Ensiled maize and whole crop wheat forages for beef and dairy cattle: effects on animal performance

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Key points

1. Maize silage can be produced and fed to beef and dairy cattle at a similar price to grazed grass.
2. Including maize silage in the diet increases feed intake and performance of beef and dairy cattle.
3. The optimum stage of maturity at harvest for increased performance is at a dry matter concentration of approximately 300 g/kg.
4. Including maize silage in grass silage-based diets has a concentrate sparing effect of up to 5 kg/cow/d.
5. There is a negative relationship between stage of maturity at harvest and milk fat concentration.
6. Whole crop wheat can be produced and fed at a similar cost to grass silage.
7. Including whole crop wheat either fermented, urea- or alkalage-treated in grass silage-based diets increases feed intake but does not alter performance of beef or dairy cattle.

Keywords: grass silage, maize silage, whole crop wheat silage, cost of production, carcass gain, milk yield

Introduction

Traditionally in many parts of Europe, Scandinavia, New Zealand, Australia and North America, grass silage was offered to beef and dairy cattle during the winter indoor feeding period. However in recent times, other ensiled forages, such as maize and whole crop wheat have increased in popularity and have partially replaced grass silage in the diet. Major developments, both in plant breeding and in agronomic practices, have enabled consistent production of high yields of these forages in areas in which it was not possible to grow these crops 20-30 years ago. Alongside these developments major improvements have also occurred in the genetic merit/production potential of beef and dairy herds. Given the reduced margins in beef and milk production, producers aim to reduce costs of production by feeding forages with high intake potential and reduce concentrate feed level whilst maintaining or increasing animal performance. The aim of this paper is to evaluate the effect of including maize and whole crop wheat silages in grass silage-based diets on performance of beef and dairy cattle.

Materials and methods

Data from studies in which grass silage was offered as the sole forage and in which grass silage was replaced by either maize of whole crop wheat were collated to evaluate the effects of replacing grass silage with alternative forages.

Grass silage metabolisable energy (ME) concentration, if not determined in the original study, was estimated from digestible organic matter in the dry matter (D-value) using the equations

The effects of including maize silage in grass silage-based diets on feed intake and performance of dairy cows from 34 comparisons, is presented in Table 2. There is a substantial body of evidence to indicate that the inclusion of maize silage in grass silage-based diets significantly increased forage intake (1.5 kg DM/d), the yields of milk (1.4 kg/d) and fat plus protein (0.15 kg/d), milk fat (0.6 g/kg) and protein (0.8 g/kg) concentrations.

The effects of the including maize silage in grass silage-based diets on feed intake, and performance of finishing beef cattle from nine comparisons is presented in Table 3. Including maize silage increased forage intake (1.5 kg DM/d), carcass gain (0.11 kg/d), liveweight gain (0.23 kg/d) and carcass weight (12 kg).

The studies quoted in Tables 2 and 3 show that the inclusion of maize in grass silage-based diets has produced variable effects on animal performance. These different responses may have been due to variations in the feed value of either the grass and maize silages offered in these studies or in the level of inclusion of maize silage in the diet.

Level of forage maize inclusion

A number of studies have been undertaken to evaluate the effect of level of maize silage inclusion in grass-based diets on the performance of beef cattle (O'Kiely & Moloney, 1995, 2000; Browne *et al*., 2000) and dairy cows (Phipps *et al*., 1992b; O'Mara *et al*., 1998). O'Kiely & Moloney (1995) concluded that replacing up to 0.67 of moderate feed value grass silage (DM 208 g/kg; DMD 746 g/kg DM) with low dry matter (DM = 205 g/kg) maize silage did not alter liveweight gain of beef cattle. However these authors noted that replacing either 0, 0.33, 0.66 or 1.00 of grass silage with maize silage had a quadratic effect on feed intake, with the highest intakes being recorded when 0.33 and 0.67 of the forage component consisted of maize. In a subsequent study O'Kiely & Moloney (2000) replaced a similar feed value grass silage as that used by O'Kiely & Moloney (1995) with either 0.50 or 1.00 of maize silages with DM concentrations of either 260, 300 or 380 g/kg and concluded that increasing the proportion of maize silage in the diet increased carcass gain. Similarly Browne *et al*. (2000) concluded that replacing either 0, 0.33, 0.67 or 1.00 of a medium feed value grass silage (DM = 265 g/kg, ME 10.4 MJ/kg DM) with maize silage (DM = 332 g/kg, starch = 301 g/kg DM) increased feed intake and carcass gain.

Changes in the diet of dairy cows can impact on milk yield and composition as well as body weight change. Phipps *et al*. (1992b) replaced either 0, 0.25, 0.50 or 0.75 of low feed value (DM = 260 g/kg, D-value = 620 g/kg DM) or average feed value (DM = 266 g/kg, D-value = 660 g/kg DM) grass silages with maize silage (DM = 273 g/kg). These authors concluded that with the low feed value grass silage, the higher the level of maize silage inclusion the higher the feed intake and milk yield. However, with the average grass silage, peak feed intake and milk yield were achieved when 0.50 of the grass silage was replaced with maize silage. Similarly O'Mara *et al*. (1998) replaced 0.33, 0.67 or1.00 high feed value grass silage (DM = 223 g/kg DMD = 759 g/kg DM) with medium DM maize silage (DM = 257 g/kg, starch = 329 g/kg DM) and noted that the highest feed intake and milk yield occurred when 0.33 of the forage component of the diet consisted of maize silage. However, body weight gain improved with maize silage inclusion up to 0.67.

