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Effects of replacing grass silage with either maize or whole-crop wheat silages on the performance and meat quality of beef cattle offered two levels of concentrates

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A randomised design involving 66 continental cross beef steers (initial live weight 523 kg) was undertaken to evaluate the effects of the inclusion of maize or whole-crop wheat silages in grass silage-based diets on animal performance, carcass composition, and meat quality of beef cattle. Grass silage was offered either as the sole forage or in addition to either maize or whole-crop wheat silages at a ratio of 40:60, on a dry matter (DM) basis, alternative forage: grass silage. For the grass, maize, and whole-crop wheat silages, DM concentrations were 192, 276, and 319 g/kg, ammonia-nitrogen concentrations were 110, 90, and 150 g/kg nitrogen, starch concentrations were not determined, 225, and 209 g/kg DM and in vivo DM digestibilities were 0.69, 0.69, and 0.58; respectively. The forages were offered ad libitum following mixing in a paddle type complete diet mixer wagon once per day, supplemented with either 3 or 5 kg concentrates per steer per day, in two equal feeds, for 92 days. For the grass, grass plus maize and grass plus whole-crop wheat silage-based diets food intakes were 8.38, 9.08, and 9.14 kg DM per day, estimated carcass gains were 514, 602, and 496 g/day and carcass weights were 326, 334, and 325 kg; respectively. Altering the silage component of the diet did not influence carcass composition or meat eating quality. Increasing concentrate feed level tended ($P = 0.09$*) to increase estimated carcass fat concentration and increased sarcomere length (*$P < 0.05$*), and lean a* (*$P < 0.01$*), b* (*$P < 0.05$*), and chroma (*$P < 0.01$*). There were no significant silage type by concentrate feed level interactions for food intake, steer performance, carcass characteristics or meat eating quality. It is concluded that replacing grass silage with maize silage increased carcass gain, and weight due to higher intakes, and improved utilisation of metabolisable energy. Whilst replacing grass silage with whole-crop wheat silage increased live-weight gain, the reduced dressing proportion resulted in no beneficial effect on carcass gain, probably due to increased food intakes of lower digestible forage increasing gut fill. Meat quality or carcass composition were not altered by the inclusion of maize or whole-crop silages in grass silage based diets.*

Keywords: beef cattle, grass silage, maize silage, meat quality, whole-crop wheat silage

Introduction

Recent developments in plant breeding coupled with improvements in agronomic practices, particularly the development of the complete cover plastic mulch system have considerably increased the yield potential and feeding value of maize at more northern latitudes (Keady, 2005). Previous studies undertaken in Northern Ireland have shown that the yield potential of maize has increased from 4.1 t dry matter (DM) per ha (McAllister, 1961) and 4.9 t DM per ha (Bartholomew and Chestnutt, 1979) in the 1960 s and 1970 s; respectively, to 12 t DM per ha in the late 1990 s (Easson, 2000) primarily due to improvements in plant breeding. The complete cover plastic mulch system, which involves total cover of the maize plants with unperforated plastic 6 μm thick (the growing plant eventually forces through the degrading sheet), has considerably increased the yield potential of maize, as outlined by Keady (2003) the response to the complete cover plastic mulch system can be as high as 5 t DM per ha depending on sowing date and variety sown.

Previous studies have shown that inclusion of maize silage in grass silage-based diets has had variable effects on animal performance. Incorporating maize silage into the diet has improved (Phipps *et al*., 1995; O'Kiely and Moloney, 2000; Keady *et al*., 2002b and 2003), had no effect

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(Hameleers, 1998) or reduced (O'Kiely and Moloney, 1995) animal performance. These different responses may have been due to variations in the feed value of both the grass and maize silages offered in these studies. More recently, Phipps *et al.* (2000) and Keady *et al.* (2002b) using dairy cows concluded that the optimum stage to harvest maize for improved animal performance was at approximately 300 g/kg.

Whole-crop wheat may be ensiled at DM concentrations ranging from 250 to 450 g/kg if fermented, and 550 to 800 g/kg if treated with urea or a urea-based additive to encourage an alkaline environment. Previous studies (Leaver and Hill, 1995; Phipps *et al.*, 1995) have reported no difference in animal performance of dairy cows when either fermented or urea-treated whole-crop wheat silage were offered as a partial replacement for grass silage to lactating dairy cows.

Tenderness, colour and flavour are the major factors affecting meat quality (Buckley *et al.*, 1995). Incorporating maize silage into grass silage based diets of beef cattle has altered (Hoving-Bolink *et al.*, 1999) or had no effects (O'Sullivan *et al.*, 2002) on meat quality. However there is a paucity of data on the effects of incorporating whole-crop wheat silages in grass silage based diets on subsequent meat quality of finishing beef cattle.

Grass silage is the basal forage offered to beef cattle in Ireland and the UK. Recent developments in plant breeding and agronomic practices in the production of alternative forages, coupled with their low costs of production (Keady, 2002a), has resulted in an increase in the production of maize and whole-crop wheat silages for feeding to beef cattle. There is a paucity of data where grass silage was replaced with either maize or whole-crop wheat silages in the same study on animal performance of, and subsequent meat quality from, finishing beef cattle. Therefore, the present study was undertaken to evaluate the effects of the inclusion of maize or whole-crop wheat silages in grass silage-based diets on animal performance, carcass composition, and meat quality of beef cattle.

