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Effect of age and nutrient restriction pre partum on beef suckler cow serum immunoglobulin concentrations, colostrum yield, composition and immunoglobulin concentration and immune status of their progeny

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The effect of cow age (multiparous (MP) v. primiparous (PP)) and nutritional restriction pre partum (grass silage *ad libitum* v. straw only *ad libitum* for the last 15 (s.d. 3.3) days of gestation) on cow serum immunoglobulin (Ig) concentration, on colostrum yield, composition and Ig concentration and on calf serum Ig concentrations (at ~8 and 48 h post partum) using spring-calving Limousin × Holstein-Friesian cows and their progeny was studied over 3 years. The method of colostrum administration (stomach tube vs. assisted suckling within 1 h post partum) on calf immune status was also investigated. When feeding colostrum the target was to give each calf 50 mL per kg birthweight via stomach tube. Colostrum yield and Ig concentration were measured following administration of oxytocin and hand-milking of half (Experiments 1 and 2) or the complete udder (Experiment 3). Following an 8-h period after birth during which suckling was prevented a further colostrum sample was obtained. There was no significant difference in first milking colostrum Ig subclass concentrations between the within-quarter fractions or between the front and rear quarters of the udder in either MP or PP cows. Colostrum Ig subclass concentrations at second milking were 0.46 to 0.65 of that at first milking. Compared to MP cows offered silage, colostrum yield and the mass of colostrum IgG_1, IgG_2, IgM, IgA and total Ig produced was lower ($P < 0.001$) for PP cows and the mass of IgG_1, IgM and total Ig produced was lower ($P < 0.05$) for

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MP cows offered straw. Calves from PP cows and MP cows offered straw had significantly lower serum IgG_1 and total Ig concentrations at 48 h post partum than calves from MP cows offered silage but there was no difference ($P > 0.05$) between colostrum feeding methods. In conclusion, calves from PP cows and MP cows offered straw had a lower humoral immune status than those from MP cows offered grass silage.

Keywords: beef suckler cow; colostrum; immunoglobulins

Introduction

Suckler cow systems depend on the production of a healthy calf. Morbidity and mortality of the young calf represent a major cause of economic loss for beef producers (Earley *et al.*, 2000). The importance of passive or humoral immunity, through absorption of colostral antibodies or immunoglobulins (Ig), to the survival and health of a newborn calf is well recognised (Roy, 1990; Barrington and Parish, 2001). Each of the major Ig subclasses namely immunoglobulin G (IgG_1 and IgG_2), immunoglobulin M (IgM) and immunoglobulin A (IgA) have a specific role to play in protecting the calf against disease or infection (Earley *et al.,* 2000). Ensuring that calves receive adequate passive immunity via colostrum ingestion reduces the incidence of disease and subsequent costs of morbidity and/or mortality.

In comparison to the dairy calf or bucket rearing systems there is a deficit of information in the scientific literature on beef suckler cow serum Ig concentration, colostrum yield, chemical composition, and Ig concentration and subsequent calf serum Ig status (McGee, Drennan and Caffrey, 2005a). In Ireland, colostrum management for the suckler calf is based on modified dairy calf guidelines.

While the literature shows that calves from older cows generally have a higher immune status than those from younger, and principally primiparous, cows (McGee, 1997), the explanation for and the quantification of this, particularly for beef suckler cows, is ambiguous. Feed restriction of beef suckler cows pre partum may adversely affect the immune status of their progeny (Hough *et al.*, 1990). Beef suckler cows with excess body condition are often severely feed restricted (straw diet) in the last 2 weeks pre partum in order to reduce potential calving difficulties (M.J. Drennan, personal communication). The effect of this feeding practice on level of passively acquired Ig in the calf has not been quantified.

The objectives of the experiments outlined here using spring-calving beef suckler cows over 3 years were to determine the effect of (i) cow age (primiparous v. multiparous) and (ii) severe nutrient restriction for the last 15 days pre partum (grass silage v. straw *ad libitum*) on cow serum Ig subclass concentrations, colostrum yield, composition and Ig concentration and subsequent humoral immune status of their calves. Additional aims were to evaluate the method of colostrum administration (stomach tube v. assisted suckling) on calf immune status and to determine the variation in colostrum Ig concentrations, within and between, quarters of the udder.