Table 1 The costs of producing and feeding forages

	Grass	Grass silage			Whole crop wheat[a]		Maize	
		3-cut	4-cut	Baled	Fermented	Urea	Mulch	Open
Yield (t DM/ha)								
Forage	10.6	13.8	12.8	13.8	13.0	13.0	18.0	12.2
Utilised	8.0	11.5	10.9	11.7	11.1	11.8	15.5	10.5
ME (MJ/kg DM)	11.7	11.4	12.1	11.4	9.5	8.2	11.6	10.5
Costs (£/ha)								
Reseeding	24	45	32	45	-	-	-	-
Establishment	-	-	-	-	132	132	215	212
Fertiliser	149	160	176	160	51	51	67	73
Sprays	8	8	8	8	110	110	32	32
Plastic mulch	-	-	-	-	-	-	174	-
Additive	-	75	51	-	46	86	59	67
Silo cover	-	4	4	-	4	7	4	4
Infrastructure	49	75	63	26	70	74	67	68
Contractor	74	298	369	417	202	202	163	173
Feed-out	28	114	108	151	110	117	125	104
Land charge	250	200[b]	225[b]	200[b]	250	250	250	250
Total costs	582	979	1036	1007	975	1029	1156	983
Cost of forage (£/t UDM)	73	85	95	86	88	87	75	94
Relative cost of grazed grass	1.0	1.2	1.3	1.2	1.2	1.2	1.0	1.3

(After Keady *et al.*, 2002a)

[a] Winter sown crop

[b] Land charge reduced to allow for grazing after herbage is ensiled

Table 2 The effects of including maize silage in grass silage-based diets on the performance of dairy cows

Reference	Grass silage (GS)		Maize silage (MS)		GS:MS ratio	Forage intake (kg DM/d)		Milk (kg/d)		Fat (g/kg) (F)		Protein (g/kg) (P)		F+P (kg/d)	
	DM (g/kg)	ME (MJ/kg DM)	DM (g/kg)	Starch (g/kg DM)		GS	Maize	GS	Maize	GS	Maize	GS	Maize	GS	Maize
Phipps *et al*. (1995)	213	10.9	354	339	67:33	9.3	10.6	23.0	26.4	41.7	41.8	29.9	31.2	1.62	1.93
Hameleers (1998)	248	11.4	275	256	60:40	10.6	11.4	27.4	26.3	48.9	46.9	34.1	33.6	2.25	2.11
Patterson *et al*. (2004)	187	11.2	297	225	60:40	7.9	9.8	25.8	27.4	39.8	39.0	30.9	31.5	1.82	1.94
Murphy (2004)	240	10.5	221	140	33:67	8.8	11.2	27.6	29.6	39.6	40.4	30.7	31.2	1.93	2.11
	231	10.9	302	324	33:67	8.7	13.2	30.8	33.7	36.7	38.5	29.7	31.5	2.05	2.32
Patterson & Kilpatrick	185	10.7	305	359	50:50	10.4	13.3	27.9	29.8	40.7	42.2	30.8	31.9	1.96	2.20
(2005)	234	12.5	305	359	50:50	12.5	13.9	31.5	32.1	38.5	38.5	32.8	32.5	2.23	2.28
Phipps *et al*. (1992b)	260	9.9	273		50:50	6.9	8.1	23.8	25.2	38.8	38.7	30.2	30.6	1.64	1.75
	266	10.6	273		50:50	8.0	8.5	24.5	25.7	39.4	38.3	30.9	30.8	1.72	1.78
O'Mara *et al*. (1998)	223	11.5	257	219	33:67	8.8	10.3	21.4	22.9	37.7	37.2	30.6	31.2	1.46	1.56
Phipps *et al*. (2000)	296	11.1	226	114	75:25	9.2	10.9	28.0	29.4	45.0	45.8	30.6	32.4	2.14	2.31
	296	11.1	290	274	75:25	9.2	13.3	28.0	32.7	45.0	43.4	30.6	32.7	2.14	2.48
	296	11.1	302	309	75:25	9.2	13.1	28.0	33.0	45.0	41.8	30.6	31.9	2.14	2.44
	296	11.1	390	354	75:25	9.2	12.8	28.0	30.8	45.0	44.6	30.6	31.9	2.14	2.37
Keady *et al*. (2002b)	193	9.8	202	100	60:40	8.7	10.8	24.8	25.8	40.3	42.1	30.4	31.6	1.75	1.89
	193	9.8	280	273	60:40	8.7	11.2	24.8	26.4	40.3	41.6	30.4	31.8	1.75	1.94
	193	9.8	298	270	60:40	8.7	10.9	24.8	25.8	40.3	41.2	30.4	31.2	1.75	1.85
	193	9.8	384	332	60:40	8.7	11.1	24.8	25.5	40.3	41.0	30.4	32.0	1.75	1.86
	326	11.8	202	100	60:40	13.1	13.7	28.8	28.8	39.4	42.6	32.7	33.0	2.03	2.16
	326	11.8	280	273	60:40	13.1	13.8	28.8	29.5	39.4	41.9	32.7	33.0	2.03	2.22
	326	11.8	298	270	60:40	13.1	13.4	28.8	29.3	39.4	41.6	32.7	33.0	2.03	2.19
	326	11.8	384	332	60:40	13.1	13.6	28.8	30.1	39.4	39.4	32.7	33.1	2.03	2.14
Keady *et al*. (2003)	218	10.2	189	15	60:40	9.8	11.4	25.9	27.3	38.6	39.2	31.8	32.5	1.79	1.93
	218	10.2	249	161	60:40	9.8	11.6	25.9	26.9	38.6	40.6	31.8	32.9	1.79	1.96
	218	10.2	362	270	60:40	9.8	11.9	25.9	27.4	38.6	39.0	31.8	32.7	1.79	1.93
	218	10.2	429	320	60:40	9.8	11.7	25.9	27.5	38.6	40.4	31.8	33.1	1.79	2.00
	234	11.0	189	15	60:40	10.2	11.6	27.3	28.5	38.9	40.3	31.5	32.2	1.93	2.07
	234	11.0	249	161	60:40	10.2	11.2	27.3	28.2	38.9	40.7	31.5	33.4	1.93	2.06
	234	11.0	362	270	60:40	10.2	12.4	27.3	29.0	38.9	39.1	31.5	32.9	1.93	2.08
	234	11.0	429	320	60:40	10.2	11.4	27.3	28.0	38.9	38.9	31.5	32.7	1.93	2.01
	307	12.0	189	15	60:40	14.3	13.6	30.4	30.1	41.5	44.1	34.6	35.0	2.30	2.37
	307	12.0	249	161	60:40	14.3	13.7	30.4	30.8	41.5	43.5	34.6	34.4	2.30	2.39
	307	12.0	362	270	60:40	14.3	14.9	30.4	31.1	41.5	41.3	34.6	34.7	2.30	2.35
	307	12.0	429	320	60:40	14.3	14.7	30.4	31.1	41.5	41.3	34.6	35.0	2.30	2.35
Mean (n = 34)	252	11.0	297	235		10.5	12.0	27.2	28.6	40.5	41.1	31.7	32.5	1.95	2.10
SED						0.227		0.211		0.24		0.12		0.016	
Significance						***		***		*		***		***	