Material and methods

Forages

Grass silage was harvested from the primary growth of predominantly perennial ryegrass swards between 27 and 29 May and ensiled following treatment with a bacterial inoculant (Ecosyl, Ecosyl Products Limited, Stokesley, North Yorkshire, England) at the rate of 3 l/t after a 3-h wilting period. The herbage was mown using a mower fitted with a V-spoke grass conditioner and harvested using a self-propelled precision-chop forage harvester.

Whole-crop wheat was harvested at mealy stage (growth stage 11.2 on Feeke's scale (Large, 1954)) on 7 August from the winter variety Claire and ensiled treated with a bacterial inoculant (Wholecrop Gold, Biotal Ltd, Cardiff, Wales) at the rate of 4 l/t.

Maize was harvested on 18 October from the variety Tassilo, which had been grown under the complete cover plastic mulch system, and ensiled treated with a bacterial inoculant and potassium sorbate additive (Ecocorn, Ecosyl Products Limited, Stokesley, North Yorkshire, England) applied at the rate of 2 l/t.

The whole-crop wheat and maize silages were harvested direct cut using a self-propelled forage harvester (John Deere 6850, John Deere, Moline, Illinois, USA) fitted with a crimper header (Kemper model Champion 4500, Stadtlohn, Germany). The harvester was fitted with a corn cracker to crack the maize grains at the time of harvest. The forages were ensiled in trench silos. During filling, each silo was consolidated between loads by rolling with an industrial loader and for a further 60 min after filling was completed. Following consolidation two polythene sheets were used to seal each silo. The entire surface was then weighed down with a layer of tyres.

Animals and management

Grass silage was offered as the sole forage or in addition to either maize or whole-crop wheat silages at a ratio of 40:60 on a DM basis alternative forage: grass silage and supplemented with either 3 or 5 kg concentrates per steer per day. The six treatments were offered to 66 continental cross beef steers (mean age $= 632$ days) with mean initial live weight of 523 ± 37.2 kg in a randomised design experiment for 92 days. Eleven cattle were allocated to each of the six treatments at random balanced with respect to breed, live weight and conformation classification (European Carcass Classification Scheme (Kempster *et al.*, 1982) undertaken on the live animals). For 2 months prior to the experiment the cattle received a medium feed value grass silage supplemented with 3 kg concentrate per day. The cattle were housed in slatted pens in two groups of four and one group of three per treatment.

The forages were mixed in a paddle type complete diet mixer wagon (Redrock, Armagh, Northern Ireland) for 5 min once daily and offered in sufficient quantities to allow a refusal of 50 to 100 g/kg offered and were supplemented with either 3 or 5 kg concentrates per steer daily. The fresh weight of the forages to be placed in the mixer wagon, at a ratio of 40:60 on a DM basis alternative forage: grass silage was based on the daily DM concentrations of the silages offered the previous week. The blocks of silage were removed from the silos and transferred into the mixer wagon using a shear grab (1.8 m cutting width). Concentrates were offered as a loose mix, unpelleted, in two meals daily, separate from the forages. The concentrates consisted of 500, 120, 200, 150, and 30 g/kg barley, maize meal, sugar-beet pulp, soya bean, and molasses respectively. All cattle received 100 g of a beef mineral and vitamin mix per day (per kg: calcium 221 g; phosphorus 40 g; sodium120 g; magnesium 8 g; cupric sulphate 1600 mg; sodium selenite 20 mg; retinol 120 mg; cholecalciferol 2 mg; alpha-tocopherol 1342 mg) with the concentrate feed offered in the afternoon.

Measurements

Silage and concentrate intakes were recorded daily for the duration of the experiment. Silage DM intakes were calculated as described by Keady *et al.* (1994). Concentrates offered were sampled daily and bulked weekly for the determination of oven DM, crude protein (CP), ash, acid-detergent fibre (ADF), neutral-detergent fibre (NDF), gross energy (GE), and acid detergent insoluble nitrogen (ADIN).

Silages offered, and refusals, were sampled daily for determination of oven DM and dried samples of offered silage were bulked weekly for the determination of ADF, NDF, ADIN, and ash. Further composite sample of fresh offered silage was taken twice weekly and analysed for alcohols, GE, CP, ammonia nitrogen (N), acetate, propionate, butyrate, valerate, and lactate concentrations, buffering capacity, and pH. A further composite sample of fresh silage was obtained once weekly and dried at 60°C for 48 h and analysed for water-soluble carbohydrate (WSC) concentration in grass silage and WSC and starch concentration in maize and whole-crop wheat silages.

