Available online at www.sciencedirect.com
ScienceDirect
Livestock Science 120 (2009) 1 – 12
LIVESTOCK SCIENCE
www.elsevier.com/locate/livsci

Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems

M.J. Drennan, M. McGee *

Teagasc, Grange Beef Research Centre, Dunsany, Co. Meath, Ireland

Received 15 February 2008; received in revised form 10 April 2008; accepted 16 April 2008

Abstract

The performance of rotationally grazed beef suckler cows and their progeny to slaughter on two lowland grassland management systems differing in stocking rate (SR) and fertiliser nitrogen (N) level was compared over eight years. The two Systems were 1) Intensive (INT): SR of 0.56 (bull production) or 0.71 (steer production) ha cow^{-1} unit, 211 kg fertiliser N ha^{-1}, two silage harvests, and 2) Extensive (EXT): SR of 0.69 (bull production) or 0.88 (steer production) ha cow^{-1} unit, 97 kg fertiliser N ha^{-1} and one staggered silage harvest. A cow unit was defined as a cow plus progeny to slaughter. On the silage harvesting area, the mean application rate for fertiliser N was 110 and 80 kg ha^{-1} for first and second harvests, respectively. Herbage dry matter digestibility both pre- and post-grazing was similar ($P>0.05$) for the two systems, whereas herbage crude protein concentrations were generally significantly lower for the EXT than the INT system. There was no difference ($P>0.05$) between the Systems in cow live weight, body condition score or their changes or in calf live weight gain from birth to weaning. Post-weaning, live weight gain, slaughter weight, carcass weight, kill-out proportion, estimated carcass gain, carcass conformation score or carcass fat score did not differ ($P>0.05$) between the systems for heifer, steer or bull progeny. It can be concluded that similar animal performance levels can be expected in an extensive grassland-based suckler calf-to-beef system compatible with the EU, Rural Environmental Protection Scheme as that attained in a more intensive System comprising of both a moderately high SR (~1.25 higher) and fertiliser N application (~2.1 higher).

Keywords: Beef suckler cow; Cattle; Extensification; Grassland management systems

1. Introduction

In many parts of Northern and Western Europe, current climatic conditions dictate that grass, either grazed or conserved, is the principal forage for beef cow and calf (suckler beef) production. Beef suckler cows are kept in a wide range of lowland nutritional environments, varying from high stocking rates (SR) and high inputs of nitrogenous (N) fertiliser to lower variable input systems with low SR, low inputs of N and potentially only one silage (or hay) harvest.

When maximising beef output per hectare was most profitable, the recommended level of N use was in the range of 200 to 250 kg N per hectare for most moderately

* Corresponding author. Tel.: +353 46 9061100; fax: +353 46 9026154.
E-mail address: Mark.Mcgee@teagasc.ie (M. McGee).

1871-1413/$ - see front matter
doi:10.1016/j.livsci.2008.04.013

intensive commercial cattle farms (Keane and Allen, 1999). Extensive beef farming has been encouraged by financial incentives such as the EU Rural Environmental Protection Scheme (REPS) (Crosson et al., 2006) and also to develop production systems involving lower inorganic fertiliser Nitrogen input. Many farmers would thus need to operate to lower input criteria than heretofore, as determined by environmental legislation such as the Nitrates Directive of the European Union (EU) (Directive 91/676/EEC) and (or) stipulated in REPS. Consequently, grassland management systems may reduce in intensity and thus, there is a need to develop more extensive, REPS-compatible, systems of suckler beef production.

Within the context of a grassland-based spring-calving suckler beef production system, matching grass supply to animal requirements during the grazing season, while ensuring sufficient silage is produced for the indoor winter period, is largely achieved by balancing the use of fertiliser N and SR by altering the emphasis on harvesting grass by grazing or as silage. Thus, whereas harvesting grass for silage facilitates the concurrent and subsequent utilisation of grass by grazing (McGee, 2005), and the use of two silage harvests have traditionally been advocated for moderately intensive spring-calving suckler beef production systems (Drennan, 1993) the considerable cost often associated with a second-harvest silage (O'Kiely et al., 1997) makes it necessary to consider replacing the two-harvest system with a simpler one-harvest system. Previous research has suggested the possibility of a lower fertiliser N grass-based system involving one, staggered silage cut particularly, where qualification for REPS is dependent on moderate stocking densities (Drennan and McGee, 2008).