Materials and Methods

Treatments and animal management

Data were obtained over three consecutive experiments (years 1994

to 1996) using multiparous cows and replacement heifers at parturition from a spring-calving (commencing mid-February) Limousin × Holstein-Friesian suckler herd. Cows were serviced by a Simmental (artificial insemination) (AI) and a Charolais (natural mating) bull. The replacement heifers were bred to calve at 2 years of age and were serviced by an easy-calving Limousin bull (AI). Animals were accommodated in pens in a slatted floor shed and were offered second-cut grass silage *ad libitum* pre partum and received 60 g of a mineral and vitamin supplement per head (Ca, 45 g/kg; Na, 200 g/kg; Mg, 165 g/kg; Cu, 4250 mg/kg; Co, 90 mg/kg; I, 300 mg/kg; Mn, 6670 mg/kg; Zn, 5200 mg/kg; Vit. A, 600,000 iu/kg; Vit. D3, 100,000 iu/kg and Vit. E, 5000 iu/kg) applied daily on top of the forage. All animals had access to fresh water. The treatments were:

1. Multiparous (MP) cows offered grass silage *ad libitum* pre partum (n=36).
2. Multiparous cows offered straw only *ad libitum* for the last 15 (9 to 21, s.d. 3.3) days pre partum (n=26).
3. Primiparous (PP) cows offered grass silage *ad libitum* pre partum (n=21).

The immune status of calves from Treatment 1 was compared with that of calves from contemporary cows similarly fed but that suckled naturally rather than being artificially fed. Any calf not sucking within 1 h of birth was assisted (Treatment 4, n=14). This comparison was made in years 1 and 2 only.

The animals used in each year were the early-calving cows and their calves (single born) from a larger herd. Multiparous cows were randomly assigned to their respective treatments. Their average lactation number was 6.0 (s.d. 2.74) and post partum body condition score (scale 0–5) was 2.1 (s.d. 0.64). Approximately 14 days prior to the expected calving date cows assigned to treatment 2 were moved to straw-bedded calving pens and offered straw *ad libitum* plus a daily mineral and vitamin supplement. Cows in the remaining 2 treatments were moved from the slatted house prior to parturition (generally 1 to 4 days) and placed in straw-bedded calving pens and continued to receive the same diet.

Tincture of iodine (*Iodine Tincture B.P. (*Ovelle Ltd, Dundalk, Co. Louth, Ireland); Iodine 2.5% w/v, Potassium Iodide 2.5% w/v) was applied once to the umbilical cord of the calf immediately post partum. After the experimental protocol was implemented cows remained in the pens with the calf having free access to the dam. Multiparous cows received grass silage *ad libitum* while primiparous animals additionally received 1.5 kg per head of a barley-based concentrate daily. Due to a previously identified persistent outbreak of diarrhoea in the herd, a combined bovine rotavirus and *E. coli* vaccine (*Rotavec K99,* Schering-Plough Animal Health, Bray, Co. Wicklow, Ireland) was given to all cows by intramuscular injection between 4 and 12 weeks prior to expected calving date as part of the routine management.

Births were supervised to ensure that calves did not suckle the cow prior to implementing the experimental protocol.

Colostrum yield, sampling and feeding

For treatments 1, 2 and 3 the calf was weighed immediately following parturition, and the cow was put into a restraining pen and the calf placed at her head to allow grooming. Forty i.u. of oxytocin (*Oxytocin Leo,* Leo Laboratories Ltd., Dublin, Ireland) was given intramuscularly to the cow. In Experiments 1 and 2 one half of the udder was hand milked to completion. In Experiment 1, one

front and one rear quarter were milked out separately in three individual fractions consisting of approximately 0.25 L followed by a 0.5 L and the remainder treated as a third quantity (where applicable) and samples were obtained from each fraction. In Experiment 2, one front and rear quarter was milked out separately, 3 × 20 mL samples were retained for analyses and the volume of each quarter was recorded and combined and then multiplied by two to obtain an overall yield estimate. The objective was to feed each calf 50 mL of colostrum per kg birth weight. If the udder half did not yield sufficient the other quarters were milked out as required and a further 20 mL sample taken. All calves were then fed colostrum using a stomach tube (oesophageal feeder and bag), (*Tyco Healthcare* UK Ltd, Gosport, Hampshire, UK) within 1 h of birth. After feeding, a muzzle was placed on the calf to prevent suckling and the calf was left in the presence of the dam to avoid any adverse effect on Ig absorption (Fallon, Harte and Keane, 1989). At 8 h (±10 min) post feeding, a further colostrum sample was obtained (without oxytocin) from the previously milked half by hand milking approximately 100 mL from the front and back quarters and compositing it. The calf was then assisted to suckle for about 10 to 20 minutes as deemed necessary and left permanently, as normal, with the cow. In Experiment 3 the procedure was as described in Experiment 2 except that the entire udder was hand milked to completion. Colostrum in excess of the calf's allowance (if any) of 50 mL per kg birth weight was stored in an incubator at approximately 30 °C. At 8 h post feeding a further colostrum sample (without oxytocin) was obtained by hand milking out approximately 70 mL from each quarter and compositing it. The calf (27 out of 29) was then fed the excess colostrum, if any (0 to 4830 mL), from the first milking using a stomach tube and assisted to suckle if interested. Subsequently, the calf was left as normal with the cow. Some calves experienced discomfort coping with relatively large volumes (*circa* 4.0 L) at the second feeding. When any discomfort occurred, the stomach tube was withdrawn and the remaining volume was fed a further 8 h later. All colostrum samples were stored at –20 °C prior to analyses for Ig and composition.