Steers were weighed on two consecutive days at the beginning and end of the experiment and live-weight gain of each steer was calculated by difference using the mean of the two values. Seven steers per treatment consisting of one pen of four and one pen of three were slaughtered when the treatments had been imposed for 90 days and the remaining four were slaughtered after a further 6 days. The animals were stunned using a pneumatically operated captive bolt stunning system and bled immediately after stunning at an EU approved abbatoir which had routine veterinary inspection provided by the Department of Agriculture for Northern Ireland. Carcass weight was recorded for each steer at slaughter. Daily carcass gain was calculated for each steer, the initial carcass weight of each steer derived by using the relationship between live weight and carcass weight developed using similar steers (Keady and Kilpatrick, 2005). Carcass conformation and fat classification were determined by visual assessment according to the European Carcass Classification Scheme as described by Kempster *et al.* (1982). The weights of kidney, cod and channel fat were recorded for every animal during the dressing procedure. All carcasses were changed from achilles suspension at 45 min *post mortem* to suspension from the aitch bone (tenderstretch) and chilled under standard commercial conditions. The carcasses were placed in a chill subjected to an air temperature of 10 °C for 10 h after which the air temperature was reduced to 1 °C for 24 hours. Subsequently the carcasses were stored at 2 to 4 °C. At 48 h *post mortem* the carcass was quartered between the 10th and 11th ribs and the depth of subcutaneous fat was measured (mm) at points 0.25, 0.50, and 0.75 over the *m. longissimus dorsi* (LD). Marbling of the LD was assessed using the eight-point scale of the United States Department of Agriculture photographic standards (Agricultural Research Council, 1965). The area of the LD muscle at the tenth rib on each side of the carcass was determined from a photograph using a PC image programme (Foster Findlay Assosiates Ltd, Newcastle Technopole, Kings Manor, Newcastle upon Tyne, England). Sampling for sarcomere length determination was as described by Koolmees *et al.* (1986). Prepared samples were measured by laser diffraction (Cross *et al.*, 1981).

The sample joint (termed fore-rib in the UK, 6/7 rib to 10/11 rib) was removed from the left forequarter of each carcass. A cut was made between the 6th and 7th ribs from the backbone to a point not more than 5 cm from the lateral tip of the LD. The joint was removed from the flank portion by making a cut perpendicular to the ribs 5 cm from the lateral tip of the LD. At 7 days *post mortem* the LD was removed from the fore-rib joint for meat quality assessment. The fore-rib joint was retained for dissection into lean, fat and bone as described by Cuthbertson *et al.* (1972). The composition of the carcass of each individual animal was estimated from the composition of its fore-rib joint using the equations given by Steen and Robson (1995) for animals that were considered to be of predominantly Charolais breeding, and using the small adjustments to the first-term constants in these equations for the Simmental cross animals as given by Steen and Kilpatrick (2000) and for Limousin and Blonde d'Aquitaine crosses as given by Steen and Kilpatrick (1995). The quantity of lean previously removed for analysis was added back prior to calculation.

A 3 cm steak of LD was removed at the 11th rib with the freshly cut side facing upwards and left to bloom for 1 h prior to measuring lean and fat colour at 7 days *post mortem* by reflectance spectra (380 to 800 nm) at 1 nm intervals using the Monolight Spectrophotometer, Model 6800 Controller fitted with a 0/45° Reflectance head (Monolight Instruments Ltd, Weybridge, England). The colour space values, L* (lightness), a* (redness), and b* yellowness, were calculated according to CIE (Commission Internationale de l'Eclairage) specifications using the software supplied by Monolight Instruments (UK) Ltd.

A 1 g sample of LD muscle was taken from the freshly cut surface and homogenised in 10 ml of distilled water and the pH of the homogenate measured using a Sentron pH meter, 7 days *post mortem*.

Cooking loss and shear force were assessed at 7 days *post mortem* on a 35 to 40 mm thick slice of the LD cut transverse to the muscle fibre direction from the posterior end of the fore-rib. Steak slices 35 mm thick were weighed and placed in a polythene bag and cooked by placing in a water bath at 75°C for 50 min, after this time the mean internal temperature was 71 °C (range 70 to 72 °C). Subsequently the slices were cooled in an ice water bath for 1 h with subsequent storage in a cold room at 4 °C, such that the core temperature at shearing was 4 to 5 °C. Excess liquid was removed by gently patting the slices with absorbent paper toweling, and the slices then re-weighed to calculate cooking losses. Ten cores 12.7 mm diameter were drilled from each slice paralled to the muscle fibre direction and sheared transversely on a Warner Bratzler shear blade fitted to a Model 6021 Instron Universal Testing Instrument (Instron, High Wycombe, Buckinghamshire, England).

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Twelve additional steers (two per treatment) of similar live weight to the experimental steers that had been given the diets for 20 days, were used to determine the total tract digestibilities and N retention for the total diets. Procedures for the determination of digestibilities were as described by Steen (1984). The metabolisable energy (ME) concentrations of the diets were calculated as described by Keady *et al.* (1994). In addition, apparent digestibilities of the forages offered at maintenance were determined using four castrate male sheep (Texel $\times$ Greyface, 1.5 years) per silage. The silage for the apparent digestibility study using sheep was removed, as described by Keady *et al.* (1998).

Corrected silage DM was determined as described by Porter and Murray (2001). Chemical composition of silage, concentrates, urine and faeces were determined as described by Keady *et al.* (1998 and 1999).

Statistical analysis

Animal performance and carcass data were analysed as randomised designs using a factorial model to test for the main effects of silage type and concentrate feed level plus their interactions. For the analysis of variance of live-weight gain, carcass gain, carcass data, meat quality assessments, carcass composition, and diet digestibilities, each steer was treated as an individual, while for food intake the mean values obtained for each group of three or four steers were used. Animal performance data were adjusted by covariance analysis using initial live weight as a covariate and food intakes were adjusted using the 7 day pre-experimental intake and initial live weight as covariates. Silage and total ration digestibilities were analysed as randomised design experiments. When significant ($P < 0.05$) main effects were found, differences between the individual factor levels were tested using Students *t* test.

Results

Chemical composition of the silages and concentrates

The chemical composition of the silages and concentrates offered in the present study are presented in Table 1. The silages were well preserved as indicated by their pH and concentrations of ammonia N and butyrate. The DM concentration of the grass silage was low, being 192 g/kg while for the maize and whole-crop wheat silages the DM concentrations were 276 and 319 g/kg; respectively. The maize and whole-crop wheat silages had starch concentrations of 225 and 209 g/kg, respectively.