Most published research has focused on individual aspects or segments of beef systems despite the fact that outcomes of one phase are often altered by subsequent phases and consequently, there is a need to evaluate integrated systems from birth-to-slaughter (Lewis et al., 1990; Drouillard and Kuhl, 1999; Anderson et al., 2005). Furthermore, in comparison to grass-based systems for dairy cows (Dillon et al., 2006) and dairy calf-to-beef production (Keane and Allen, 1998, 1999; Thenard et al., 2006) there is relatively little information pertaining to rotationally grazed, temperate, lowland grassland suckler calf-to-beef systems.

The objective of this study was to compare two lowland grassland management systems differing in SR and fertiliser N level on the performance of rotationally grazed beef suckler cows and their progeny to slaughter. The underlying hypothesis was that, compared to a high SR and high fertiliser N input (intensive system), reducing the input of fertiliser N combined with a low SR would result in similar individual animal performance during the grazing season to the intensive system. Additionally, a lower SR would permit adequate grass silage to be produced from one as opposed to two harvests thereby reducing costs.

2. Materials and methods

The study was conducted at Teagasc, Grange Beef Research Centre (Longitude 6° 40' W; Latitude 53° 30' N; Elevation 92 m asl) over a period of 8 consecutive years (1997–2004), each year comprising a summer grazing period (April to October/November) and the subsequent indoor winter feeding period. The soil type was a moderately well drained Brown Earth of medium to high base content and of clay loam texture (Gardiner, 1962). Meteorological data were obtained at the recording station at Grange Research Centre. The instruments and standards used by Irish weather stations were described by Fitzgerald and Fitzgerald (2004). Grass production was measured annually in a separate plot experiment as described by O'Riordan (1997) involving a cutting regime to a 4 cm stubble height on a 4-week cycle using an annual fertiliser N input of 300 kg ha^{-1}.

2.1. Animals

The animals used were spring-calving (commencing mid-February) beef suckler cows consisting of Limousin × Holstein–Friesian (LF) and Simmental × (Limousin × Holstein–Friesian) (SLF) for the first four years. Primiparous animals were introduced in 2001 and 2002 which, in addition to LF and SLF, included Limousin × (Limousin × Holstein–Friesian), purebred Limousin and purebred Charolais. Mature cows were mated to Charolais or Simmental sires and replacement heifers were bred to calve at 2 years of age using a Limousin sire. The breeding season commenced each year in May, primarily by artificial insemination. Average cow parity was 2.7 (s.d. 1.91) and calving date was 27 March (s.d. 26.7 days).

2.2. Grassland management systems

The two Systems were 1) Intensive (INT): SR of 0.56 (bull production) or 0.71 (steer production) ha cow^{-1} unit, 211 kg fertiliser N ha^{-1}; two silage harvests, and 2) Extensive (EXT): SR of 0.69 (bull production) or 0.88 (steer production) ha cow^{-1} unit, 97 kg fertiliser N ha^{-1} and one silage harvest (Table 1). A cow unit was defined as a cow plus her progeny to slaughter. The SR of the INT system was 0.25 higher than the EXT System. The EXT system was designed to be compatible with REPS where maximum permissible levels of organic (including grazing deposition) N and total N (inorganic and organic) were 170 and 260 kg ha^{-1}, respectively, (Council Regulation (EC) No. 1257/1999 as amended by Council Regulation (EC) No. 1783/2003–5 February 2004). The total number of cows was 40, 72, 76, 72, 98, 98, 94 and 84 for the years 1997 to 2004, respectively.

For the first two years of the study (1997 and 1998) the heifer progeny were slaughtered at about 20 months of age in November and the male progeny were slaughtered as steers at about 24 months of age in March. In Year 3 (1999) and subsequently, the production of male progeny was changed from steer to bull production with slaughter age at about 15 months of age. Additionally, in 1999 and 2000 a high proportion of the heifer progeny were retained for breeding and thus, post-weaning data for those animals was unavailable for those two years.