Blood sampling

In Experiments 2 and 3 blood samples were obtained by jugular venipuncture every 2 weeks prior to morning feeding and at parturition using a plain 10 mL vacutainer. A blood sample was similarly obtained by jugular venipuncture from calves at 8 h (±10 min) post feeding and at 48 h (44 to 52 h) post partum in all three experiments. As precolostral calf serum is normally devoid of Ig (Halliday *et al.,* 1978; Field *et al.,* 1989) it was deemed unnecessary to blood sample the calf at birth. Although there is general agreement in the literature that Ig absorption closure in the calf occurs around 24 h post partum some studies have suggested later closure for individual subclasses (Langholz *et al.,* 1987). Consequently, it was decided to blood sample the calf at 48 h post partum. Blood samples were left at room temperature for 1 h followed by a period of approximately 24 h at 4 °C to permit clotting. They were subsequently centrifuged at 1600 g for 20 minutes and the serum samples were stored at approximately –20 °C prior to analysis for Ig.

Immunoglobulin absorption efficiency

In the artificially fed calves, efficiency of absorption at 8 h post feeding was cal-

culated for each Ig subclass by using the Ig concentration in serum to determine the circulating Ig mass in the calf divided by the Ig mass consumed by the calf. Mass of Ig in the calf was calculated by multiplying the concentration of serum Ig by the plasma volume. Plasma volume was presumed to be 7% of calf birth weight (Vann *et al.*, 1995). Mass of Ig fed was calculated from the colostrum volume × Ig concentration.

Chemical analysis

Colostrum composition was determined according to the methods outlined previously (McGee *et al.,* 2005a). Colostrum and serum IgG_1, IgG_2, IgM and IgA concentrations were determined using the single Radial Immuno-Diffusion (sRID) test as previously described (McGee *et al.,* 2005a). Ig concentrations in colostrum were determined on a fat-free sample obtained by centrifugation. Additionally, in order to permit direct comparisons with previous results from this centre, the zinc sulphate turbidity (ZST) test was performed on calf serum samples at 20 °C (McEwan *et al*., 1970) with turbidity readings carried out at 520 *nm* using a spectrophotometer. Feed analysis was carried out as described previously (McGee, Drennan and Caffrey, 2005b).

Statistical analysis

The objective was to supervise all calvings but this was not always possible. Unsupervised calvings and twin-bearing animals were omitted from the respective treatments. Due to difficulty in accurately predicting calving date, a number of cows assigned to treatment 2 also had to be excluded.

Cow blood data were analysed using the Proc MIXED procedure of the Statistical Analysis System Institute (SAS, 2001) with repeated measures. Remaining data were analysed using an analysis of variance using Proc GLM of SAS with terms for treatment, experiment, treatment × experiment and calf sex in the model. Calving day was included as a covariate. When significant effects due to treatments were detected, mean separation of pre-planned comparisons (Treatments 1 vs. 2; 1 vs. 3; 1 vs. 4) was conducted by the PDIFF option.

Results

The quality of the grass silage offered for Experiments 1, 2 and 3 and the quality of the straw offered in Experiments 2 and 3 are presented in Table 1.

Cow Ig concentration

Cow serum Ig subclass concentrations pre and post partum are presented in

Table 1. Chemical composition of silage and straw offered

Chemical composition	Experiment				
	1	2		3	
	Silage	Silage	Straw	Silage	Straw
Dry matter (DM) (g/kg)	230	184	-	278	-
In vitro DM digestibility (g/kg)	692	628	438	653	609
Acid detergent fibre (g/kg DM)	-	-	519	-	419
Crude protein (g/kg DM)	127	145	65	151	64

Figures 1 to 4. Compared to MP cows offered silage, serum IgG_1 and IgG_2 concentrations were lower ($P < 0.05$) both pre and post partum in PP cows but concentrations were not different ($P > 0.05$) for MP cows offered straw. Serum IgA concentrations were also lower pre-partum in PP cows compared to MP cows offered silage. Serum IgG_1 concentrations decreased pre-partum and increased post-partum ($P < 0.001$) for all three treatments. Cow serum IgG_2 concentrations

