triticale silages.

Grass silage was made from a sward at Teagasc Grange (53°30′N; 6°39′W) that was perennial ryegrass (*Lolium perenne* L.) dominant. The crop was mown, using a Pottinger Cut Nova 310 (T. Traynor and Sons Ltd., Clonmel, Co. Tipperary), on 18 May and precision-chop harvested, using a Pottinger Mex VI, (T. Traynor and Sons Ltd., Clonmel, Co. Tipperary) the following day (there was heavy rain overnight). The herbage (201 t) was treated with silage additive (Add SafeR; Trouw Nutrition UK Ltd., Belfast, Northern Ireland; ammonium tetraformate (Add SafeR [ammonium tetraformate - formic acid 640 g/kg, NH_3 70 g/kg; density 1.18]; Trouw Nutrition UK Ltd., Belfast, Northern Ireland) applied (2.9 L/t) through the harvester. Storage was as described above (silage face dimensions: 4.55 m wide × 2.38 m high). Silage was removed for feeding, starting 10 days after ensilage, sampled, processed and analysed as described above for triticale silages, except that starch was not measured.

Assessment of the aerobic stability of each of the silages was carried out on 5 occasions using the technique reported by Walsh *et al.* (2008a).

Concentrate feeds were prepared as coarse mixtures of rolled barley, soyabean meal, molasses, feed grade urea, and mineral plus vitamin pre-mixture; the ingredient inclusion rates for Concentrates A, B and C are given in Table 1. Concentrates were formulated to provide cattle assigned to treatments TS-L, TS-H, GS, MS-HS and ALC with similar amounts of supplementary energy and with adequate (but not excess) CP. The concentrate offered to

Table 1. Ingredient inclusion rate and mean (s.d.) chemical composition for three concentrate mixtures (n=6)

Item	Concentrate		
	A	B	C
Ingredient (g/kg fresh weight)			
Rolled barley	870	470	710
Soyabean meal	60	460	190
Urea	0	0	30
Molasses	50	50	50
Mineral+vitamin pre-mix[1]	20	20	20
Composition			
Dry matter (DM; g/kg)	845 (8.2)	858 (17.1)	850 (6.0)
Ash (g/kg DM)	43 (7.2)	71 (12.0)	47 (2.9)
Starch (g/kg DM)	487 (17.2)	289 (48.3)	424 (18.1)
Crude protein (g/kg DM)	124 (13.1)	271 (25.1)	236 (9.5)
Organic matter digestibility *in vitro* (g/kg)	805 (20.6)	868 (14.4)	841 (15.7)

[1] Contribution per 1 kg concentrate: salt 6.8 g, Ca 4.7 g, Zn 100 mg, Mn 50 mg, Fe 20 mg, Cu (as $CuSO_4$) 10 mg, Cu (protected) 10 mg, I 5 mg, Co 2 mg, Se 0.5 mg, vitamin A 10000 IU, vitamin B_1 5 mg, vitamin B_{12} 0.15 mg, vitamin D_3 2000 IU, and vitamin E 40 IU.

cattle on MS-LS provided a sub-optimal quantity of crude protein while the concentrate offered to those on MS-SU was formulated to replace 0.59 of the soyabean meal with urea plus barley. Each concentrate was sampled once weekly when cattle were being fed, and samples were stored at –18 °C. Samples were composited on a 3 week basis and analysed for DM, OMD, CP, ash and starch.

Treatments

The seven dietary treatments were:

TS-L: Whole-crop triticale (low cutting height) silage *ad libitum* + Concentrate B (3 kg head^{-1} day^{-1})

TS-H: Whole-crop triticale (high cutting height) silage *ad libitum* + Concentrate B (3 kg head^{-1} day^{-1})

GS: Grass silage *ad libitum* + Concentrate A (3 kg head^{-1} day^{-1})

MS-LS: Maize silage *ad libitum* + Concentrate A (3 kg head^{-1} day^{-1})

MS-HS: Maize silage *ad libitum* + Concentrate B (3 kg head^{-1} day^{-1})

MS-SU: Maize silage *ad libitum* + Concentrate C (3 kg head^{-1} day^{-1})

ALC: Concentrates A *ad libitum* + grass silage (1 kg head^{-1} day^{-1} on a DM basis)

Cattle management

Ninety-eight continental-cross (predominantly Charolais) steers were purchased from commercial farms, treated for internal parasites (Trodax 34%, Merial Animal Health Ltd., Buckinghamshire, UK; Qualimec Solution for injection, Janssen Animal Health, UK) and skin lice (Butox Pour-on, Intervet Productions S. A.; deltamethrin 0.75% w/v, Igoville, France) and offered grass silage *ad libitum* for more than 30 days prior to the start of the experiment. These cattle (mean (s.d.) initial (starting) age 726 (119.8) days; mean (s.d.) initial live weight 509 (38.6) kg) were weighed unfasted at 0800 on 2 consecutive days; the average of these weights was used as the initial live weight. They were allocated to the 7 treatments in a randomized complete block design, with blocking based on initial live weight. The animals were accommodated in a slatted-floor building with 2 pens of 6 animals per treatment and the remaining 2 animals per treatment shared a pen with two other animals. This allowed a mean lying area of 2.44 m^2 per animal; pens within treatment were distributed in different locations throughout the building. All animals had continuous access to clean, fresh drinking water. They were individually offered their diets through electronically controlled Calan doors (American Calan Inc., Northwood, NH, USA), with the appropriate forages offered once daily, after 0800, for 134 days. Refused feed was weighed daily and discarded twice weekly, and *ad libitum* access was based on approximately 1.1 times the intake of the previous day. The DM concentration of refused feed was assumed to be the same as that of the offered feed. This non-correction for the DM concentration of refusals may have introduced some minor error to the estimates of DM intake. Supplementary concentrate was offered in a single feed shortly after 0800 but before the fresh silage was offered.