2.3. Experimental area

The experimental area was a permanent grassland site comprising in total up to a maximum of 66 ha. The maximum number of paddocks was 76, grouped into 19 sets of four of equal size (balanced for location and soil type) and randomly assigned to two grazing management Systems. Because of differences in cow (and progeny) numbers annually, the area of land used changed accordingly. At pasture there were 2 replicates per System for the cows and calves (4 herds), whereas the Systems for the yearlings were not replicated (2 herds). Average paddock size was 1.02 ha (ranged from 0.56 to 1.42 ha) and each paddock had its own water supply. The same total area of land was assigned to each System so consequently, in order to achieve the required SR, the number of cow units on the INT system was 1.25 of the EXT system. The paddocks assigned to grazing and silage harvesting were generally the same over the duration of the study. The allocation of cows to the Systems was random within genotype as they calved and did not take account of the treatments imposed in previous years (Wright et al., 1994; Drennan and McGee, 2004, 2008). The progeny remained within their allocated Systems until slaughter but were offered the same silage to avoid the possibility of differences between Systems from factors not associated with the treatments such as preservation quality. The cows were offered the grass silage from their respective treatments for Years 1 to 4 but subsequently, for logistic reasons, were offered the same grass silage.

Table 1
Summary of the intensive and extensive calf-to-beef grassland management systems

	Grassland management system	
	Intensive	Extensive
Stocking rate (ha cow^{-1} unit)		
Steer+heifer production	0.71	0.88
Bull+heifer production	0.56	0.69
Annual fertiliser nitrogen (kg ha^{-1})	211	97
Steer+heifer production	210	102
Bull+heifer production	214	94
Number of silage harvests	2	1
Age of animals when finished (months)		
Heifers	20	20
Steers or (Bulls)	24 (15)	24 (15)

2.4. Fertiliser and slurry application

In the spring, inorganic fertiliser N was applied to the grazing area of both Systems at a rate of 57 kg ha^{-1} in early March. No further chemical fertiliser N was applied to the grazing area of the EXT system while, depending on grass supply, the INT system received an additional application after the first grazing cycle at the rate of 57 kg N ha^{-1} and one further application of 34 kg N ha^{-1} between then and 20 August. On the silage harvesting area the mean fertiliser application rate was 110 and 80 kg N ha^{-1} for first and second harvests, respectively. Following the final harvest of herbage for silage, 57 and up to 20 kg N ha^{-1} was applied on the INT and EXT systems, respectively. Mean total annual chemical fertiliser N application rates were 211 (s.d. 12.1) and 97 (s.d. 5.5) kg ha^{-1} for the INT and EXT systems, respectively. Urea (46% N) was generally used as the nitrogen source except in dry weather conditions when calcium ammonium nitrate (CAN; 27.5% N) was applied. Phosphorus (P) and potash (K) fertiliser application rates were based on soil test analyses (Gately, 1994). Slurry produced during the winter indoor feeding period was returned to the area harvested for silage in early Spring and again after silage harvesting at a rate proportional to the SR for the grassland management systems.

2.5. Grazing

The land area for each System was notionally divided into a cow plus calf and yearling grazing area and animal types did not generally graze outside their designated areas. The swards consisted predominantly of perennial ryegrass (*Lolium perenne*) and were rotationally grazed. Botanical composition was not measured but visually there was very little white clover (*Trifolium repens*) present. Residency time in a paddock was primarily determined by visual assessment of post-grazing herbage height. Potential surpluses and deficits in grass supply were controlled by flexible use of the conservation area and additionally, in the INT system by applications of fertiliser N. When grass supply was in deficit, part of the silage area was grazed and when supply was in surplus, paddocks within the grazing area were harvested and (or) in the INT system, fertiliser N applications were curtailed. In some years, grass supplies exceeded demand in July for the EXT System and paddocks within the grazing area were harvested and conserved as big-bale silage. Additionally, the cows and calves were occasionally used to graze surplus herbage of an advanced maturity from paddocks grazed by the yearlings.