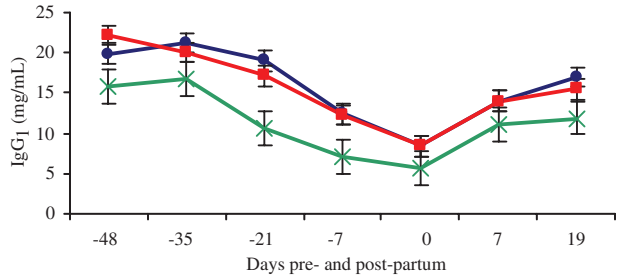

Figure 1: Serum IgG_1 concentration pre and post partum for multiparous cows offered silage (◆) or straw (■) and primiparous cows offered silage (×). Vertical bars = s.e.

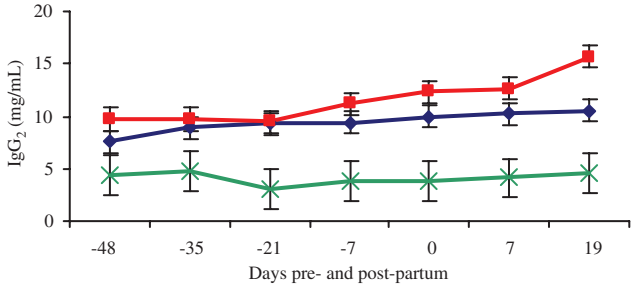

Figure 2: Serum IgG_2 concentration pre and post partum for multiparous cows offered silage (◆) or straw (■) and primiparous cows offered silage (×). Vertical bars = s.e.

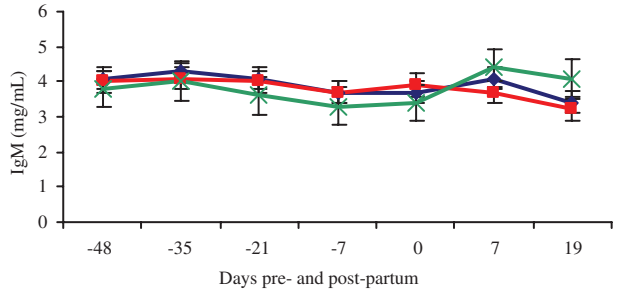

Figure 3: Serum IgM concentrations pre and post partum for multiparous cows offered silage (◆) or straw (■) and primiparous cows offered silage (×). Vertical bars = s.e.

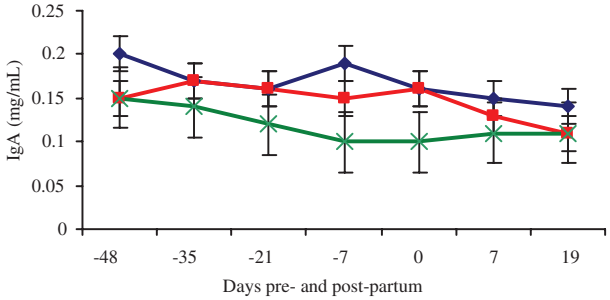

Figure 4: Serum IgA concentrations pre and post partum for multiparous cows offered silage (—◆—) or straw (—■—) and primiparous cows offered silage (—×—). Vertical bars = s.e.

increased ($P < 0.05$) pre-partum in MP cows but not in PP cows ($P > 0.05$). There was no effect of treatment on cow serum IgM concentrations.

Colostrum composition, yield, Ig concentration, Ig mass and colostrum feeding

There was no difference ($P > 0.05$) in first milking colostrum Ig subclass concentrations between the within-quarter fractions (Table 2) or between the front and rear quarters (Table 3) of the udder in either MP or PP cows. Colostrum yield, composition and Ig subclass concentrations are presented in Table 4. Colostrum yield was lower ($P < 0.001$) for PP cows than MP cows but there was no difference between MP cows offered

Table 2. Ig concentration (mg/mL) of within-quarter fractions of first milking colostrum for multiparous and primiparous cows

Ig subclass	Udder quarter	Within-quarter fraction[3]			s.e.
		1	2	3	
		Multiparous (n=13)[1]			
IgG_1	Front (F)	175.7	173.0	169.4	12.26
	Rear (R)	185.1	184.6	184.6	14.42
IgG_2	F	2.8	2.7	2.7	0.22
	R	3.1	2.9	2.9	0.26
IgM	F	10.5	10.2	9.6	0.74
	R	10.3	10.3	10.5	0.79
IgA	F	3.0	3.0	2.9	0.35
	R	3.1	3.2	3.3	0.40
		Primiparous (n=9)[2]			
IgG_1	F	147.6	143.0	-	8.73
	R	146.6	146.1	-	9.32
IgG_2	F	2.7	2.6	-	0.39
	R	2.7	2.6	-	0.41
IgM	F	10.1	9.6	-	0.87
	R	9.8	9.5	-	0.96
IgA	F	3.0	3.0	-	0.43
	R	2.9	3.0	-	0.43

[1]Only cows which yielded sufficient for three within quarter fractions.
[2]Data presented for 2 within quarter fractions as only 3 heifers yielded sufficient for a third quantity.
[3]Ig subclass concentrations were not significantly different between within-quarter fractions.