Live weight was recorded prior to morning feeding every 21 days, and final live weight was the mean of such weighings on the final 2 days of the experiment. A kill-out rate of 510 g/kg was assumed when calculating initial carcass weight from initial live weight (Caplis *et al*. 2005). Cold carcass weight (hot carcass weight × 0.98) was recorded post-slaughter and carcass conformation and fat scores were obtained from carcass classification, using a video imaging analysis system (VBS 2000, E+P, Oranienberg, Germany) based

on the EU Beef Carcass Classification Scheme (EUROP scale, Commission of the European Communities 1982). Perinephric and retroperitoneal (P+R) fat was removed from both sides of the carcass and weighed. Carcass gain was estimated as the difference between initial and final carcass weight and kill-out rate was determined by dividing cold carcass weight by final live weight. Feed efficiency was expressed as carcass gain divided by total DM intake.

On days 43 to 45, 50 to 52, 57 to 59, 64 to 66 and 71 to 72, sequential blocks (heaviest to lightest) of the 14 blocks of steers were individually penned on solid floors for 24 h. A representative sample of each animal's total faecal output over 24 h was dried for the determination of starch concentration.

Blood samples were collected from all animals on days 114 (at 1400), 115 (at 1000) and 116 (at 0700) via jugular venipuncture into 10 mL evacuated vials (Greiner Vacuette, Cruinn Diagnostics, Dublin, Ireland) containing lithium heparin as an anticoagulant, and plasma glucose and urea concentrations were measured.

The extent to which the protein required by the cattle was supplied by the diets consumed was calculated, for each treatment, using the Protéines vraies réellement Digestibles dans l'Ingestin grêle (PDI) system (Vérité and Peyraud 1989) and feed table 9.3 from O'Mara (1998). In this system PDIA=dietary protein undegraded in the rumen but truly digestible in the small intestine, PDIM=microbial protein that is truly digestible in the small intestine, PDIN=PDIA+PDIMN (microbial protein that could be synthesized in the rumen from the degraded dietary N, when energy and other nutrients are not limiting), PDIE=PDIA+PDIME (microbial protein that could be synthesized from the energy available in the rumen, when degraded N and other nutrients are not limiting) (Vérité and Peyraud 1989).

Chemical analyses

Pre-ensiled forage samples were dried in an oven, with forced air circulation at 98 °C for 16 h, for DM determination, while all silages were oven dried at 85 °C for 16 h. Oven DM values for grass silage were corrected for loss of volatiles using the volatility coefficients for lactic acid, VFA, ethanol and ammonia reported by Porter and Murray (2001). It was considered that these coefficients were not appropriate for maize or, particularly, triticale silages due to their higher pH values (higher pH should result in less undissociated acid and thus less loss of volatile acid than would be predicted using a single volatility coefficient for all silages) and the fact that triticale DM was outside the range for which these coefficients were determined. The DM concentration of maize and triticale silages were therefore calculated from oven DM, without volatility coefficients, using equation 1 of Porter and Murray (2001). All concentrate samples were oven dried, at 98 °C for 16 h, for DM determination. Subsamples of silages, concentrates and faeces for subsequent chemical analysis were oven dried at 40 °C for 48 h and were then milled through a screen(1 mm aperture; Wiley mill, Arthur H. Thomas, Philadelphia, PA, USA) prior to chemical analysis. Determination of *in vitro* OMD was carried out using the Tilley and Terry (1963) technique, which was modified so that the final residue was isolated by filtration (Whatman GFA 55 mm, Whatman International, Maidstone, UK) rather than centrifugation. The NDF and ADF concentrations were determined using the ANKOM Technologies filter bag technique (ANKOM 2006a; 2006b), and ash was determined by complete combustion in a muffle furnace at 550 °C for 5 h.

The crude protein (N×6.25) concentration was determined using a Leco FP 528 nitrogen analyser (Elementec, Summerhill, Co. Meath) based on the methods of the Association of Official Analytical Chemists (AOAC) 990-03 (AOAC 1990) and starch concentration was determined according to McCleary, Gibson and Mugford (1997). The concentration of WSC was determined using the anthrone method (Thomas 1977) and buffering capacity was measured using the method of Playne and McDonald (1966).

The pH of aqueous extracts from silage samples was determined using a pH meter (Model 420 pH meter and electrode, Thermo Orion, USA). The concentrations of VFA and ethanol in the silage extracts were measured using an automated gas chromatograph (Shimadzu GC-17A, Shimadzu Corporation, Kyoto, Japan) with a flame ionization detector fitted with a Chromapack column (INV21042; Analytical Columns, Addington Business Centre, New Addington, Croydon CR0 9UG, England) using the method described by Ranfft (1973). Lactic acid concentration was determined using the SP-Ace Clinical Chemical Analyser (Alfa Wassermann, NJ, USA) and the L-lactic acid UV-method test kit (Roche/R-Biopharm, Darmstadt, Germany; catalogue number 101309084035); D-lactate was determined using the enzyme D-lactate dehydrogenase (Roche/R-Biopharm, catalogue number 1016941001). Concentration of ammonia (NH_3) was determined using the SP-Ace analyser and the Thermo Electron Infinity ammonia liquid stable reagent kinetic method (Waltham, MA, USA).

Blood samples were centrifuged (15 min at 4 °C) at 2000×*g* and plasma was harvested. Concentrations of plasma urea (kinetic urease method; Olympus catalogue method OSR6134) and glucose (hexokinase method; Olympus catalogue number OSR6121) were measured using an Olympus AU 400 Clinical Analyser (Beckman Coulter Inc., 250 South Kraemer Boulevard, Brea, CA, USA).

Statistical analyses

Data on the chemical composition of feeds (or their components) and on the aerobic stability and deterioration of silages are presented as mean (±s.d.). Analysis of variance for a general linear model that accounted for treatment and block was used to analyse all data relating to animal performance. The mean concentrations of plasma glucose and urea for each steer were used in the analyses of those variables. Comparisons among treatments were made using the Tukey-B test.

Results

Feed characteristics

The composition of the three concentrate mixtures (Table 1), the plant components and whole-crops at harvest time (Table 2), and the four silages (Table 3), indicate that sizeable differences occurred between dietary components, but that all of the silages underwent lactic-acid-dominant fermentations. The aerobic stability and deterioration characteristics of the silages are summarized in Table 4, and show that high-cut triticale silage was numerically more aerobically stable and underwent less deterioration than the other three silages.