2.6. Conservation

The planned grass conservation programmes for both systems producing heifers and either steers or young bulls are shown in Table 2. In the INT System two silage harvests were taken annually, the first on 24 May (s.d. 3.4 days) and the second on 4 August (s.d. 7.2 days). In the EXT system, only one staggered silage harvest was planned with half of the area cut at the same time as the INT system (24 May) with the remainder deferred and conserved (14 days was planned) 17 days later (10 June s.d. 2.8 days). Grass was precision-chop harvested, usually with minimal wilting and with the addition of an acid-based additive when required and, ensiled in unroofed, horizontal clamps which were rolled thoroughly, before sheeting with 2 layers of polythene and covering with tyres. The objective was to produce high nutritive value first-harvest grass silage for the progeny and moderate nutritive value silage for the cows in the deferred (EXT) and second harvest (INT). The cutting date of the second and deferred harvest was delayed to produce a higher yield, of lower digestibility silage (at a lower cost unit^{-1} DM) as this is adequate for spring-calving beef suckler cows with relatively modest energy requirements for production because they were not lactating for most of the indoor winter period (Drennan and McGee, 2004). Following the final harvest of herbage for silage, the subsequent regrowth was grazed in their respective systems. In each instance the grass harvested from the two replicates per System was conserved together.

2.7. Animal management

The date on which grazing commenced in spring was dictated by a combination of grass supply, ground conditions and calving date, as all cows had calved prior to turnout. The mean date on which grazing commenced for the cows and calves was 21 April (s.d. 16.1 days). Cows and calves grazed together during the grazing season with the exception of Year 2 (1998) when, from mid-July, 0.5 of the calves in each system were permitted to creep graze in the paddock due to be grazed next in a leader-follower system (O'Neill et al., 1999). Male calves were castrated in August (steer production). All calves were abruptly weaned and accommodated in a slatted floor house in October/November at an average of 218 (s.d. 28.4) days of age. No concentrates were offered pre-weaning. Post-weaning, the cows remained at pasture up to mid-November in most years. There were two notable exceptions, Years 5 and 6 (2001 and 2002) when all animals were housed by mid-to-late October due to inclement weather and ensuing poor ground conditions.

During the first winter indoor period, the weanling heifers and steers were offered grass silage *ad libitum* (proportionately 0.1 in excess of the previous days allowance) and 1.0 kg of concentrate daily with the exception of Years 2 and 3 (1998 and 1999) when 0.5 of the calves received 0.5 kg and the remainder received 2.0 kg of concentrate per head daily as described by Kyne et al. (2001) and O'Neill et al. (2001). At the end of the winter period they were turned out to pasture for a second grazing season. To facilitate early turnout by the yearling animals in some years, the designated silage area was grazed prior to closing for silage as outlined by Kyne et al. (2001) and O'Neill et al. (2001). The mean date on which grazing commenced for the yearling animals was 6 April (s.d. 7.0 days).

In Year 1, heifers on the EXT system were finished at pasture, whereas those on the INT system were finished indoors on grass silage and both received the same level of concentrate supplementation as described by Drennan et al. (1997). In subsequent years, all heifers were finished indoors with concentrate supplementation usually commencing at pasture prior to housing. Average commencement of housing for heifers was 3 October (s.d. 28.8 days). They were accommodated in either a slatted floor house or on wood chip out-wintering pads and received grass silage *ad libitum* plus concentrate increasing gradually to approximately 3 kg per head daily over a final 54 (s.d. 30.9) day finishing period. Mean slaughter age was 607 (s.d. 26.8) days. Mean housing date for steers was 27 October (s.d. 12.0 days). They were accommodated in a slatted floor house and received grass silage *ad libitum* plus concentrate increasing gradually to approximately 4 kg per head daily over a 129 (s.d. 10.5) day finishing period. They were slaughtered at 717 (s.d. 20.4) days of age. For bull production, weanling bulls were accommodated in a slatted floor house at the end of the first grazing season, and received grass silage *ad libitum* plus concentrates increasing gradually to approximately 5 kg per head daily over a 238 (s.d. 17.1) day finishing period. Mean slaughter age was 453 (s.d. 25.3) days. Slaughter dates were always the same for the two Systems.