Table 3 The effects of including maize silage in grass silage-based diets on the performance of beef cattle

Reference	Grass silage (GS)		Maize silage (MS)		GS:MS ratio	Forage intake (kg DM/d)		Carcass gain (kg/d)		Liveweight gain (kg/d)		Carcass weight (kg)	
	DM (g/kg)	ME (MJ/kg DM)	DM (g/kg)	Starch (g/kg DM)		GS	Maize	GS	Maize	GS	Maize	GS	Maize
Keady & Kilpatrick (2004)	192	10.6	276	225	60:40	5.1	5.8	0.51	0.60	0.86	1.10	326	334
Walsh *et al*. (2005)	161		303		100:0	4.5	6.8	0.48	0.78	0.80	1.20	290	335
O'Kiely & Moloney (2000)	180	11.3	375	446	25:75	5.1	7.2	0.65	0.73	0.85	0.98	324	336
	180	11.3	297	379	25:75	5.1	6.7	0.65	0.72	0.85	0.96	324	334
	180	11.3	256	332	25:75	5.1	6.5	0.65	0.71	0.85	0.95	324	333
Brown *et al*. (2000)	265	10.4	332	301	33:67	6.3	7.3	0.58	0.79	0.92	1.17	311	321
O'Kiely & Moloney (1995)	208	11.2	205		33:67	6.1	6.8	0.87	0.74	1.39	1.27	316	304
Gorman *et al*. (1998)	244	10.3	232	93	0:100	6.7	8.6	0.43	0.54	0.73	0.82	369	380
	244	10.3	336	265	0:100	6.7	8.2	0.43	0.61	0.73	0.83	369	387
Mean (n = 9)	206	10.8	290	292		5.6	7.1	0.58	0.69	0.89	1.02	328	340
SED						0.19		0.04		0.045		4.91	
Significance						***		*		*		*	

Milk composition, namely fat and protein concentrations, have a major impact on milk value, the relative value of each component depending on the prevailing market conditions. Whilst Phipps *et al*. (1992b) and O'Mara *et al*. (1998) reported positive effects on milk yield to varying levels of inclusion of maize silage in grass silage-based diets, they concluded that increasing the level of maize in the diet did not alter milk fat or protein concentration.

The optimum level of inclusion of maize silage in grass silage-based diets depends on the quality of both grass silage and maize silage. If offered low feed value grass silage, then increasing the inclusion rate of maize silage increases animal performance. However, with average quality grass silage, most of the benefit to inclusion of maize silage is obtained from replacing approximately 0.50 of the forage component of the diet with maize silage.

Stage of maturity

Whilst the optimum stage of harvesting grass silage for feeding to finishing beef cattle and lactating dairy cows is at the leafy immature stage (Keady *et al*., 1999; 2000; 2002b; 2003), for maize silage the intention is to increase starch content and consequently harvest as a mature crop. Major changes occur in the composition of the maize plant as it matures. Neutral detergent fibre, acid detergent fibre and crude protein concentrations decrease (Phipps *et al*., 2000; Keady *et al*., 2002b; 2003) whilst starch concentrations increase (Phipps *et al*., 2000, Keady *et al*., 2002b; 2003) due to the cob accounting for a larger proportion of plant weight. A number of studies have evaluated the impact of stage of maturity of maize at harvest on performance of dairy cattle (Harrison *et al*., 1996; Bal *et al*., 1997, Phipps *et al*., 2000; Keady *et al*., 2002b; 2003). Harrison *et al*. (1996) concluded that increasing maize silage DM from 357 to 451 g/kg in mixed maize silage/alfalfa hay-based diets decreased milk yield by 1.4 kg/d. Bal *et al*. (1997) increased maize silage DM from 301 to 420 g/kg in maize silage/alfalfa silage-based diets and observed that the highest milk yields were obtained from diets that included maize silage DM of 351 g/kg. However inclusion of maize silage did not alter milk composition.

Phipps *et al*. (2000) increased maize silage DM content from 226 to 390 g/kg with maize included in grass silage diets at 0.75 of the forage component and concluded that maize silage with DM of 290 and 302 g/kg increased milk yield by up to 3.6 kg/cow/d relative to maize silage of 226 g/kg DM. However, Phipps *et al*. (2000) also observed that as maize silage DM content increased further to 390 g/kg, milk yield was decreased by 2.2 kg/head relative to maize at 302 g/kg. Neither milk fat or milk protein concentrations were affected by maize silage DM content. More recently, Keady *et al*. (2002b) offered maize silages with DM concentrations varying from 202 to 384 g/kg in grass silage-based diets to lactating dairy cows. These authors concluded that the highest yields of milk and fat plus protein were obtained from maize silage of 280 g/kg. Furthermore, Keady *et al*. (2002b) concluded that maize silage with a dry matter of 384 g/kg did not significantly decrease milk solid output relative to maize silage with a dry matter of 280 g/kg.