Silage digestibilities determined through sheep at maintenance level are presented in Table 2. Relative to the grass silage, maize silage had lower ($P < 0.001$) ADF and NDF digestibilities but similar DM digestibility and digestible organic matter in the DM (DOMD). Relative to the grass and maize silages, the whole-crop wheat had significantly lower ($P < 0.001$) DM, ADF and NDF digestibilities and DOMD.

Steer performance

The effects of silage type and concentrate feed level on food and energy intakes are presented in Table 3. There were no silage type by concentrate feed level interactions for food or energy intakes. Inclusion of either maize or whole-crop wheat silage in the diet increased forage DM ($P < 0.01$), total DM, ($P < 0.01$) and GE ($P < 0.05$)

Table 1 *Chemical composition of the silages and concentrates as fed*

	Silage			
	Grass	Maize	Whole crop wheat	Concentrates
Dry matter (g/kg)	192	276	319	834
pH	4.23	4.11	4.25	–
Composition of DM (g/kg)				
Crude protein	116	80	98	171
Ammonia N (g/kg N)	110	90	150	–
Ethanol	21.1	13.2	5.9	–
Propanol	21.1	13.3	6.5	–
Acetate	64	48	41	–
Propionate	3.0	1.2	8.0	–
Butyrate	1.0	0.2	2.4	–
Valerate	0.1	0.2	0.4	–
Lactate	30.6	14.1	16.2	–
Acid detergent fibre	376	279	314	88
Acid detergent insoluble nitrogen	1.89	0.99	1.37	1.36
Neutral detergent fibre	604	539	536	212
Water soluble carbohydrate	5.0	4.4	4.8	–
Ash	77.5	37.1	47.1	47.6
Starch	–	225	209	–
Gross energy (MJ/kg DM)	19.26	19.22	18.58	18.18

Table 2 *Silage digestibilities determined through sheep at maintenance level*

	Silage				
	Grass	Maize	Whole crop wheat	s.e.	Sig[†]
Digestibility coefficient					
Dry matter	0.692^{b}	0.686^{b}	0.580^{a}	0.0064	***
DOMD[‡] (g/kg DM)	662^{b}	675^{b}	566^{a}	5.74	***
Acid detergent fibre	0.762^{c}	0.582^{b}	0.427^{a}	0.0101	***
Neutral detergent fibre	0.717^{c}	0.569^{b}	0.398^{a}	0.0101	***

[†] Means within a row having a different superscript differ, ($P < 0.05$).
NS $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[‡] Digestible organic matter in the DM.

intakes. Maize silage inclusion increased digestible energy (DE) intake ($P < 0.05$) and tended ($P = 0.08$) to increase ME intake.

Increasing concentrate feed level significantly decreased ($P < 0.001$) forage DM and increased total DM ($P < 0.001$), DE ($P < 0.001$), ME ($P < 0.001$) and GE ($P < 0.01$) intakes.

The effects of silage type and concentrate feed level on steer performance and carcass assessments are presented in Table 4. Relative to grass silage only, inclusion of maize silage in the diet increased ($P < 0.05$) final live weight, live-weight gain, carcass weight, and estimated carcass gain. Whole-crop wheat silage inclusion increased ($P < 0.05$) final live weight and live-weight gain and decreased ($P < 0.05$) dressing proportion relative to grass silage. Inclusion of either maize or whole-crop wheat silages did not alter ($P > 0.05$) carcass conformation or fat classification, mean fat depth over LD, marbling score, area of LD muscle at 10th rib, kidney, channel and cod fat, the lean, fat and bone contents of the fore-rib joint or estimated lean, fat or bone contents. Increasing concentrate feed level tended to increase live-weight gain ($P = 0.07$), marbling score ($P = 0.06$) and the weight of kidney, channel and cod fat ($P = 0.06$). Concentrate feed level did not alter ($P > 0.05$) final live weight, carcass weight, dressing proportion, estimated carcass gain, carcass conformation or fat classification, mean fat depth over, or area of the LD muscle, the lean and bone contents of the fore-rib joint, or estimated lean and bone content of the carcass. Increasing concentrate feed level tended ($P = 0.09$) to increase the fat content of the fore-rib and estimated fat content of the carcass. There were no silage type by concentrate feed level interactions for steer performance or carcass assessments.

The effect of silage type and concentrate feed level on fat and lean colour and meat quality is presented in Table 5. Increasing concentrate feed level increased a* ($P < 0.01$), b* ($P < 0.05$), and chroma ($P < 0.01$) for lean colour and sarcomere length ($P < 0.05$). Otherwise silage type or concentrate feed level did not alter fat or lean colour, pH, cooking loss or Warner Bratzler shear force. There were no silage type by concentrate feed level interactions for fat and lean colour or meat quality.