The concentrates offered were primarily barley-based and were fed separately to the silage for the weanling, steer and heifer progeny, and fed separately or as a total mixed ration (2:1 silage to concentrate ratio) to the bull progeny. Total concentrate input per animal was the same for the two Systems with mean values (including weanling stage) of 442 (s.d. 110.1),

Table 2
Total grassland areas and grass conservation areas cow^{-1} unit for the intensive and extensive grassland management systems

	Grassland management system			
	Intensive		Extensive	
	Ha	% of total area	Ha	% of total area
Grassland use cow^{-1} unit (ha)				
Producing steers at 24 months and heifers at 20 months of age				
Total grazing + silage area	0.71		0.88	
First harvest silage: Early	0.41 [a]	58	0.27 [a]	31
: Late	–	–	0.27 [b]	31
Second harvest silage	0.27 [c]	38	–	–
Overall % harvested		96		62
Producing bulls at 15 months and heifers at 20 months of age				
Total grazing + silage area	0.56		0.69	
First harvest silage: Early	0.34 [a]	61	0.24 [a]	35
: Late	–	–	0.22 [b]	32
Second harvest silage	0.20 [c]	36	–	–
Overall % harvested		97		67

[a] November to late May (remainder grazed early April to November).
[b] November to mid-June (remainder grazed early April to November).
[c] Late May to mid-August (remainder grazed). All land grazed after second harvest silage.

715 (s.d. 46.0) and 1091 (s.d. 178.0) kg for the heifers, steers and bulls, respectively.

Cows were accommodated in a slatted floor house and offered grass silage *ad libitum* plus 60 g cow^{-1} day^{-1} of a mineral/vitamin supplement (Ca, 45 g kg^{-1}; Na, 200 g kg^{-1}; Mg, 165 g kg^{-1}; Cu, 4250 mg kg^{-1}; Co, 90 mg kg^{-1}; I, 300 mg kg^{-1}; Mn, 6670 mg kg^{-1}; Zn, 5200 mg kg^{-1}; Vit. A, 600,000 iu kg^{-1}; Vit. D3, 100,000 iu kg^{-1} and Vit. E, 5000 iu kg^{-1}) applied on top of the forage for the duration of the winter, except at first calving when additionally, 1.5 kg of a barley-based concentrate was offered post-partum until grazing commenced.

2.8. Animal health

Cows were vaccinated 4 to 12 weeks before parturition using an *E. coli,* Rotavirus and coronavirus vaccine. Both cows and breeding heifers were vaccinated prior to commencing the breeding season against Leptospirosis. The calves were treated 2 or 3 times during the grazing season and always at housing for the control of lung and gastrointestinal worms. In spring each year, the grazing area was dusted with calcined magnesite (32 kg ha^{-1}) to prevent hypomagnesaemia in the cows. In autumn, hypomagnesaemia control measures involved free access to a 50:50 calcined magnesite/molasses mixture. Animals were treated for ecto-parasites during the indoor winter period as deemed necessary.

2.9. Measurements

During Years 1, 2 and 3 (1997, 1998 and 1999) pre- and post-grazing sward height was recorded on each grazing paddock within the cow grazing area and additionally in Year 1 in the yearling grazing area using a rising-plate meter. At least circa 30 estimates were taken in a "W" fashion per paddock. Furthermore, in Years 1 (1997) and 3 (1999) pre- and post-grazing herbage yield (above the 4 cm horizon) was determined on a minimum of four strips of grass (0.53 or 0.56 m wide, 5.0 or 4.5 m long) per paddock cut with a lawnmower or an Agria mower when pre-grazing yields were high. The grass from each strip was weighed and sampled. The herbage from the four samples was composited and a sub-sample (ca 100 g) was obtained for dry matter (DM) determination (24 h at 98 °C) and a further sub-sample (ca 200 g) was obtained for chemical analysis. Following drying at 40 °C for 48 h these samples were milled and analysed for dry matter digestibility (DMD) (Tilley and Terry, 1963) and crude protein (CP) (Kjeldhal nitrogen × 6.25). Apparent herbage intake was estimated for the cows and calves in Year 1 as the difference between pre- and post-grazing herbage masses plus estimated grass growth (measured in a separate experiment at the centre) during the residency time divided by the number of animals in the paddock and the number of days grazing the paddock. Each year the *in vitro* DMD was determined on representative samples of the grass silages.