In the study of Keady *et al.* (2003) in which maize silage dry matter concentrations varied from 189 to 429 g/kg there were no maize silages with a dry matter content between the range of 249 to 362 g/kg DM, possibly explaining the absence of an effect of maize maturity on animal performance. In contrast to the results of Phipps *et al*. (2000), Keady *et al*. (2002b; 2003) observed no negative impacts of high DM maize silage on animal performance. The negative effect of high dry matter maize silage on animal performance as reported by Phipps *et al*. (2000) may be due to silo management, as Keady *et al*. (2002b; 2003) ensiled in narrow silos and used an additive to improve aerobic stability at the point of feed-out.

Using the data of Harrison *et al.* (1996), Bal *et al*. (1997), Phipps *et al*. (2000) and Keady *et al*. (2002b; 2003), the effect of maize silage dry matter content on subsequent milk yield is best described by the following relationship:

MY = 21.86 (s.e. = 2.94***) + 0.0408 (s.e. = 0.01900*) MDM – 0.0000615 (s.e. = 0.0000295*) MDM^2 $R^2 = 0.24$, $P = 0.12$
where MY = milk yield (kg/d), MDM = maize silage dry matter content (g/kg).

The relationship between maize silage DM and milk yield is presented in Figure 1.

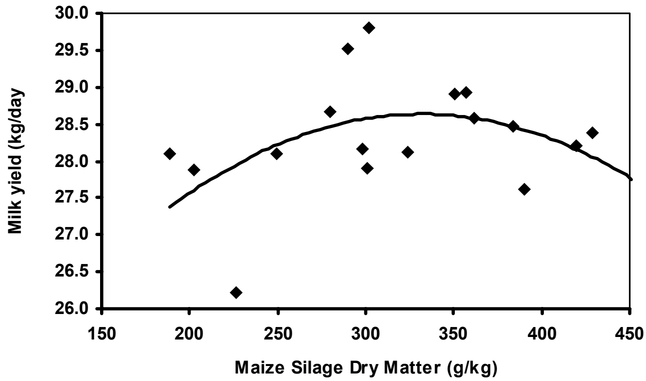

Figure 1 Effect of maize silage dry mater content on milk yield

In contrast to Bal *et al*. (1997) and Phipps *et al*. (2000), Keady *et al*. (2002b; 2003) observed that increasing maize silage DM content decreased milk fat concentration. Keady (2003) using the data from Keady *et al*. (2002b; 2003) presented the following relationship between maize silage dry matter content and milk fat concentration:

Milk fat (g/kg) = 43.61 (s.e. 0.739) – 0.0085 MDM (s.e. 0.00239) $R^2 = 0.68$
where MDM = maize dry matter content (g/kg).

Using the data of Bal *et al*. (1997), Phipps *et al*. (2000) and Keady *et al*. (2002b; 2003) the effect of maize silage dry matter content on milk fat concentration is best described by the following relationship:

MF = 42.42 (s.e. 1.01) – 0.00674 MDM (s.e. 0.00314) $R^2 = 0.25$*
where MF = milk fat concentration (g/kg) MDM = maize silage dry matter (g/kg).

The relationship between silage DM and milk fat concentration is presented in Figure 2.

The negative relationship between milk fat concentration and maize silage dry matter concentration may be attributed to the increased intake of digestible fibre and the decreased intake of starch associated with low dry matter content maize. Previous studies (Keady *et al*., 1998; 1999) have shown negative relationships between concentrate starch intake and milk fat concentration.

In summary, in order to achieve optimum levels of performance in beef and dairy cattle offered grass silage-based diets, forage maize should be ensiled at a dry matter concentration of approximately 300 g/kg.

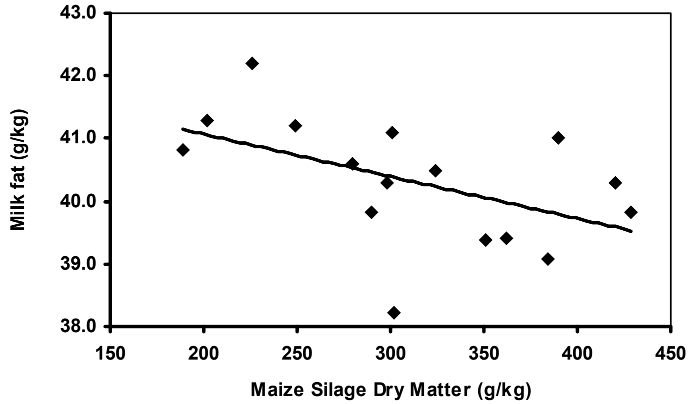

Figure 2 Effect of maize silage dry mater content on milk fat concentration

Interaction between grass silage feed value and maturity of maize at harvest
Whilst many studies have reported differences in the response to the inclusion of maize silage with grass silage-based diets offered to beef and dairy cattle, few have evaluated if the response depends on feed value of maize silage or that of the grass silage. Keady *et al.* (2002b; 2003) evaluated the effects of including four maize silages, differing in stage of maturity at harvest, on performance of lactating dairy cattle offered either two or three grass silages respectively, differing in feed value. Keady *et al.* (2002b, 2003) concluded that the response to maize silage inclusion in the diet in terms of the yields of fat and protein corrected milk (Figure 3), fat plus protein yield and the concentrations of fat and protein were similar irrespective of grass silage feed value or maize silage DM content.