Animals

Results relating to the steers are summarized in Table 5. Silage intake was lowest ($P<0.001$) for cattle on ALC, did not differ between cattle on TS-L, TS-H and GS, and was highest ($P<0.01$) for cattle on diets based on maize silage (MS-LS, MS-HS and MS-SU). In contrast, although total DM intake did not differ ($P>0.05$) between

Table 2. Mean (s.d.) composition of plant components and whole-crop material pre-ensiling (n=6 except for whole-crop maize where n=8)

	Triticale						Maize			Grass
	Component				Whole-crop		Component		Whole-crop	
	Grain	Chaff	Straw		Low cut	High cut	Cob	Stover		
			Top	Bottom						
Dry matter (DM) (g/kg)	–	–	–	–	547 (85.8)	584 (99.0)	–	–	274 (10.9)	168 (7.6)
Proportion of crop[a] (g/kg)	348 (52.1)	109 (21.4)	59 (11.0)	484 (72.6)	–	–	552 (14.0)	448 (14.0)	–	–
OMD[b] (g/kg)	819 (7.1)	288 (24.0)	308 (27.4)	346 (60.6)	470 (25.1)	500 (24.1)	–	514 (24.7)	733 (26.8)	753 (8.0)
Ash (g/kg DM)	20 (0.6)	59 (4.4)	39 (5.9)	53 (9.0)	53 (7.1)	44 (4.4)	–	–	42 (2.0)	89 (4.0)
Starch (g/kg DM)	642 (14.0)	–	–	–	108 (18.4)	156 (26.8)	615 (20.0)	–	320 (37.6)	
WSC[c] (g/kg DM)	–	–	–	–	26 (2.1)	25 (1.9)	–	–	29 (4.2)	181 (14.6)
Crude protein (g/kg DM)	137 (7.3)	62 (4.7)	50 (5.6)	65 (17.2)	82 (4.4)	88 (4.8)	–	–	86 (3.8)	146 (8.3)
BC[d] (mEq/kg DM)	–	–	–	–	213 (19.7)	190 (23.3)	–	–	269 (11.4)	392 (21.5)

[a]Dry matter basis.
[b]Organic matter digestibility *in vitro*.
[c]Water-soluble carbohydrates.
[d]Buffering capacity.

cattle on treatments TS-L, TS-H and GS, it was lower (P<0.001) for those on TS-L and GS but not for TS-H (P>0.05) when compared to MS-HS. No difference was detected (P>0.05) between the total DM intake of the steers on the three diets based on maize silage, or between those on MS-HS and ALC, although the value for steers on ALC was higher (P<0.01) than for TS-L, TS-H or GS.

The mean CP concentrations (g/kg DM) of the diets were 139 (TS-L), 139 (TS-H), 143 (GS), 94 (MS-LS), 129 (MS-HS), 119 (MS-SU) and 127 (ALC).

No differences occurred (P>0.05) in live-weight or carcass-weight gain, kill-out rate, P+R fat weight or carcass fatness or conformation scores between cattle on TS-L and TS-H. Although cattle on TS-L had lower (P<0.05) live- and carcass-weight gain and a lower (P<0.05) P+R fat weight than those on GS or MS-HS, there was no difference (P>0.05) in conformation or fatness scores. The kill-out rate of cattle on TS-L did not differ (P>0.05) from those on GS but was lower (P<0.05) than those on MS-HS.

The lighter P+R fat weight (P<0.01) of steers on TS-H compared with GS was the only growth or carcass trait difference between these two treatments. However, cattle on TS-H had lower (P<0.05) live- and carcass-weight gain and kill-out rate, and a lighter (P<0.001) P+R fat weight compared to those on MS-HS. The conformation and fatness scores for these two treatments did not differ (P>0.05).

Although steers on treatment GS had live-weight gain, kill-out rate, P+R fat weight and conformation and fatness scores that did not differ (P>0.05) from steers on MS-HS, they had a lower (P<0.05) rate of carcass-weight gain.

There were no differences (P>0.05) among the groups of cattle offered the three diets based on maize silage for

Table 3. Mean (s.d.) chemical composition of the four silages (n=6)

Component†	Silage			
	Triticale		Maize	Grass
	Low cut	High cut		
Dry matter (DM) (g/kg)	556 (58.3)	563 (47.2)	300 (10.4)	232 (7.7)
OMD (g/kg)	495 (20.2)	507 (29.0)	701 (30.5)	716 (7.1)
Ash (g/kg DM)	50 (7.1)	43 (7.7)	40 (3.3)	79 (2.3)
NDF (g/kg DM)	567 (20.8)	556 (14.7)	422 (38.5)	499 (11.9)
ADF (g/kg DM)	363 (19.7)	345 (11.6)	237 (24.5)	311 (8.4)
Starch (g/kg DM)	203 (19.0)	219 (19.0)	349 (40.6)	
Crude protein (g/kg DM)	92 (11.8)	95 (12.1)	86 (8.6)	149 (10.1)
Lactic acid (g/kg DM)	60 (19.7)	53 (18.4)	62 (5.7)	109 (10.9)
D-lactic acid (g/kg DM)	34 (10.3)	30 (10.6)	32 (3.4)	45 (8.3)
L-lactic acid (g/kg DM)	26 (9.4)	23 (7.7)	30 (2.4)	64 (4.6)
D-lactic (g/kg lactic acid)	572 (29.4)	571 (12.5)	516 (11.9)	413 (42.1)
Acetic acid (g/kg DM)	24 (10.9)	25 (9.2)	21 (4.4)	18 (2.8)
Propionic acid (g/kg DM)	0	0	0	0
Butyric acid (g/kg DM)	0	0	0	0
Volatile fatty acids (g/kg DM)	24 (10.9)	25 (9.2)	22 (4.8)	18 (2.8)
Fermentation acids (FA; g/kg DM)	84 (30.3)	78 (26.7)	84 (8.7)	127 (9.0)
Ethanol (g/kg DM)	4 (1.4)	4 (1.7)	14 (3.4)	23 (5.5)
Fermentation products (FP; g/kg DM)	89 (30.0)	82 (27.1)	98 (11.8)	151 (10.1)
Lactic acid (g/kg FA)	732 (72.6)	686 (36.9)	742 (39.6)	854 (28.9)
Lactic acid (g/kg FP)	687 (33.7)	649 (33.7)	640 (36.7)	723 (42.0)
WSC (g/kg DM)	14 (5.3)	14 (5.2)	10 (2.2)	27 (9.0)
NH_3-N (g/kg DM)	140 (59.2)	118 (46.9)	88 (19.8)	83 (11.3)
pH	4.2 (0.09)	4.3 (0.13)	3.9 (0.11)	3.6 (0.04)