Table 3. Colostrum Ig concentrations (mg/mL) of the front and rear quarters of the udder

Cow type	Ig subclass	Quarter of udder[1]		s.e.
		Front	Rear	
Multiparous (n=18)	IgG_1	180.8	192.6	10.50
	IgG_2	3.5	3.6	0.54
	IgM	11.3	11.2	0.99
	IgA	3.3	3.6	0.33
Primiparous (n=12)	IgG_1	145.2	145.8	9.54
	IgG_2	2.7	2.7	0.39
	IgM	9.7	9.5	0.88
	IgA	3.0	3.0	0.41

[1]No significant differences were detected.

grass silage and straw. Chemical composition of the colostrum was similar among treatments with the exception of fat where there was a treatment × experiment interaction. Fat concentration was significantly higher in MP cows offered straw compared to silage in Experiments 1 and 2 but not in Experiment 3. There were no significant differences in first milking colostrum Ig subclass concentrations between MP cows offered grass silage and straw or between PP and MP cows offered grass silage. In the colostrum from the second milking, IgA concentrations were lower ($P < 0.01$) in PP cows. Colostrum Ig subclass concentrations at second milking were only 0.46 to 0.65 times that at first milking. At first milking, MP cows offered silage produced a greater ($P < 0.001$) mass of IgG_1, IgG_2, IgM, IgA and total Ig than PP cows and a greater ($P < 0.05$) mass of IgG_1, IgM and Ig total than MP cows offered straw. Mass of IgG_1, IgG_2, IgA and Ig total fed at birth, calf birth weight and volume of colostrum fed at birth were significantly lower for PP cows than MP cows offered grass silage. In Experiment 3, colostrum volume fed at 8 h was also lower ($P < 0.05$) for PP cows than for MP cows offered silage. There were no significant effects of pre partum nutrition of MP cows on these variables.

Calf serum Ig concentration and Ig absorption efficiency

Calf serum Ig subclass concentrations, ZST units and Ig absorption efficiency are presented in Table 5. Serum IgG_1 and Ig total concentrations were higher ($P < 0.05$) in calves from MP cows offered silage than in calves from MP cows offered straw or PP cows at both 8 and 48 h post partum. There was no significant difference in serum Ig subclass concentrations at 48 h post partum between calves that received colostrum via stomach tube or via assisted suckling; the mean (s.e.) values were 60.4 (4.80), 0.9 (0.16), 3.6 (0.49), 0.7 (0.19) and 65.6 (5.07) mg/mL for IgG_1, IgG_2, IgM, IgA and total Ig, respectively, and 27.3 (1.91) ZST Units. The difference between 8-h and 48-h serum Ig total concentrations was greater ($P < 0.05$) for calves from MP cows offered grass silage than calves from PP cows but there was no significant difference between the MP cow treatments. The absorption efficiency of the Ig subclasses did not differ significantly between treatments.

Table 4. Cow colostrum yield, chemical composition, Ig subclass concentration, Ig mass, calf birth weight and colostrum volume fed (s.e.) for Experiments 1, 2 and 3 combined