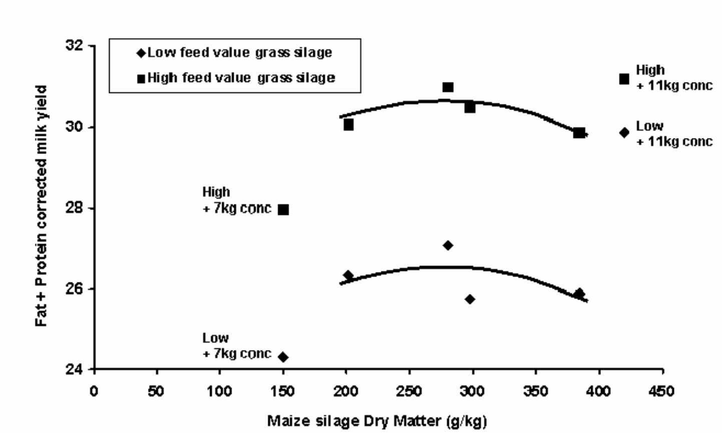

Figure 3 Effect of maize and grass silage feed value on fat plus protein corrected milk yield

However, whilst there were no interactions between maize silage and grass silage feed value for milk yield or composition, it was noted that the response to maize silage inclusion tended to decrease as grass silage feed value increased (Table 4).

Table 4 The effects of the addition of maize silage (40:60 maize silage:grass silage) to diets of differing grass silage feed value on performance of dairy cows

	Grass silage feed value		
	Low	Medium	High
Keady *et al*. (2002)			
Grass silage ME (MJ/kg DM)	9.80		11.84
Dry matter intake (kg/d)	2.25		0.54
Milk yield (kg/d)	+1.08		+0.58
Fat (g/kg)	+1.23		+1.97
Protein (g/kg)	+1.20		+0.37
Keady *et al*. (2003)			
Grass silage ME (MJ/kg DM)	10.17	10.96	11.99
Dry matter intake (kg/d)	+1.83	+1.44	-0.15
Milk yield (kg/d)	+1.38	+1.13	+0.38
Fat (g/kg)	+1.21	+0.84	+1.06
Protein (g/kg)	+1.01	+1.29	+0.16

Potential concentrate sparing effect of including maize silage

One of the potential benefits of including maize silage in the diet of lactating dairy cattle is the ability to maintain animal performance whilst reducing the level of concentrate supplementation required, consequently reducing the costs of production. Keady *et al*. (2002b; 2003) evaluated the potential concentrate sparing effects (reduction in the quantity of concentrates required due to the inclusion of maize silage in the diet to maintain animal performance) of maize silages, differing in stage of maturity at harvest, when offered with grass silages of contrasting feed value to lactating dairy cows. Grass silages offered as the sole forage were supplemented with either 7 or 11 kg concentrates/cow/d and it was assumed that any response in animal performance expressed as combined yield of fat plus protein to concentrate supplementation was linear between these two points. No interactions were observed between stage of maturity of maize silage at harvest or grass silage feed value on the concentrate sparing effect of maize silage. In the study of Keady *et al*. (2002b) the mean concentrate sparing effects for the maize silages, included as 0.40 of the forage proportion of the diet, with dry matter concentrations of 202, 280, 298 and 398 g/kg when determined for fat plus protein yield are presented in Figure 4, and were 2.1, 3.4, 2.1 and 2.0 kg fresh weight respectively. Similarly, Keady *et al*. (2003) concluded the mean concentrate sparing effects for maize silage, included as 0.4 of the forage proportion in grass silage-based diets, with dry matter concentrations of 189, 249, 362 and 429 g/kg when determined for fat plus protein yield were 2.8, 3.1, 2.6 and 2.6 kg fresh weight respectively. In this study a greater concentrate sparing effect was observed as grass silage feed value declined, with concentrate sparing effects of 3.3, 2.6 and 2.5 kg fresh weight for low, medium and high feed value grass silages respectively. More recently, Patterson & Kilpatrick (2005) reported a potential concentrate sparing effect of 5.0 kg fresh weight for maize silage (DM = 305 g/kg) included as 0.50 of the forage proportion of high feed value (ME = 11.6 MJ/kg DM) grass silage-based diets offered to lactating dairy cows.

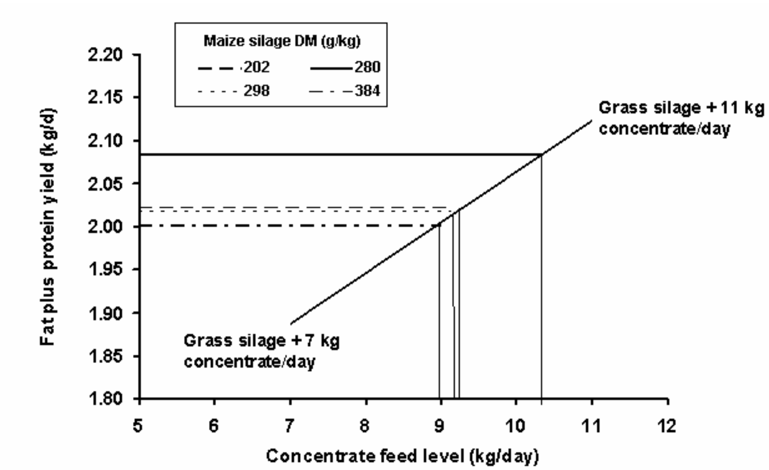

Figure 4 Effect of maize silage dry matter content on potential concentrate sparing effect

With beef cattle, Keady & Kilpatrick (2004) concluded that replacing 0.4 of the forage component of grass silage-based diets with maize silage had a concentrate sparing effect of greater than 2 kg/d.