†OMD=organic matter digestibility *in vitro*; NDF=neutral detergent fibre; ADF=acid detergent fibre; VFA=volatile fatty acids=acetic+propionic+butyric; FA=fermentation acids=lactic acid+VFA; FP=fermentation products=FA+ethanol; WSC=Water-soluble carbohydrates.

live- or carcass-weight gain, kill-out rate, P+R fat weight, or carcass or conformation score.

Cattle assigned to the ALC treatment had the highest ($P<0.001$) live- and carcass-weight gain, the highest ($P<0.01$) kill-out rate (except relative to those on MS-HS), and their P+R fat weight was greater ($P<0.001$) than for cattle on diets involving triticale silage. They had lower ($P<0.01$) conformation score than steers assigned to TS-L, TS-H or GS and higher

Table 4. Mean (s.d.) aerobic stability and deterioration characteristics of the four silages (n=5)

Variable	Silage			
	Triticale		Maize	Grass
	Low cut	High cut		
Time to temperature rise >2 °C (h)	35 (29.0)	74 (65.3)	20 (10.3)	48 (28.5)
Time to temperature rise >5 °C (h)	65 (65.0)	86 (64.6)	21 (12.5)	66 (41.8)
Maximum temperature rise (°C)	15.4 (8.64)	17.2 (10.88)	26.1 (5.71)	29.0 (3.67)
Time to maximum temperature rise (h)	90 (52.6)	114 (63.3)	45 (16.8)	100 (61.8)
Accumulated temperature to 120 h (°C)	55 (43.5)	35 (26.6)	87 (22.2)	54 (41.8)
Accumulated temperature to 192 h (°C)	91 (70.1)	65 (42.1)	148 (33.8)	110 (52.2)

Table 5. Effect of dietary treatment on feed intake, animal performance, faecal starch concentration, and plasma urea and glucose concentrations

Variable	Dietary treatment[†]							s.e.d.	Significance
	TS-L	TS-H	GS	MS-LS	MS-HS	MS-SU	ALC		
Silage dry matter (DM) intake (kg/d)	7.1^{w}	7.7^{w}	7.4^{w}	8.8^{x}	8.5^{x}	8.8^{x}	1.5^{v}	0.26	***
Concentrate DM intake (kg/d)	2.5^{v}	2.5^{v}	2.5^{v}	2.5^{v}	2.5^{v}	2.5^{v}	9.9^{w}	0.13	***
Total DM intake (kg/d)	9.6^{v}	10.3^{vw}	9.9^{v}	11.3^{x}	11.0^{wx}	11.3^{x}	11.3^{x}	0.30	***
Total DM intake (g/kg LW[a]/d)	17.2^{v}	18.0^{vw}	17.1^{v}	19.2^{x}	18.7^{wx}	19.3^{x}	18.5^{wx}	0.44	***
Initial live weight (kg)	509	509	509	508	508	510	508	1.7	
Final live weight (kg)	615^{v}	635^{vw}	648^{wx}	662^{wx}	671^{x}	668^{wx}	721^{y}	11.8	***
Live-weight gain[b] (g/d)	790^{v}	934^{vw}	1033^{wx}	1148^{wx}	1218^{x}	1177^{wx}	1583^{y}	87.6	***
Live-weight gain[c] (g/d)	800^{v}	901^{vw}	971^{vwx}	1077^{wx}	1184^{x}	1156^{x}	1532^{y}	83.5	***
Kill-out rate (g/kg)	515^{v}	513^{v}	525^{vw}	526^{vw}	536^{wx}	526^{vw}	551^{x}	6.4	***
Carcass weight (kg)	316^{v}	326^{vw}	340^{wx}	348^{xy}	360^{y}	351^{xy}	396^{z}	6.7	***
Carcass gain (g/d)	422^{v}	491^{vw}	600^{wx}	661^{xy}	752^{y}	680^{xy}	1021^{z}	49.6	***
Carcass gain/live-weight gain (g/kg)	534^{v}	532^{v}	594^{vw}	582^{vw}	620^{vw}	577^{vw}	655^{w}	35.5	**
Live-weight gain/total DM intake (kg/t)	82^{v}	91^{vw}	105^{w}	102^{w}	111^{w}	104^{w}	139^{x}	6.9	***
Carcass gain/total DM intake (kg/t)	44.1^{v}	48.2^{v}	60.8^{w}	59.3^{w}	68.3^{w}	59.8^{w}	90.1^{x}	4.26	***
P+R fat[d] (kg)	6.80^{v}	6.04^{v}	9.27^{w}	9.99^{w}	10.07^{w}	10.07^{w}	10.92^{w}	0.972	***
P+R fat[d] (g/kg carcass)	21.5^{vw}	18.6^{v}	27.2^{w}	29.0^{w}	28.4^{w}	28.8^{w}	27.5^{w}	3.02	**
Conformation score[e]	3.57^{w}	3.57^{w}	3.50^{w}	3.36^{w}	3.21^{vw}	3.21^{vw}	2.79^{v}	0.201	**
Fatness score[f]	2.57^{v}	2.98^{vw}	3.00^{vw}	3.29^{w}	3.01^{vw}	3.24^{w}	3.44^{w}	0.197	**
Faecal starch (g/kg DM)	18.5^{w}	28.7^{vw}	17.8^{v}	26.2^{v}	22.4^{v}	22.7^{v}	37.0^{w}	3.81	***
Plasma glucose (mmol/L)	3.82^{vw}	3.70^{v}	3.90^{vwx}	3.96^{wx}	4.06^{xy}	4.02^{wxy}	4.20^{y}	0.077	***
Plasma urea (mmol/L)	5.53^{y}	5.35^{y}	3.16^{w}	1.96^{v}	3.85^{x}	3.58^{wx}	4.13^{x}	0.245	***
PDI[g] requirement (g/d)	660	710	743	777	798	789	884		
PDIA[h] (g/d)	412	425	324	253	416	306	423		
PDIE[i] (g/d)	851	887	861	850	986	893	1164		
PDIN[j] (g/d)	949	985	860	689	965	888	1044		