	Multiparous silage (1)	Multiparous straw (2)	Primiparous silage (3)	Significance	
				1 v. 2	1 v. 3
No. of animals	36	26	21		
Colostrum yield (mL)	4517 (233.3)	3901 (279.2)	2539 (316.1)		***
Chemical composition – first milking					
Dry matter (g/kg)	285 (65)	285 (79)	274 (88)		
Crude protein (g/kg DM)	184 (6.5)	179 (7.9)	166 (8.8)		
Ash (g/kg DM)	11 (0.3)	10 (0.4)	11 (0.4)		
Fat (g/kg DM)	55 (3.0)	70 (3.7)	64 (4.1)	**[1]	
Lactose (g/L)	26 (1.0)	26 (1.2)	30 (1.3)		
Ig concentration (mg/mL)					
First milking					
IgG_1	190.4 (8.16)	180.6 (9.76)	165.4 (11.04)		
IgG_2	3.2 (0.26)	3.6 (0.30)	2.7 (0.34)		
IgM	10.6 (0.64)	9.3 (0.76)	11.3 (0.86)		
IgA	3.5 (0.23)	3.3 (0.28)	2.6 (0.32)		
Ig Total	206.4 (8.51)	195.5 (10.2)	181.0 (11.53)		
Second milking					
IgG_1	106.5 (6.74)	95.8 (8.06)	79.9 (9.29)		
IgG_2	2.1 (0.25)	1.9 (0.29)	1.5 (0.34)		
IgM	6.0 (0.55)	4.9 (0.66)	6.0 (0.76)		
IgA	1.9 (0.16)	1.7 (0.19)	1.2 (0.22)		**
Ig Total	116.4 (7.3)	104.3 (8.74)	88.6 (10.08)		
Ig mass produced (g) – first milking					
IgG_1	824 (39.7)	673 (47.6)	401 (53.8)	*	***
IgG_2	14 (1.0)	14 (1.2)	6 (1.3)		***
IgM	45 (2.4)	36 (2.8)	27 (3.2)	*	***
IgA	15 (1.1)	12 (1.3)	6 (1.5)		***
Ig Total	862 (42.0)	730 (50.2)	438 (56.9)	*	***
Ig mass fed at birth (g)					
IgG_1	400 (18.2)	372 (22.1)	285 (24.6)		**
IgG_2	6.5 (0.51)	7.3 (0.61)	4.6 (0.68)		*
IgM	22.0 (1.12)	19.3 (1.36)	19.4 (1.52)		
IgA	7.2 (0.49)	7.7 (0.59)	4.6 (0.68)		**
Ig Total	434.0 (18.9)	403.3 (23.0)	311.3 (25.6)		**
Calf birth wt (kg)	43.7 (0.76)	43.8 (0.87)	37.5 (0.96)		***
Volume fed at birth (mL)	2115 (53.2)	2070 (64.6)	1737 (72.0)		***
(mL/kg birth weight)	48.4 (0.90)	47.2 (1.10)	46.1 (1.22)		
Volume fed at 8-h[2] (mL)	2074 (329.6)	2285 (377.2)	785 (491.4)		*
(mL/kg birth weight)	49.8 (8.06)	51.8 (9.23)	22.1 (12.02)		

[1]Treatment × Experiment interaction.
[2]Applies to Experiment 3 only.

Table 5. Calf serum Ig subclass concentrations and Zinc Sulphate Turbidity (ZST) levels at 8 and 48-h post partum and Ig absorption efficiency (s.e.)

	Multiparous silage (1)	Multiparous straw (2)	Primiparous silage (3)	Significance	
				1 v. 2	1 v. 3
No. of animals	36	26	21		
Ig concentration (mg/mL) at 8 h					
IgG_1	48.3 (2.06)	41.9 (2.51)	40.2 (2.80)	*	*
IgG_2	0.8 (0.07)	0.9 (0.08)	0.6 (0.09)		
IgM	3.4 (0.20)	3.1 (0.25)	3.2 (0.28)		
IgA	1.0 (0.09)	0.9 (0.11)	1.0 (0.12)		
Ig Total	53.4 (2.19)	46.7 (2.66)	45.0 (2.96)	*	*
ZST units	14.5 (0.84)	16.3 (1.05)	16.0 (1.13)		
Ig concentration (mg/mL) at 48 h					
IgG_1	59.3 (2.66)	50.1 (3.15)	45.7 (3.45)	*	**
IgG_2	1.0 (0.09)	1.0 (0.10)	0.70 (0.11)		
IgM	3.9 (0.29)	3.3 (0.32)	3.2 (0.35)		
IgA	1.0 (0.10)	0.90 (0.12)	0.9 (0.14)		
Ig Total	65.1 (2.82)	55.2 (3.34)	49.9 (3.66)	*	**
ZST units	24.4 (1.07)	21.0 (1.29)	20.0 (1.37)	*	**
Ig absorption efficiency at 8 h					
IgG_1	0.38 (0.018)	0.36 (0.022)	0.37 (0.023)		
IgG_2	0.38 (0.019)	0.34 (0.023)	0.36 (0.026)		
IgM	0.47 (0.027)	0.49 (0.033)	0.44 (0.037)		
IgA	0.42 (0.041)	0.43 (0.050)	0.56 (0.057)		
Ig Total	0.38 (0.017)	0.37 (0.021)	0.38 (0.024)		

Discussion

The silage offered was of moderate to low dry matter digestibility (DMD) across the three experiments. The DMD of the straw in Experiment 2 was 438 g/kg, which is a typical value for straw while that of Experiment 3 was far above average. Visual inspection indicated that some grass was included in this straw. There was no chemical analysis for the straw in Experiment 1 but visually it was similar to that in Experiment 2. This is supported somewhat by the fact that in Experiments 1 and 2, a number of cows on the straw-only diet suffered from constipation and 4 cows had to receive a laxative under veterinary supervision. This did not occur in Experiment 3.