The effects of silage type and concentrate feed level on total diet digestibilities and N retention are presented in Table 6. Inclusion of maize silage in the diet decreased ($P < 0.05$) ADF and NDF digestibilities and increased ($P < 0.05$) N retention compared with grass silage-based diets. Maize silage inclusion in the diet did not alter ($P > 0.05$) DM, organic matter (OM), or energy digestibilities,

Table 3 *Effects of silage type and concentrate feed level on dry matter and energy intakes*

	Silage (S)				Concentrate (kg/day) (C)			Significance[†]		
	Grass	Grass plus maize	Grass plus whole crop wheat	s.e.	3	5	s.e.	S	C	S × C
Forage intake (kg DM/day)	5.05^{a}	5.75^{b}	5.80^{b}	0.153	5.96^{b}	5.10^{a}	0.128	**	***	NS
Total food intake (kg DM/day)	8.38^{a}	9.08^{b}	9.14^{b}	0.153	8.46^{a}	9.23^{b}	0.128	**	***	NS
Gross energy intake (MJ/day)	158^{a}	172^{b}	171^{b}	2.9	160^{a}	174^{b}	2.5	*	**	NS
Digestible energy intake (MJ/day)	121^{a}	130^{b}	127^{ab}	2.2	120^{a}	132^{b}	1.9	*	***	NS
Metabolisable energy intake (MJ/day)	104	111	108	1.9	102^{a}	113^{b}	1.6	$P = 0.08$	***	NS

[†] Means within a row for silage type of concentrate feed level having a different superscript differ, ($P < 0.05$).
NS $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

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Table 4 *Effects of silage type and concentrate feed level on animal performance and carcass assessments*

	Silage (S)				Concentrate (kg/day) (C)			Significance†	
	Grass	Grass plus maize	Grass plus whole crop wheat	s.e.	3	5	s.e.	S	C
Final live weight (kg)	601[a]	621[b]	614[b]	4.3	608	616	3.5	*	NS
Live-weight gain (kg/day)	0.86[a]	1.07[b]	1.01[b]	0.042	0.93	1.03	0.034	*	$P = 0.07$
Carcass weight (kg)	326[a]	334[b]	325[a]	3.0	326	331	2.4	*	NS
Dressing proportion (g carcass per kg live weight)	543[b]	539[b]	528[a]	3.5	537	537	2.8	*	NS
Estimated carcass gain (g/day)	514[a]	602[b]	496[a]	31.4	515	560	25.6	*	NS
Carcass conformation‡	2.75	2.82	2.77	0.072	2.79	2.77	0.059	NS	NS
Carcass fat classification§	3.25	3.77	3.52	0.161	3.35	3.68	0.132	NS	NS
Mean fat depth over *longissimus dorsi* muscle (mm)	4.63	5.49	5.83	0.395	4.98	5.66	0.323	NS	NS
Marbling score‖	2.23	2.45	2.41	0.145	2.18	2.54	0.118	NS	0.06
Area of *longissimus dorsi* muscle at 10th rib (cm^2)	69.8	69.3	67.8	1.80	68.8	69.1	1.47	NS	NS
Kidney, channel and cod fat (kg)	14.8	17.0	15.7	0.74	15.0	16.7	0.60	NS	0.06
Composition of fore-rib joint (g/kg)									
lean concentration	592	591	582	8.0	596	580	6.5	NS	NS
fat concentration	209	214	212	9.9	201	222	8.1	NS	$P = 0.09$
bone concentration	191	188	200	4.4	195	191	3.6	NS	NS
Estimated carcass composition (g/kg)									
lean concentration	651	650	645	4.8	654	644	3.9	NS	NS
fat concentration	158	161	159	6.1	153	166	5.0	NS	$P = 0.09$
bone concentration	183	182	186	1.7	184	183	1.4	NS	NS

† Means within a row having a different superscript differ, ($P < 0.05$).
‡ EUROP scale: 5 (best), 4, 3, 2, 1 (worst); respectively.
§ Five-point scale: 1 = leanest, 5 = fattest.
‖ Eight-point scale: 1 = leanest, 8 = fattest.
NS $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
There were no significant silage type by concentrate interactions.

DOMD or ME concentration of the total diet. Relative to grass silage, inclusion of whole-crop wheat silage decreased DM ($P < 0.05$), OM ($P < 0.05$), ADF ($P < 0.001$), NDF ($P < 0.001$), and energy ($P < 0.05$) digestibilities, DOMD ($P < 0.05$) and ME concentration ($P < 0.05$) and increased N retention ($P < 0.05$) and starch digestibility ($P < 0.05$) of total diet. Relative to the inclusion of maize silage, inclusion of whole-crop wheat silage decreased ($P < 0.05$) DM, OM, ADF, NDF, and energy digestibilities of the total diet. Increasing concentrate feed level increased OM ($P < 0.05$) digestibility and DOMD ($P < 0.01$) and did not alter ($P > 0.05$) DM, ADF, NDF, energy, N or starch digestibilities, ME concentrations or N retention. There were no silage type by concentrate feed level interactions ($P > 0.05$) on diet digestibilities, ME concentration, or N retention of the total diets.

Discussion

While the main aim of the present study was to establish the effects of replacing grass silage with alternative forages on feed intake and animal performance of beef cattle, the study also provided the opportunity to compare maize and whole-crop wheat. Furthermore, potential interactions between forage type and concentrate feed level were also studied. The concentrate was formulated so that the diet with the lowest CP concentration would have sufficient protein to meet animal requirements. Inadequate intakes of protein have been found to have detrimental effects on live-weight gain and carcass composition of beef cattle (Lindsay and Davies, 1981).