[†]TS-L=low-cut triticale silage *ad libitum*+concentrate B; TS-H=high-cut triticale silage *ad libitum*+concentrate B; GS=grass silage *ad libitum*+concentrate A; MS-LS=maize silage *ad libitum*+concentrate C; MS-HS=maize silage *ad libitum*+concentrate B; MS-SU=maize silage *ad libitum*+concentrate C; ALC=concentrate A *ad libitum*+grass silage. For all diets except ALC concentrate (see Table 1 for composition of concentrates A, B and C) was offered at 3 kg per head daily.
[a]Mean live weight; [b]Calculated by difference (Final – Initial); [c]Calculated by linear regression of live weight on day of experiment; [d]Perinepheric+retroperitoneal fat; [e]1=E (best) to 5=P (worst) on EUROP scale; [f]1=least fat and 5=most fat ; [g]PDI=true protein truly digestible in the small intestine; [h]PDIA=dietary protein undegraded in the rumen but truly digestible in the small intestine; [i]PDIE=PDIA+PDIME (amount of microbial protein that could be synthesized from the energy available in the rumen when degraded N and other nutrients are not limiting); [j]PDIN=PDIA+PDIMN (amount of microbial protein that could be synthesized in the rumen from the degraded dietary N when energy and other nutrients are not limiting);
[vwxyz]Means, within a row, without a superscript in common differ at $P<0.05$.

($P<0.001$) fat score than steers assigned to TS-L.

Cattle on the TS-L diet had a lower ($P<0.05$) feed efficiency than those on GS or MS-HS (which did not differ, $P>0.05$)), and these in turn had lower efficiency ($P<0.001$) than those on ALC. The efficiency of feed conversion to live-weight gain for cattle on the TS-H diet did not differ ($P>0.05$) from that on TS-L, GS or MS-HS. The efficiency of conversion of feed to carcass gain for cattle on TS-H did not differ ($P>0.05$) from those on TS-L but was lower ($P<0.05$) than for steers on GS or MS-HS. There was no difference ($P>0.05$) in feed efficiency among the three diets based on maize silage, while cattle on ALC had the highest ($P<0.001$) feed efficiency.

Faecal starch concentration was higher ($P<0.05$) for cattle on ALC than any other treatment except TS-H.

Plasma glucose concentration did not differ ($P>0.05$) between steers on the TS-L, TS-H and GS treatments, and both diets based on triticale silage were associated with lower ($P<0.05$) concentrations than were MS-HS or ALC. Plasma glucose concentration for cattle on the GS treatment did not differ ($P>0.05$) from those on MS-HS but was lower ($P<0.01$) than for cattle on ALC. There was no difference ($P>0.05$) for this trait among the three treatments involving maize silage, and the value associated with MS-HS did not differ from that associated with ALC ($P>0.05$). Cattle on treatments TS-L and TS-H did not differ ($P>0.05$) for plasma urea concentration, and their values were higher ($P<0.001$) than those associated with GS, MS-HS and ALC. A lower urea concentration ($P<0.05$) occurred in steers on treatment GS than those on MS-HS, which in turn did not differ ($P>0.05$) from those on ALC. For cattle consuming maize silage, the plasma urea concentration was lowest ($P<0.001$) with the MS-LS treatment.

Discussion

One of the caveats when drawing conclusions from experiments comparing the nutritive value of silage made from different crops is that the outcome in any particular experiment is conditioned by the quality of the specific silage that represents each crop. Since a considerable range exists within the population of silages that can be made from any crop it is important not to extrapolate the rankings on silage nutritive value from a single experiment to all circumstances.

Feeds

The crop of triticale, despite having been treated with growth regulator, grew to a height of *ca.* 1.5 m, and this was reflected in a high proportion of straw (543 g/kg on a DM basis) in the harvested crop. The harvest index (348 g grain DM per 1 kg crop DM) was consequently much lower than reported for crops of wheat, barley and triticale by Stacey *et al.* (2008; 436 to 520 g/kg), Walsh *et al.* (2008a; 494 to 502 g/kg) or Walsh *et al.* (2008b; 576 to 578 g/kg). Thus, the harvested crop was composed of two components of distinctly different nutritive value – a grain component of high quality (OMD 819 g/kg and CP 137 g/kg DM) and a straw plus chaff component of low quality (OMD 333 g/kg and CP 63 g/kg DM). The results also indicate that the top and bottom fractions of the straw component of the crop were of similar nutritive value. Thus, raising the cutting height would have reduced the contribution of straw in the harvested material, thereby explaining the modest numerical increase in OMD, starch and crude protein, and the decline in ash concentration evident in the whole-crop at harvest time.