Cow serum Ig subclasses

The significant decrease in cow serum IgG_1 pre-partum in association with colostrogenesis concurs with previous results obtained with beef × Friesian cows at this centre (McGee *et al.*, 2005a) and with studies in the literature (Guy *et al.,* 1994; Barrington *et al.,* 2001*).*

Transfer of IgG_1 to the colostrum was not significantly affected by feeding straw. This may partly be attributed to the fact that the straw was introduced in the last 15 days of gestation and IgG_1 concentration had started declining between 35 and 21 days pre-partum. It is suggested that cows have a well-developed capacity to maintain the homeostasis of their humoral

immune system during nutritional restriction (Olson *et al*., 1981). The subsequent increase in IgG_1 in MP cows post-partum and increase in IgG_2 concentrations both pre- and post-partum agrees with the previous studies from this centre (McGee *et al*., 2005a) and the literature (Williams and Millar, 1979).

The significantly higher serum concentrations of IgG_1, IgG_2 and IgA in MP cows compared to PP cows is consistent with previous reports where older cows have higher total Ig concentrations than younger cows (Norman *et al*., 1981; Devery-Pocius and Larson, 1983).

Colostrum yield, composition, Ig concentration and Ig mass

The effect of nutritional restriction on colostrum yield of suckler cows is not well documented. The studies that have investigated energy and/or protein restriction pre partum were usually long-term, with restriction periods in excess of 80 days compared to the 15-day period imposed here. In those studies, the restricted cows had significantly lower (Logan, 1977) or as in the present experiments numerically lower (Petrie, Acres and McCartney, 1984) colostrum yields. The ability of a cow to mobilize body reserves during periods of nutrient restriction may be a factor. The lower colostrum yield in heifers compared to mature cows agrees with literature reports in dairy (Kruse 1970; Devery-Pocuis and Larson, 1983) and suckler (Langholz *et al.*, 1987) cows.

The similar colostrum CP concentrations between the treatments reflected the similar Ig total concentrations. The higher fat concentration in colostrum from MP cows offered straw compared to those offered silage in Experiments 1 and 2 is consistent with the increase in milk fat concentration observed in dairy cows offered high fibre diets (Sutton and Morant, 1989). The absence of a significant difference between the treatments in Experiment 3 is in accord with the superior nutritional quality of the straw offered.

The similar Ig concentrations of within-quarter fractions of first milking colostrum is in agreement with work in dairy cows by Stott, Fleenor and Kleese (1981) and confirms that the same is true for suckler cows. The comparable Ig concentrations in the front and rear quarters of the udder agrees with results of Halliday *et al.* (1978) for beef cows but not with those of Langholz *et al.* (1987) where Ig concentrations were higher in the rear quarters. The data in the present study clearly illustrate that when assisting a calf to suckle or milking colostrum from a cow it does not matter which teat is suckled or milked, or whether first or last milk from the first milking of the teat is used. This has important practical implications as it is easier to assist the calf to suckle the front quarters because it is naturally inclined to do so (Langholz *et al.*, 1987). The importance of first milking colostrum was clearly demonstrated and agrees with previous results (McGee *et al.,* 2005a) where all Ig subclass concentrations in second milking colostrum were substantially less than concentrations in first milking.

The similar colostrum Ig subclass concentrations between MP cows offered silage or straw agrees with most studies of energy and/or protein (usually >80 days) restriction (e.g., Logan, 1977; Halliday *et al.*, 1978; Delong *et al.*, 1979; Blecha *et al.,* 1981; Olson *et al.*, 1981; Hough *et al.*, 1990). The non-significantly lower colostrum Ig subclass concentrations in PP compared to MP cows is in general agreement with Delong *et al.* (1979) working with beef cows. This contrasts with the literature on dairy breeds where colostrum

Ig concentrations are generally lower in PP than MP cows (McGee, 1997).

Calf serum Ig concentration and absorption efficiency

The objective of the feeding procedure used was to give all calves a similar colostrum volume relative to birth weight at a fixed time after birth (within 1 h). Colostrum was fed by stomach tube as it is quicker than trying to encourage a calf to drink from a bucket or nipple but more importantly it guaranteed that the calculated volume offered was consumed. Despite different routes prior to absorption, studies have shown only slightly lower or non-significant effects on serum IgG concentrations in calves fed colostrum with a stomach tube compared to a nipple bottle (Quigley and Drewry, 1998).