In production systems where animal product output is limited due to quotas, or concentrate prices are excessively expensive relative to forage, maize silage inclusion in the diet can enable animal performance to be maintained whilst considerably reducing the level of concentrate input.

Effect of whole crop wheat inclusion on animal performance

There has been an increased interest in the production of whole crop cereal silage for feeding to beef and dairy cattle in recent years. The increased interest in this crop is due primarily to the similar cost of production relative to grass silage (Table 1) and the perceived potential benefits in forage intake and subsequently animal performance. Whole crop wheat is predominantly ensiled and fermented at dry matter concentrations ranging from 250 to 450 g/kg. However, whole crop wheat can also be ensiled at high dry matter concentrations ranging from 550 to 800 g/kg and treated with either urea or a urea-based additive to encourage an alkaline environment. Recent developments in the ensiling of whole crop cereals involves the ensiling of crops at high dry matter concentrations (700-800 g/kg), harvested through a forage harvester fitted with a grain processor and ensiled with a urea-based additive. Including whole crop wheat significantly increased the quantity of forage by 1.1 kg DM/kg fat plus protein yield.

The effects of including of whole crop wheat in grass silage-based diets on feed intake and performance of lactating dairy cows from 20 comparisons are presented in Table 5. Including whole crop wheat in dairy cow diets did not significantly alter the yields of milk or fat plus protein, or the concentrations of milk fat or protein. However whole crop wheat inclusion increased feed intake by 2.3 kg DM/d to produce milk solid output. When the 20 comparisons were subdivided into datasets depending on whether the whole crop wheat was either fermented or urea/alkalage treated whole crop wheat inclusion resulted in an increased feed intake of up to 2-3 kg DM/cow/d but had no beneficial effects on milk yield or fat plus protein yield or milk fat and protein concentrations. Furthermore, when including fermented whole crop wheat in grass silage-based diets, milk fat concentration was significantly decreased.

The effects of including whole crop wheat in grass silage-based diets on feed intake and performance of finishing beef cattle based on seven comparisons, is presented in Table 6. Including whole crop wheat in grass silage-based diets increased feed intake by 1.4 kg DM/d but did not alter carcass gain or liveweight gain of finishing beef cattle. When the seven comparisons were sub-divided into datasets depending on whether the whole crop wheat was fermented or urea treated/alkalage treated, whole crop wheat inclusion increased forage intake by 1.2 and 1.6 kg DM/d respectively but did not affect animal performance.

The results of the data presented in Tables 5 and 6 indicate that whilst whole crop wheat inclusion in the diet increased feed intake, it had no beneficial effects on animal performance. A number of studies (Leaver & Hill, 1995; Sutton *et al*., 2002; Keady & Kilpatrick, 2004) have shown that whole crop wheat has high intake characteristics, but lower ME concentration relative to most grass silages.

Levels of inclusion

When including an alternative forage in the diets of beef or dairy cattle, level of inclusion may impact on the optimum level of animal performance achieved. A number of studies have been undertaken (Hill & Leaver, 1990; Phipps *et al*., 1992a) to evaluate the effect of level of inclusion of whole crop wheat in grass silage-based diets on the performance of dairy cows.

Phipps *et al*. (1992a) replaced low feed value grass silage (organic matter digestibility = 658 g/kg DM) with either 0.25, 0.50, 0.75 or 1.0 whole crop wheat (DM = 515 g/kg) and concluded that whilst the inclusion of whole crop wheat increased feed intake it did not alter milk yield or protein concentration. Hill & Leaver (1990) replaced whole crop wheat with either 0.22 or 0.44 low feed value grass silage (ME = 10 MJ/kg DM) and concluded that increasing the proportion of grass silage in the diet increased milk yield but did not alter milk composition. These authors concluded that with mixed forage-based diets, inclusion of whole crop wheat did not improve animal performance, but if included in the diet, it should account for a low proportion of the forage DM component. Sutton *et al*. (1997) concluded that replacing medium feed value grass silage (DMD = 695 g/kg DM) with either 0.33 or 0.66 urea-treated whole crop wheat, had no effect on milk yield or protein concentration whilst feed intake was increased. However, inclusion of 0.33 whole crop wheat improved butterfat content. Sutton *et al*. (1997) concluded that the lack of response in milk yield with whole crop inclusion in the diet was due to reduced diet digestibility, particularly starch resulting from the egestion of whole wheat grains in the faeces. However, Jackson *et al*. (2004) ensiled whole crop wheat at a dry matter concentration of 700 g/kg either after the crop was passed through a harvester with or without a grain cracker and concluded that use of the grain cracker did not affect milk yield or composition of lactating dairy cows.

In studies with beef cattle, O'Kiely & Moloney (2002) replaced medium feed value grass silage (DMD = 732 g/kg DM) with 0.33, 0.67 or 1.00 of either a medium (380 g/kg) or high (519 g/kg) DM whole crop wheat silage. These authors reported that replacing 0.33 grass silage with either whole crop wheat increased carcass gain. However further inclusions of whole crop wheat did not significantly alter carcass gain.