The grass silage used in the present study was representative of the average silage produced in Ireland. Keady (2000) quoted mean pH and concentrations of DM, CP, ammonia N and DM digestibility of grass silage analysed by the Hillsborough Feeding Information System of 4.1, 230 g/kg fresh, 127 g/kg DM, 120 g/kg DM, and 700 g/kg DM; respectively. The maize silage offered in the present study had a DM concentration of 276 g/kg fresh which was near the optimum stage of maturity at harvest. Phipps *et al.* (2000) and Keady *et al.* (2002b) using dairy cows previously concluded that the optimum stage of maturity to harvest maize for ensiling to maximise animal performance was approximately 300 g/kg fresh. The fermented whole-crop wheat silage offered in the present study had a DM

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Table 5 *Effects of silage type and concentrate feed level on fat and lean colour and meat quality*

	Silage (S)				Concentrate (kg/day) (C)			Significance[†]	
	Grass	Grass plus maize	Grass plus whole-crop wheat	s.e.	3	5	s.e.	S	C
Fat colour									
L*	71.4	71.9	72.6	2.07	73.9	70.0	1.69	NS	NS
a*	5.7	7.1	5.5	1.01	5.7	6.5	0.83	NS	NS
b*	16.6	17.9	17.9	0.89	17.3	17.6	0.72	NS	NS
Chroma	17.9	19.5	18.8	1.11	18.5	18.9	0.90	NS	NS
Hue	71.7	69.6	73.7	2.47	73.0	70.4	2.01	NS	NS
Lean colour									
L*	42.2	40.7	41.4	0.87	41.0	41.9	0.71	NS	NS
a*	20.7	21.4	20.9	0.51	20.0^{a}	22.0^{b}	0.42	NS	**
b*	15.9	16.2	15.9	0.37	15.4^{a}	16.6^{b}	0.31	NS	*
Chroma	26.1	26.8	26.3	0.59	25.2^{a}	27.6^{b}	0.48	NS	**
Hue	37.6	37.2	37.4	0.52	37.6	37.2	0.43	NS	NS
pH	5.57	5.56	5.55	0.011	5.56	5.56	0.009	NS	NS
Sarcomere length (μm)	2.28	2.29	2.34	0.055	2.23^{a}	2.38^{b}	0.050	NS	*
Cooking loss (%)	26.2	26.5	26.1	0.97	26.1	26.4	0.79	NS	NS
Warner Bratzler shear force (kg)	2.64	2.75	2.65	0.23	2.73	2.63	0.187	NS	NS

[†a,b]Means within a row having a different superscript differ significantly ($P < 0.05$).
NS $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
There were no significant silage type by concentrate interactions.

concentration of 310 g/kg, and Sinclair *et al.* (2003) have shown that ensiling whole-crop wheat at DM concentrations between 300 and 370 g/kg did not affect animal performance of dairy cows.

Due to the absence of forage by concentrate feed level interactions only the main treatment effects are discussed.

Feed intake

In the present study alternative forages accounted for proportionately 0.40 and 0.25 of forage and total DM intakes respectively. Previous studies have reported increased food intake due to the inclusion of maize silage in the diet of beef cattle (Browne *et al.*, 1999; O'Kiely and Moloney, 1995 and 2000) and dairy cows (Phipps *et al.*, 2000; Keady *et al.*, 2002b and 2003). However, Keady *et al.* (2002b and 2003) concluded that the factor which had the greatest effect on the response to the inclusion of maize silage in grass silage-based diets offered to dairy cows was grass silage quality. For example, Keady *et al.* (2002b) replaced 0.40 of low (ME 9.8 MJ/kg DM) and high (ME 11.8 MJ/kg DM) feed value grass silages with a range of maize silages differing in maturity at harvest and concluded that varying

Table 6 *Effects of silage type and concentrate feed level on total diet digestibilities and nitrogen retention*

	Silage (S)				Concentrate (kg/day) (C)			Significance[†]	
	Grass	Grass plus maize	Grass plus whole crop wheat	s.e.	3	5	s.e.	S	C
Digestibility coefficient									
Dry matter	0.765^{b}	0.760^{b}	0.743^{a}	0.0048	0.750	0.763	0.0039	*	NS
Organic matter	0.782^{b}	0.770^{b}	0.753^{a}	0.0048	0.761^{a}	0.776^{b}	0.0039	*	*
DOMD (g/kg DM)	689^{b}	684^{ab}	667^{a}	4.5	668^{a}	692^{b}	3.7	*	**
Acid detergent fibre	0.747^{c}	0.709^{b}	0.670^{a}	0.0075	0.716	0.701	0.006	***	NS
Neutral detergent fibre	0.728^{c}	0.684^{b}	0.658^{a}	0.0087	0.700	0.680	0.0071	**	NS
Energy	0.768^{b}	0.760^{b}	0.743^{a}	0.0052	0.752	0.762	0.0042	*	NS
Nitrogen	0.689	0.699	0.716	0.0129	0.698	0.705	0.0105	NS	NS
Starch	0.974^{a}	0.981^{ab}	0.986^{b}	0.0024	0.982	0.979	0.0020	*	NS
ME (MJ/kg DM)	12.41^{b}	12.22^{ab}	11.80^{a}	0.131	12.08	12.20	0.107	*	NS
Nitrogen retention (g/day)	17.8^{a}	25.6^{b}	28.0^{b}	1.84	23.9	23.7	1.50	*	NS

[†] Means within a row having a different superscript differ, ($P < 0.05$).
NS $P > 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
There were no significant silage type by concentrate interactions.