Despite receiving a similar colostrum IgG_1 mass, serum IgG_1 concentrations were significantly lower at 8 h (and 48 h) post feeding in calves from MP cows that received straw than those from MP cows that received silage. There are inconsistent effects of dam nutrition on calf immune status in the literature (McGee, 1997; Lake *et al*., 2006) and the degree of control over the colostrum feeding regime varies widely. Blecha *et al*. (1981) reported that maternal protein restriction of primiparous beef cows during the last trimester of gestation significantly reduced the ability of calves to absorb IgG_1 and to a lesser extent IgG_2 but not IgM from colostrum. Hough *et al*. (1990) found that the ability of calves to absorb IgG *per se* was not altered by maternal energy and protein restriction, but that calves fed colostrum from restricted cows tended to have lower serum IgG concentrations at 24 h post partum. They suggested the involvement of some unmeasured factor in colostrum.

The lower serum IgG_1 and Ig total concentrations at 48 h post partum in calves from PP than from MP cows is in agreement with other reports (Muggli *et al*., 1987; Langholz *et al*., 1987). This reflected the lower Ig mass produced by these animals primarily attributed to a lower colostrum yield. Likewise, the greater increase in Ig total concentrations between 8 h and 48 h in calves from MP cows offered silage than in calves from PP cows reflected the much greater (almost double) Ig mass produced by the former.

The similarity in serum Ig concentrations at 48 h post partum between calves that were assisted to suckle and those that were fed colostrum via stomach-tube suggests that the colostrum feeding procedure used is an alternative strategy to attain a comparable immune status to a well-managed suckling situation where the calf suckles within 1 h of birth. The latter is very important as delaying the time of first colostrum ingestion adversely affects Ig absorption (Bush and Staley, 1980). In practice, time to first suckling without assistance in suckler herds is greater than 1 h and while it generally ranges from 60 to 260 minutes (Le Neindre and Vallet, 1992) it can be much longer (Langholz *et al.,* 1987). Furthermore, the time to naturally suckle to satiation or suckle a volume equivalent to what was fed in the present study takes between 20 and 26 minutes (Selman, McEwan and Fisher, 1971; Langholz *et al.*, 1987). These factors are likely to be exacerbated in PP cows where poorer mothering and incidences of attacking or avoiding calves is greater than in MP cows combined with poorer motility and vigour in calves from PP cows (Selman, McEwan and Fisher, 1970 a,b; Langholz *et al.,* 1987).

Furthermore, while research that has measured the intake of IgG by calves that were allowed to suckle the dam early have reported that IgG absorption efficiency was better than for calves artificially fed (nipple

bottle), suckled calves, in addition to consuming colostrum later, often consume less colostrum than artificially fed calves in practice (Quigley and Drewry, 1998).

It is generally recommended to feed 4.0 L of colostrum to dairy calves as soon as possible after birth (Quigley and Drewry, 1998). Drennan (1993) advised that the beef suckler calf should receive adequate colostrum (at least 3 L) within 4 h of birth. However, this would not always be possible with lower yielding cow genotypes (McGee *et al.,* 2005a) or primiparous cows. From a practical perspective, feeding colostrum within 1 h post partum at a rate of 50 mL/kg birth weight provided a large proportion ($\geq$0.8) of 48 h Ig concentration. This finding is consistent with previous research at this centre (McGee *et al.*, 2005a). Reports in the literature have shown that on average, at first feed, a calf will voluntarily drink between 1.9 and 2.7 L from a bucket, suckle between 1.6 and 2.6 L from a nipple bottle, or voluntarily suckle from its dam between 1.5 and 2.5 kg of colostrum (McGee, 1997). The quantity of colostrum fed at birth in the present study broadly falls within the range reported. As intake of a second feed of colostrum is generally only about half that of a first feed, when calves are artificially fed (Fallon *et al.,* 1989) or when suckling naturally (Selman *et al.,* 1971), the additional feed given to calves from MP cows at 8 h post feeding in Experiment 3 is probably greater than would be achieved under natural suckling conditions.

The incidence of disease was low and sporadic in the present studies. This can be partly attributed to the fact that cows were vaccinated prior to parturition which enhances colostral immunity and protects the calf from the specific disease (Castrucci *et al.*, 1989) in combination with a hygienic environment and careful stock management. Besides serum Ig concentration, many other interactive factors determine the occurrence of disease in calves (Barrington and Parish, 2001; Filteau *et al.,* 2003).

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