Table 5 The effects of including whole crop wheat (WCW) with grass silage-based diets on the performance of dairy cows

Reference	Type	Grass silage (GS)		Whole crop (WCW)		GS:WCW	Forage intake (kg DM/d)		Milk (kg/d)		Fat (g/kg) (F)		Protein (g/kg) (P)		F+P (kg/d)	
		DM (g/kg)	ME (MJ/kg DM)	DM (g/kg)	Starch (g/kg DM)		GS	WCW	GS	WCW	GS	WCW	GS	WCW	GS	WCW
Sinclair *et al.*	F	252	11.7	296	52	33:67			29.8	30.1	40.9	40.9	32.1	30.7	2.15	2.14
(2003)	F	252	11.7	371	221	33:67			29.8	30.7	40.9	39.7	32.1	31.6	2.15	2.19
Leaver & Hill	F	243	11.3	353	20	60:40	9.4	11.1	28.0	28.7	40.4	40.5	31.3	31.3	2.01	2.06
(1995)	U	243	11.3	549	218	60:40	9.4	11.6	28.0	29.6	40.4	39.8	31.3	31.2	2.01	2.10
	F	237	11.4	372	23	67:33	11.7	12.1	30.0	29.1	41.9	41.0	32.5	31.9	2.24	2.12
	U	237	11.4	555	258	67:33	11.7	12.5	30.0	29.4	41.9	40.7	32.5	32.2	2.24	2.13
	U	237	11.4	549	258	67:33	11.7	12.5	30.0	29.9	41.9	41.4	32.5	32.5	2.24	2.21
Phipps *et al.*	F	213	10.9	323	11	67:33	9.3	10.6	23.0	24.2	41.7	41.7	29.9	30.8	1.62	1.73
(1995)	U	213	10.9	495	280	67:33	9.3	10.2	23.0	24.0	41.7	42.1	29.9	30.8	1.62	1.73
Hameleers	F	248	11.4	557	359	60:40	10.6	12.2	27.4	27.1	48.9	49.0	34.1	34.0	2.25	2.24
(1998)	U	248	11.4	791	373	60:40	10.6	13.1	27.4	26.9	48.9	48.1	34.1	34.3	2.25	2.21
Patterson *et al.* (2004)	F	187	11.2	316	209	60:40	7.9	9.6	25.8	26.5	39.8	39.0	30.9	31.3	1.82	1.86
Patterson &	F	185	10.7	459	350	50:50	10.4	11.2	27.9	28.3	40.7	40.1	30.8	31.1	1.96	1.96
Kilpatrick	F	234	12.5	459	350	50:50	12.5	13.3	31.5	31.0	38.5	37.8	32.8	32.9	2.23	2.14
(2005)	A	185	10.7	751	420	50:50	10.4	11.3	27.9	26.5	40.7	39.3	30.8	30.8	1.96	1.85
	A	234	12.5	751	420	50:50	12.5	13.8	31.5	30.9	38.5	39.8	32.8	33.2	2.23	2.26
Murphy *et al.*	F	240	10.5	406	282	33:67	8.8	12.8	27.6	29.7	39.6	38.4	30.7	31.7	1.93	2.07
(2004)	A	240	10.5	733	324	33:67	8.8	14.8	27.6	29.4	39.6	37.8	30.7	31.7	1.93	2.03
	F	231	10.9	370	323	33:67	8.7	14.3	30.8	32.8	36.7	36.2	29.7	30.8	2.05	2.19
	A	231	10.9	763	341	33:67	8.7	16.4	30.8	31.2	36.7	40.2	29.7	31.9	2.05	2.26
Mean (n = 20)		230	11.3	511	255		10.1	12.4	28.4	28.8	41.0	40.7	31.6	31.8	2.05	2.07
SED							0.50		0.23		0.256		0.17		0.021	
Significance							***		NS		NS		NS		NS	
Comparisons involving fermented WCW																
Mean (n = 11)							9.9	11.9	28.3	28.9	40.9	40.4	31.5	31.6	2.04	2.06
SED							0.57		0.29		0.15		0.23		0.025	
Significance							**		NS		**		NS		NS	
Comparisons involving urea treatment and alkalage																
Mean (n = 9)							10.3	12.9	28.5	28.6	41.1	41.0	31.6	32.1	2.06	2.09
SED							0.85		0.36		0.55		0.26		0.036	
Significance							*		NS		NS		NS		NS	

Table 6 The effects of including whole crop wheat with grass silage-based diets on the performance of beef cattle

		Grass silage (GS)	Whole crop (WCW)		GS:WCW	Forage intake (kg DM/d)		Carcass gain (kg/d)		Liveweight gain (kg/d)	
Reference	Type	DM (g/kg)	DM (g/kg)	Starch (g/kg DM)		GS	WCW	GS	WCW	GS	WCW
Keady & Kilpatrick (2004)	Fer	192	319	209	60:40	5.1	5.8	0.51	0.50	0.86	1.01
O'Kiely & Moloney (1995)	Fer	188	371		0:100	5.0	5.2	0.75	0.58	1.05	0.89
	Urea	188	456		0:100	5.0	5.5	0.75	0.53	1.05	0.89
O'Kiely & Moloney (2002)	Fer	191	381		33:67	4.8	6.0	0.64	0.70	0.87	0.98
	Urea	191	519		33:67	4.8	6.1	0.64	0.69	0.87	0.96
Walsh *et al*. (2005)	Fer	161	391		100:0	4.5	7.1	0.48	0.72	0.80	1.15
	Alk	161	705		100:0	4.5	7.6	0.48	0.69	0.80	1.13
Mean (n = 7)		182	449	209		4.8	6.2	0.61	0.63	0.90	1.00
SED						0.396		0.07		0.077	
Significance						**		NS		NS	
Comparisons involving fermented WCW											
Mean (n = 4)						4.9	6.1	0.58	0.62	0.89	1.01
SED						0.50		0.088		0.105	
Significance						NS		NS		NS	
Comparisons involving urea treatment and alkalage											
Mean (n = 3)						4.8	6.4	0.61	0.63	0.91	0.99
SED						0.75		0.127		0.141	
Significance						NS		NS		NS	

The majority of studies in the literature indicate that even with low feed value grass silage-based diets, inclusion of whole crop wheat either fermented or urea-treated, has little effect on animal performance.