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DM of maize silage from 201 to 384 g/kg fresh had no effect on total DM intake. However for the low and high feed value grass silage-based diets, replacement of 0.40 of the grass silage with maize resulted in total DM intakes of 1.15 and 0.99 relative to the grass silage- based diet. Similarly, Keady *et al.* (2003) observed that for low (ME 10.2 MJ/kg DM), medium (ME 11.0 MJ/kg DM), and high (ME 12.0 MJ/kg DM) feed value grass silages, replacement with 0.4 of the grass silage component of the diet with maize resulted in total DM intake by dairy cows of 1.12, 1.09, and 0.99; respectively relative to grass silage-based diets. The increased food intake due to the inclusion of maize silage in the present study is similar to the mean response reported by Keady *et al.* (2002b and 2003).

Steen *et al.* (1998) concluded that the main factors affecting grass silage intake were forage digestibility, rumen degradability, and the concentrations of N and fibre fractions. The increased intake characteristics of maize silage are not fully explained by the findings of Steen *et al.* (1998). Steen *et al.* (1998) and Keady *et al.* (2004) developed models to predict food intake of grass silage and mixed forage-based diets by beef and dairy cattle; respectively. The models of Steen *et al.* (1998) and Keady *et al.* (2004) predicted an increase in feed intake of 0.524 and 0.65 kg DM per head per day, or 0.07 and 0.06 in forage intake; respectively due to the inclusion of maize silage. The use of these prediction models to predict intake of mixed forage-based diets illustrated that the higher intake characteristics of maize silage can be attributed to a combination of DM, fermentation and digestibility characteristics, and lower concentrations of NDF and ADF.

Previous authors have reported that the inclusion of whole-crop wheat silage in grass silage-based diets has increased forage intake of beef (O'Kiely and Moloney, 2002) and dairy (Leaver and Hill, 1995; Phipps *et al.*, 1995) cattle. Furthermore, Phipps *et al.* (1995) reported similar increased feed intake characteristics with the replacement of grass silage with either maize or whole-crop cereal silages. In the current study the whole-crop wheat had lower digestibility characteristics relative to the grass silage. Using the equations of Steen *et al.* (1998) for beef cattle and Keady *et al.* (2004) for dairy cows, including whole-crop wheat as 0.40 in grass silage-based diets would be predicted to produce an increase of 0.36 and 0.30 kg DM per head per day or 0.05 and 0.03 respectively for forage only diets. The higher intake characteristics of whole-crop wheat silage relative to grass silage are not related to digestibility, as the whole-crop wheat silage in this study had lower digestibility characteristics. However, as with the maize silage, the intake characteristics are probably associated with DM and starch concentrations and fermentation characteristics.

Increasing concentrate supplementation resulted in a mean substitution of 0.53 kg silage DM per kg increase in concentrate DM intake which is similar to the range quoted by McNamee *et al.* (2001) for similar grass silages supplemented with similar levels of concentrate.

Steer performance

While whole-crop wheat silage inclusion increased live-weight gain, it had no beneficial effect on saleable product from finishing beef cattle, namely carcass weight. Similarly, previous studies have reported that the inclusion of whole-crop wheat silage in silage-based diets decreased carcass gain of beef cattle (O'Kiely and Moloney, 1999), had no effect on milk yield or composition of dairy cows (Leaver and Hill, 1995) or increased carcass gain of finishing beef cattle (O'Kiely and Moloney, 2002). More recently Keady (2005) concluded from a review of seven beef cattle and 20 dairy cow studies that whole-crop wheat silage inclusion in grass silage based diets did not improve either carcass gain of beef cattle or milk yield of lactating dairy cows.

The decrease in dressing proportion due to the inclusion of whole-crop wheat silage is probably associated with the increased intake of lower digestible forage. Previously Steen *et al.* (2002) reported that feeding medium feed value grass silage decreased dressing proportion relative to high feed value grass silage. Furthermore, O'Kiely and Moloney (1999) found that, relative to grass silage offered as the sole forage, whole-crop wheat silages ensiled at different DM concentrations and treated with different additives, decreased dressing proportion when offered as the sole forage to beef cattle. However, more recently it is noted that O'Kiely and Moloney (2002) observed no effect of the inclusion of whole-crop wheat on the dressing proportion of finishing beef cattle.

Previous authors have reported either decreased performance of beef cattle (O'Kiely and Moloney, 1995) or increased performance of beef (Browne *et al.*, 1999) and dairy (Phipps *et al.*, 2000; Keady *et al.*, 2002b and 2003) cattle as a result of replacing a proportion of the forage component of grass silage-based diets with maize silage. More recently Keady (2005) concluded from a review of nine beef cattle and 34 dairy cow studies that including maize in grass silage based diets increased milk yield of lactating dairy cows by 1.4 kg/day and carcass gain of beef cattle by 0.11 kg/day respectively. Unlike the effect of including whole-crop wheat silage, maize silage inclusion in the diet did not alter dressing proportion, similar to the results of McCabe *et al.* (1995) and O'Kiely and Moloney (2000). The absence of an effect to the inclusion of maize silage in grass silage-based diets on carcass conformation and fat classification and weights of internal fat depths, concurs with the findings of previous authors (McCabe *et al.*, 1995).

Tenderness, colour and flavor are the major factors affecting meat quality (Devine and Chrystall, 1998). In the present study forage type did not alter fat and lean colour, or meat quality. O'Sullivan *et al.* (2002) concluded grass silage had higher vitamin E concentrations than maize silage and that beef from heifers offered grass silage-based diets had better overall quality in terms of colour, lipid oxidation, and vitamin E levels than beef from heifers offered forage-based diets where maize silage either partially or

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totally replaced the grass silage. However, contrary to the present study, Hoving-Bolink *et al.* (1999) observed that totally replacing grass silage with maize silage in forage-based diets produced lighter and more tender beef. However, Hoving-Bolink *et al.* (1999) and Moloney *et al.* (1999) also observed that partial replacement of grass silage with maize silage did not alter meat colour or quality.