Although whole-crop WSC concentration was lower than reported by McDonald, Henderson and Heron (1991), the low buffering capacity and high DM concentration indicate that at harvest time both triticale herbages would have been relatively easy to preserve as silage. In addition, the erect nature of this crop prior to direct-cut harvesting at mean stubble heights of 14 or 35 cm would have ensured relatively little contamination by undesirable soil residing micro-organisms. Therefore, it was not surprising that both triticale silages underwent a lactic-acid-dominant fermentation with no evidence of saccharolytic clostridial activity (i.e., negligible butyric acid). Under these circumstances ammonia-N accounted for a higher proportion of total N than the otherwise excellent fermentation characteristics would have suggested, while the particularly low concentration of ethanol indicates that little yeast activity occurred during ensilage. The considerably higher concentration of fermentation products plus residual WSC in silage compared with the WSC concentration in the harvested crop suggests that other substrates, such as organic acids or components of fibre, were fermented during ensilage. In contrast, the apparent increase in starch concentration during ensilage suggests that proportionately small, or no, fermentation and respiration losses of starch occurred prior to triticale silages being consumed by cattle.

The cob:stover ratio for whole-crop maize at harvest (552:448) was marginally lower than reported by Walsh *et al.* (2008a; 579:421) or Walsh *et al.* (2008b; 584:416). However, the cob proportion was sufficiently high and well developed (starch concentration 615 g/kg DM) to produce a silage with a starch concentration of 349 g/kg DM; the silage DM concentration of 300 g/kg matched the target identified by Keady (2005) as the optimum stage of maturity at which to harvest forage maize for ensiling. Stover OMD at harvest was typical of the low values reported by Little *et al.* (2005, 2007) for early maturing varieties harvested in late October and early November when senescence was advanced. Overall, the indices of nutritive value and of preservation were similar to those reported by McGeough *et al.* (2010a) and Walsh *et al.* (2008a,b). The decline in OMD during ensilage (733 to 701 g/kg) was larger than expected under good conservation conditions, but was much smaller than reported for immature forage maize by O'Kiely *et al*. (1997). Maize silage underwent a lactic-acid-dominant fermentation, reflecting the adequate supply of WSC relative to the buffering capacity at harvest time. In addition, the considerably higher concentration of fermentation products plus residual WSC in the silage compared with the WSC concentration in the harvested crop indicates that additional fermentable substrate became available during ensilage. The moderate amount of ethanol present suggests that yeast activity was not extensive.

The grass crop was typical of a leafy perennial ryegrass of intermediate heading date harvested under damp weather conditions in late May (Conaghan *et al*. 2008). The low DM concentration and relatively high WSC concentration and buffering capacity at harvesting predisposed the crop to undergoing a very extensive fermentation (151 g fermentation products per 1 kg silage DM). The latter was strongly dominated by the activity of lactic acid bacteria, although the higher ethanol concentration (relative to that for the triticale and maize silages, and relative to acetic acid concentration in the grass silage) suggests a more active yeast presence during the ensilage of grass. It is likely that a considerable amount of effluent was released from the wet grass

(Weissbach and Peters 1983) and this would, at least partly, explain the increase in DM concentration during ensilage. Such a major loss of effluent would also explain the larger decline in OMD during ensilage than occurred with triticale (no decline) or maize.

In agreement with McGeough *et al.* (2010a) and Walsh *et al.* (2008a,b), maize silage was more susceptible to aerobic instability (i.e., it had a shorter interval until temperature increased) and, subsequently, was more prone to undergoing more extensive aerobic deterioration (higher accumulated temperature rise) than the other silages under the test conditions employed. The reason for the shorter stability period and greater deterioration for low-cut compared to high-cut triticale is not apparent. Ultimately, however, the silage management practices employed during the feed-out period prevented these instabilities from being manifest in practice, so feeding value was not compromised.

Animals

The range of mean initial live weight (424 to 538 kg) and duration of diet evaluation (110 to 160 days) reported for finishing continental crossbred steers consuming *ad libitum* barley-based concentrate plus 1 to 2 kg grass silage DM per head daily by Cummins *et al.* (2007), McGeough *et al.* (2010a,b) and Walsh *et al.* (2008a,b) encompassed the type of animals used and the duration of the present experiment. Compared to the mean values in the above cited literature, and for reasons that are not apparent, the steers offered *ad libitum* concentrate in the present experiment had a higher total DM intake (11.3 vs. 9.6 to 11.0 kg/day) and a correspondingly higher live-weight gain (1583 vs. 938 to 1473 g/day) and carcass gain (1021 vs. 695 to 1002 g/day). In contrast, kill-out rate (551 vs. 546 to 552 g/kg), P+R fat weight (10.9 vs. 8.2 to 13.9 kg), feed efficiency for carcass gain (90.1 vs. 67.5 to 97.1 kg/t DM intake) and plasma urea concentration (4.1 vs. 1.9 to 5.6 mmol/L) were within the range of means from the literature cited above.

Cattle on the TS-L diet had a numerically lower total DM intake than reported by Walsh *et al.* (2008a,b) or McGeough *et al.* (2010b) for other whole-crop cereal silages offered *ad libitum* to finishing continental crossbred steers and supplemented with 3 kg concentrate per head daily. The lower total intake reflects the higher straw plus chaff proportion together with the lower *in vitro* digestibility for that combined component in the low-cut triticale silage. Thus, the lower overall *in vitro* digestibility of the low-cut triticale silage compared to the values for whole-crop cereals reported by Walsh *et al.* (2008a,b) and McGeough *et al.* (2010b) (495 vs. 619 to 760 g/kg), allied to the lower intake, resulted in a markedly lower net energy intake with the TS-L diet. This explains the correspondingly lower live- and carcass-weight gains, lower kill-out rate, inferior feed efficiency and lower P+R fat weight.