Effect of stage of maturity

As with maize silage, the objective with whole crop wheat is to increase starch content and subsequently harvest as a mature crop. Whilst starch concentration of a cereal crop increases as it matures due to increased grain fill, the fibre concentration does not decrease significantly as a result of lignification of the straw and the accumulation of chaff. Delaying harvesting of the crop increased (O'Kiely & Moloney, 2002), had no effect (Leaver & Hill, 1995; Sutton *et al*., 2002) or reduced (Phipps *et al*., 1995; Sinclair *et al*., 2003) acid detergent fibre concentration but increased (Leaver & Hill, 1995; Phipps *et al*., 1995; Sinclair *et al*., 2003; Sutton *et al*., 2002) starch concentration.

A number of studies have been undertaken to evaluate the effects of stage of maturity and preservation method of whole crop cereals on performance of beef and dairy cattle. Sinclair *et al*. (2003) replaced 0.66 grass silage with fermented whole crop wheat with a dry matter concentration of either 296 or 371 g/kg dry matter content. These authors concluded that neither inclusion of whole crop wheat or stage of maturity at harvest affected milk yield or composition of dairy cows relative to a grass silage-based diet. Leaver & Hill (1995) in two studies replaced either 0.33 or 0.40 of grass silage with whole crop wheat with dry matter concentrations of 370 and 572 g/kg and 346 and 577 g/kg respectively and concluded that neither inclusion or stage of maturity of whole crop wheat affected milk yield or composition of lactating dairy cows.

Concentrate sparing effect

A number of studies (Keady & Kilpatrick, 2004; Patterson *et al*., 2004; Patterson & Kilpatrick, 2005) have been undertaken to determine the potential concentrate sparing effect of including whole crop wheat in grass silage-based diets. Keady & Kilpatrick (2004); Patterson *et al*. (2004) and Patterson & Kilpatrick (2005) reported non-significant potential concentrate sparing effects/head/d of 0 kg, 0.5 kg and 1.3 kg for whole crop wheat. These studies clearly indicate that if whole crop wheat replaces grass silage as the forage component of the diet, concentrate feed level should not be reduced if animal performance is to be maintained.

Comparison of maize and fermented whole crop wheat silages

A number of studies (Phipps *et al*., 1995; Hameleers, 1998; Patterson *et al*., 2004; Murphy *et al.,* 2004 and Patterson & Kilpatrick, 2005) have been undertaken to compare whole crop wheat and maize silages when included in grass silage-based diets of dairy cows. All of these authors concluded that including either maize or whole crop wheat increased feed intake. Phipps *et al*. (1995); Murphy *et al.* (2004 - in two comparisons), Patterson *et al*. (2004) and Patterson & Kilpatrick (2005) concluded that maize silage inclusion increased milk yield. Furthermore, Phipps *et al*. (1995) and Murphy *et al*. (2004) in one comparison reported increased milk protein concentration. However, when whole crop wheat was included, only Murphy *et al*. (2004) in one comparison reported increased milk yield and protein concentration.

The effect of replacing grass silage with either maize or fermented whole crop wheat silages on dairy cow performance is presented in Table 7. Including either maize or whole crop wheat in grass silage-based diets increased feed intake and forage conversion rate. However, while maize silage inclusion increased milk yield by 2.2 kg/cow/d whole crop wheat inclusion had no significant effect.

Table 7 Direct comparisons of replacing grass silage (GS) with either fermented whole crop wheat (WCW) or maize (MS) on dairy cow performance

	Forage intake (kg DM/d)			Milk yield (kg/d)[1]		
Reference	GS	WCW	MS	GS	WCW	MS
Phipps *et al.* (1995)	9.3	10.6	10.6	22.9	24.4	26.8
Murphy *et al.* (2004)	8.8	12.8	11.2	27.0	29.0	29.5
	8.7	14.3	13.2	28.5	30.6	32.9
Patterson & Kilpatrick (2005)	9.8	12.3	13.6	28.0	29.3	31.2
Patterson *et al.* (2004)	7.9	9.6	9.8	25.4	25.9	26.9
Hameleers (1998)	10.6	12.2	11.4	31.7	31.3	29.5
Mean (n = 6)	9.2[a]	12.0[b]	11.6[b]	27.3 [a]	28.4[ab]	29.5[b]
SED		0.58			0.71	
Significance		***			*	

[1]Fat plus protein corrected milk yield

In studies with beef cattle Keady & Kilpatrick (2004) observed that whilst maize inclusion increased carcass gain, whole crop wheat had no effect. However, Walsh *et al.* (2005) observed increased carcass gain from either maize or whole crop wheat silage-based diets.

In deciding which alternative forage to produce, the literature indicates that maize silage will increase animal product output. In contrast, whole crop wheat silage inclusion has not significantly affected either milk yield or carcass gain, whilst increasing forage intake and therefore potentially increasing the cost of production.

Conclusions

From an extensive review of the literature on the effect of including maize and whole crop wheat silages with grass silage-based diets it is concluded that:

1. High yields of maize can be achieved in marginal areas due to improvements in plant breeding and use of the complete cover plastic mulch (CCPM) system.
2. Maize silage can be produced and fed at a similar cost to grazed grass.
3. Including maize silage in the diet of dairy and beef cattle increases animal performance.
4. The optimum stage of maturity to harvest maize for ensiling is at a dry matter content of approximately 300 g/kg.
5. There is a negative relationship between maize silage dry matter content and milk fat concentration.
6. Including maize silage in the diet has a concentrate sparing effect of up to 5 kg/cow/d.
7. Whole crop wheat silage can be produced and fed to dairy cows at a similar cost to grass silage.

8. Including whole crop wheat silage in the diet increases feed intake but has no beneficial effect on animal performance. However additional forage intake is required to produce each kg of carcass from beef cattle or fat plus protein yield from dairy cows.
9. Ensiling whole crop wheat either fermented, urea-treated or as alkalage does not alter animal performance.

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