Increased marbling has been associated with improved meat eating quality (Jones *et al.*, 1991; Wheeler *et al.*, 1994). While in the present study partial replacement of grass silage with maize silage increased carcass gain, marbling fat or estimated carcass fat content were not altered, which may explain the absence of an effect on instrumental measures of meat quality. Marbling and intramuscular fat are generally related to juiciness assessed by sensory panels and may influence cooking loss. It should be noted that the average shear force value as measured by Warner Bratzler method indicated meat of acceptable tenderness based on the 100% tenderness acceptability obtained for Warner Bratzler values of less than 3.0 kg by Miller *et al.* (2001). The low Warner Bratzler shear force values are probably due to the tenderstretch method used to hang the carcasses post slaughter which may have eliminated any treatment effects. Lively *et al.* (2005) observed differences in shear force between the Charolais and Holstein genotypes when the carcasses were suspended from the aitch bone but not when suspended from the achilles tendon. Although sarcomere length was statistically different due to level of concentrate feeding the difference in sarcomere length is small and of no practical significance. It should also be noted that while concentrate feed level increased lean colour, i.e. a more saturated colour, and tended to increase both marbling fat ($P = 0.06$) and estimated carcass fat ($P = 0.09$) concentrations, meat quality as determined by instrumental methods was unaltered. Post-slaughter factors such as applied chilling rate, which interacts with fat cover and carcass size to give the resultant chilling rate within the muscle and the rate of pH fall, and the method of hanging all influence meat quality, particularly tenderness (Thompson, 2002). Where post-slaughter conditions are optimised, meat quality is more consistent.

Although the inclusion of maize and whole-crop wheat silages increased ME intake by 0.07 and 0.04, carcass gains were altered by $+0.17$ and -0.04; respectively. The efficiency with which ME intake has been stored in the carcass has been calculated for the treatments and is presented in Table 7. Forage maize inclusion in the diet resulted in the lowest food conversion ratio (kg DMI per kg carcass) and increased carcass gain per MJ ME intake, being higher than increasing concentrate feed level by 2 kg per head per day. For calculation of energy stored in the carcass, energy concentrations of 23.6 and 39.3 MJ/kg have been assumed for protein and lipid respectively. Protein and lipid concentrations of 220 and 46 g/kg lean and 34 and 850 g/kg for separable fat have been assumed, as these concentrations have been obtained for these tissues in previous studies (Steen and Robson, 1995). On this basis, the efficiency with which ME was stored in the carcass (MJ/day) was 0.18 greater and 0.04 lower for diets containing maize and whole-crop wheat silages relative to grass silage-based diets. When efficiency of utilisation of ME is determined as energy stored in the carcass per MJ ME intake, maize silage inclusion in the diet increased efficiency of ME utilisation by 0.11 while whole-crop wheat decreased it by 0.07. Meanwhile increasing concentrate feed level improved energy stored in the carcass per MJ ME intake by 0.02. Data from this study illustrate that increased ME intake from the inclusion of forage maize silage in grass silage-based diets increased the efficiency of utilisation of ME relative to increasing concentrate feed level. Nitrogen is a primary environmental concern due to losses of ammonia to the atmosphere and nitrate contamination of the surface water and ground water (Tamminga, 1992). The increased N retention by cattle offered the mixed forage diets, relative to grass silage only, is a desirable effect considering impending legislation limiting the quantity of organic-N loading per ha per year.

Table 7 *Effects of silage type and concentrate feed level on estimated efficiency of gain*

	Silage			Concentrate (kg/day)	
	Grass	Grass plus maize	Grass plus whole crop	3	5
Food conversion ratio (kg DMI/kg carcass)	16.3	15.1	18.4	16.4	16.5
Carcass gain (g/MJ ME intake)	4.94	5.42	4.59	5.05	4.96
Energy stored in carcass					
(MJ/day)	5.0	5.9	4.8	4.9	5.6
(KJ/MJ ME intake)	47.9	53.1	44.5	48.2	49.2

One of the potential benefits of including alternative forages in the diet would be to maintain animal performance at a lower concentrate feed level. Keady *et al.* (2002b and 2003) reported that with dairy cows, replacing 0.40 of the forage component of grass silage-based diets with maize silage resulted in concentrate sparing effects of up to 3.4 and 3.1 kg per cow per day. However, the potential concentrate sparing effect will depend on the feed value of the grass silage and alternative forage silage. In the present study using medium feed value grass silage, the concentrate sparing effect of maize and whole-crop wheat was greater than 2 and 0 kg per head per day respectively. Previously Keady *et al.* (2003) observed that for low, medium and high feed value grass silage-based diets, replacing 0.40 of the forage component with maize silage had concentrate sparing effects of 3.3, 2.6, and 2.5 kg per cow per day respectively.

It is concluded that replacing grass silage with maize silage increased carcass gain and weight of finishing beef cattle due to higher intakes and improved utilisation of metabolisable energy. While replacing grass silage with whole-crop wheat silage increased live-weight gain, the reduced dressing proportion resulted in no beneficial

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effect on carcass gain probably due to increased food intakes of lower digestible forage increasing gut fill.

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