McGeough *et al*. (2010b) altered the ratio of grain to straw+chaff for wheat from 11:89 to 47:53 and recorded a quadratic increase in DM intake and a linear increase in carcass gain. Walsh *et al*. (2009) reported that when the grain:straw ratio for wheat or barley was increased across an even wider range (0:100 to 90:10) there was a marked increase in the intake of digestible nutrients. Thus, in the current experiment, elevating the cutting height of triticale from a stubble of 13.8 cm to 34.8 cm was expected to increase nutritive value by reducing the contribution of straw in the whole-crop triticale. However, it appears that this elevation in cutting height was not sufficient to have a significant impact on nutritive value. The very tall plant height and the similar

digestibility of the top and bottom ends of the straw meant that the effect of a 21 cm change in cutting height on *in vitro* digestibility and other chemical components was relatively modest. This in turn resulted in only a trend towards higher intake, liveweight gain and carcass gain for cattle offered the TS-H diet compared to the TS-L diet. The absence of a significant beneficial effect of elevating the cutting height of whole-crop cereal on intake and performance was previously reported by Sinclair, Wilkinson and Ferguson (2003), Jackson *et al*. (2004) and Walsh *et al.* (2008b). Walsh *et al.* (2008b) attributed some of this effect to a faster rate of passage with a diet based on silage made from a small-grain cereal crop harvested at an elevated cutting height, resulting in lower *in vivo* digestibility. The trend towards a higher starch concentration in faeces from cattle on the TS-H diet is in accord with this suggestion. However, it would be expected that if cutting height was raised sufficiently the consequent large increase in the proportion of grain in the harvested crop would improve both carcass gain and feed efficiency. Overall, the considerably inferior growth rates recorded for the TS-L and TS-H treatments compared with values reported by Walsh *et al.* (2008a,b) or McGeough *et al.* (2010b) reflect the low proportion of grain in the triticale silages used as well as the low digestibility of the straw plus chaff component.

Across the two diets based on triticale silage, PDIA contributed 0.60 to 0.62 of the PDI requirement, and the total PDI ingested exceeded the requirement (Table 5). The higher value for PDIN than PDIE (by 98 g/day) indicates that less degradable protein could have been provided than was supplied by Concentrate B. However, had Concentrate A been used instead then PDIN would have been 38 g/day less than PDIE (based on the guidelines of Vérité and Peyraud 1989).

Although DM intake of extensively fermented grass silage is often disappointingly low, especially compared to drier forages (McCarrick 1966), the total DM intake associated with GS was similar to that for the TS-L and TS-H treatments. The higher DM intake of grass silage compared with that reported by Walsh *et al.* (2008a) reflects the higher *in vitro* digestibility and more lactic-acid-dominant fermentation in the current experiment. In addition, the higher DM intake compared with McGeough *et al.* (2010b) reflects the higher intake capacity of the cattle in the present experiment; this is supported by the numerically higher total DM intake per unit live weight recorded on the ALC treatment in the current experiment compared to the intake of a similar diet by comparable cattle reported by McGeough *et al.* (2010b). Therefore, the significantly higher live- and carcass-weight gains for cattle on the GS diet compared to TS-L, and the trend towards a similar advantage when compared to TS-H, was expected and reflects the higher nutritive value of the grass silage and, thus, superior feed efficiency. There are two likely explanations for why cattle consuming grass silage had a heavier P+R fat than those consuming triticale silages. Firstly, the cattle consuming GS had a heavier carcass weight and secondly grass silage tends to promote fatter carcasses (McCarrick 1966; Greathead *et al.* 2006) than drier forages.

Approximately 0.44 of the PDI requirement of the steers on the GS diet was provided as PDIA, with PDIM then ensuring the animals PDI requirement was fully delivered (Table 5). The similar values for PDIE and PDIN indicate that an adequate supply of degradable N was provided for rumen micro-organisms.

The potential of maize silage to support a rapid rate of animal growth, clearly demonstrated by McEwen *et al.* (2007), was evident in the present experiment. The differences in intake, when combined with the estimated differences in nutritive value, largely explain the higher growth rate with the MS-HS treatment compared to the TS-L, TS-H or GS treatments. However, the growth rate and feed efficiency achieved with MS-HS relative to ALC in the present experiment were lower than reported by Walsh *et al.* (2008a,b) for a similar comparison. When compared with McGeough *et al.* (2010a) the data suggest that the nutritive value of the maize silage in the current experiment was not optimal despite the apparently satisfactory DM and starch concentrations. The lower *in vitro* digestibility of the maize silage in the current experiment than in the other cited experiments may partly explain the difference, and can be explained by the lower digestibility of the stover associated with the late October harvest in the current experiment.

Giardini *et al*. (1976) concluded that when finishing cattle, consuming maize silage (CP 80 g/kg DM) *ad libitum*, were supplemented with concentrate (5 g/kg live weight) to increase dietary CP concentration to 110, 130 or 150 g/kg DM (through replacing cereal with soyabean meal) there was a significant improvement in both growth rate and feed efficiency to the first increment of soyabean meal, but no benefit accrued from increasing dietary CP concentration above 110 g/kg DM. However, when Walsh *et al.* (2008a) offered a maize silage plus supplementary concentrate diet with a CP concentration of 111 g/kg DM to finishing steers, they recorded a plasma urea concentration of 2.7 mmol/L and concluded that overall protein supply to the animals may have been deficient. This finding was supported by Owens *et al.* (2009) who recorded, in ruminally fistulated steers offered the same diets as Walsh *et al.* (2008a), a mean ruminal ammonia concentration of only 28.1 mg/L which is below the threshold (50 mg/L) recommended to maintain maximal microbial protein synthesis (Satter and Slyter 1974). In contrast, Walsh *et al.* (2008b) recorded a mean plasma urea concentration of 3.5 mmol/L for finishing steers consuming a maize silage plus a concentrate with a CP concentration of 115 g/kg DM, and McGeough *et al.* (2010a) recorded plasma urea concentrations of 4.0 to 4.5 mmol/L for comparable steers consuming diets containing CP at 127 to 134 g/kg DM. Thus, the steers on the MS-HS diet, which had a crude protein concentration of 129 g/kg DM, are likely to have had an adequate supply of CP, and their plasma urea concentration (3.9 mmol/L) was within the normal range (3.4 to 7.3 mmol/L) defined by Castejon and Leaver (1994). This agrees with the PDI values in Table 5, which indicate that the MS-HS diet did in fact comfortably meet the cattle's requirement for protein, since dietary protein undegraded in the rumen, but truly digested in the small intestine, provided 0.52 of the PDI requirement. In addition, the values in Table 5 indicate that an adequate supply of degradable N was provided for rumen micro-organisms.

Although the MS-LS diet had only 94 g crude protein per kilogram DM and the corresponding plasma urea concentration of the steers consuming this diet was only 1.96 mmol/L, indicating that nitrogen intake was sub-optimal, the resultant numerical decline in live-weight gain (1218 to 1148 g/day) and carcass gain (752 to 661 g/day) relative to MS-HS failed to reach statistical significance. Larger numbers of animals per treatment and/or more homogenous groups of animals within treatments would have

increased the sensitivity of such contrasts. The PDI values in Table 5 confirm that protein supply was sub-optimal since the calculated PDIN consumed supplied only 87% of the animals overall PDI requirement (i.e., PDIN 689 g/d and PDI requirement 777 g/d). One-third of the animal's PDI requirement was met by PDIA, and the guidelines of Vérité and Peyraud (1989) suggest that these finishing steers would have been expected to respond either to the supplementary protein having a higher degradability or to additional non-protein N (+ 109 g/day of urea).

Even though replacing 59% of the soyabean meal with urea (30 g/kg concentrate) plus barley resulted in a small reduction in dietary CP concentration (proportionately a 0.07 decline) and in both PDIN and PDIE (proportionate declines of 0.08 and 0.09, respectively), the associated mean plasma urea concentration of steers on the MS-SU treatment (3.58 mmol/L) remained within the normal range and did not differ significantly from the steers on MS-HS. The fact that dietary PDIN was larger than the PDI requirement (Table 5) confirms that the MS-SU diet provided sufficient protein, while the similar values for PDIE and PDIN indicate that rumen micro-organisms were provided with sufficient degradable protein. Taking account of the slightly lower CP concentration than planned (and thus the lower PDIN and PDIE intakes) for MS-SU relative to MS-HS, the absence of an effect on live- or carcass-weight gain agrees with Giardini *et al*. (1976) who, in summarizing a series of comparisons of iso-energetic/iso-nitrogenous maize-silage based diets, found that soyabean meal could be partially or wholly replaced by urea in the supplementary concentrate without altering animal growth rate or feed efficiency.

Implications

Diets such as ALC can be attractive because of the high growth rate they generate in finishing beef cattle and because of the expected smaller variation in intake and nutritive value compared with forage-based diets. Nevertheless, the variation among experiments for apparently similar cattle, housing conditions and management system (Cummins *et al.* (2007), McGeough *et al.* (2010a,b), Walsh *et al.* (2008a,b) and the current experiment) in the performance of cattle on *ad libitum* concentrate diets similar to ALC would significantly alter the profitability of such finishing systems. Although the ALC diet clearly provided sufficient protein, and with 0.48 of the animal's requirement coming from PDIA, the data in Table 5 suggest that some of the dietary protein could have been replaced by urea (+ 82 g/day of urea, according to the guidelines of Vérité and Peyraud (1989)). This could potentially reduce the price of the concentrate and, since concentrate accounted for 0.88 of total DM intake, this should improve the profitability of a system based on concentrate *ad libitum*.

Whole-crop wheat and barley have the potential to support high growth rate in cattle, provided they are harvested at an appropriate growth stage and have a relatively high harvest index (Walsh *et al.* 2008a,b; McGeough *et al.* 2010b). This should be equally valid for whole-crop triticale, if the above requirements are met. In addition, the ability of triticale to produce a relatively high yield of grain (Stacey *et al*. 2006), but with fewer inputs than wheat, has attractions for farmers who are not expert in intensive cereal production technology. The low nutritive value of the triticale silages in the current experiment (TS-L and TS-H treatments delivered 0.41 to 0.48 of the daily carcass gain and 0.49 to 0.53 of the feed efficiency

recorded for the ALC treatment) are likely a reflection of the characteristics of this particular crop rather than a limitation of triticale *per se*. It appears that where crops are approximately 1.5 m tall the cutting height needs to be elevated to much more than 35 cm above ground level if nutritive value is to be markedly improved. However, a further but more general limitation is that silage from whole-crop cereals tends to have inferior feed efficiency compared to good quality maize or grass silage (O'Kiely, Keane and Moloney 2009) and this clearly has economic implications where diets are being formulated for finishing cattle.

The MS-HS diet appeared to provide the finishing continental crossbred steers with adequate CP and PDI, and delivered 0.74 and 0.76 of the carcass gain and feed efficiency, respectively, achieved with the ALC diet. Because of likely variability in the threshold quantity of dietary protein required for cattle, as described above when finishing on a diet where maize silage comprised 0.77 of dietary DM, it would seem prudent not to reduce dietary CP concentration much below the level of 128 g/kg DM used on the MS-HS diet. The opportunity to replace at least half of the soyabean meal in the supplementary concentrate by barley plus urea, while maintaining growth rate and feed efficiency, is a route to reducing feed costs.

Although grass silage can vary widely in both digestibility and preservation, the knowledge exists to repeatedly produce good quality grass silage. In the current experiment, the GS diet supported 0.59 and 0.67 of the carcass gain and feed efficiency, respectively, achieved with ALC, and harvesting a crop at a more vegetative growth stage would improve these values. Besides providing feed primarily for the winter, the production of grass silage within an integrated grassland management system also facilitates efficient grazing management, recycling of nutrients from slurry, and biological control of internal parasites. Therefore, assessing the economic impact of grass silage within livestock production systems that involve a major emphasis on grazed grass can be complex.

A fuller assessment of the sustainability of systems for beef finishing using these different dietary options, in addition to acknowledging the animal performance responses outlined above, also needs to account for the effects on factors such as farm profit, the availability of appropriately skilled labour, total greenhouse gas emissions, water quality, biodiversity, and animal health and welfare.

Conclusions

The diets based on triticale silage of relatively low grain proportion supported low rates of performance by finishing cattle, and elevating the cutting height of triticale had only minor effects. A diet based on maize silage supported improved animal performance where there was sufficient soyabean meal in the barley-based supplementary concentrate, and half of this soyabean meal could be replaced by barley plus urea. The diet based on grass silage was intermediate in nutritive value between the diets based on triticale or maize silage, while a diet based on concentrate *ad libitum* supported the highest animal performance.

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