Cow and calf live weight was recorded within 24 h of parturition, at turnout to pasture, intermittently during the grazing season, at weaning and at housing. Post-weaning, the progeny were weighed at regular intervals during the winter period, at turnout, during the grazing season, at housing and on two consecutive days just prior to slaughter. Cow body condition score (BCS) (scale 0–5) was assessed to the nearest 0.25 units (Lowman et al., 1976) at the same time as weighing.

At the end of the finishing period, animals were slaughtered in a commercial meat plant. After slaughter, hot carcass weight and weight of perinephric plus retroperitoneal fat were recorded. Carcasses were classified for conformation and fatness according to the European Union Beef Carcass Classification Scheme (Commission of the European Communities, 1982). Killing-out rates were calculated as the proportion of cold carcass weight (0.98 × hot carcass weight) to pre-slaughter live weight.

2.10. Statistical analysis

Animal production data was subjected to an analysis of variance using the PROC GLM procedure of SAS (2003). Data pertaining to the cows (8 years) were analysed with a model that included terms for production system, dam breed, parity (1 or more) and year. Calf pre-weaning data (8 years) were analysed with additional terms for gender and sire. Data for the progeny post-weaning (heifer, 6 years; steer, 2 years; bull, 6 years) were analysed with a model that included terms for production system, dam breed, parity, sire and year. Calving day was included as a covariate in all models. Data relating to herbage was analysed for each year separately. Least-square means are reported with standard errors.

3. Results

3.1. Weather

Total rainfall figures recorded at the centre for the years 1997 to 2004 inclusive were 837, 981, 938, 933, 667, 1066, 743 and 864 mm, respectively. Corresponding annual duration of sunshine hours were 1223, 1129, 1224, 1271, 1010, 1125, 1280 and 1309 and mean daily air temperatures were 10.2, 9.9, 10.0, 9.5, 9.8, 10.6, 9.9 and 10.2 °C. This compares with the 30-year (1971–2001) average for rainfall, sunshine and temperature of 849 mm, 1230 h and 9.1 °C, respectively.

3.2. Grass production and utilisation

Annual herbage yields (separate plot experiment) were 14.0, 9.8, 8.8, 11.9, 14.2, 13.6, 11.3 and 12.5 t DM ha^{-1} for the years 1997 to 2004, respectively. Mean annual herbage production for the period 1993 to 2004 was 11.9 (s.d. 1.69) t DM ha^{-1}.

Mean sward surface heights pre- and post-grazing for the area grazed by the cows and calves in Years 1 and 3

Table 3
Herbage availability, in vitro digestibility and crude protein concentrations for the Intensive (INT) and Extensive (EXT) grassland management systems in Years 1 and 3

	Cow plus calf								Yearling			
Year	1				3				1			
Grassland management system	INT	EXT	S.E.M.[a]	Sig.	INT	EXT	S.E.M.[a]	Sig.	INT	EXT	S.E.M.[a]	Sig.
Sward surface height (cm)												
Pre-grazing	12.1	12.6	0.48		11.6	10.9	0.24	*	11.7	12.3	0.47	
Post-grazing	5.7	6.3	0.17	*	6.3	6.2	0.11		6.5	6.5	0.19	
Herbage mass (kg DM ha^{-1})												
Pre-grazing	2022	2369	163.0		2325	2541	140.0		1809	1993	143	
Post-grazing	424	555	33.0	*	1005	1003	72.7		569	602	40.0	
In vitro DMD (g/kg)												
Pre-grazing	750	764	10.4		761	747	5.7		774	754	11.1	
Post-grazing	674	655	14.0		640	641	7.3		709	692	23.0	
Crude protein (g/kg DM)												
Pre-grazing	212	193	8.2		205	159	4.5	***	213	193	8.5	
Post-grazing	180	152	7.0	**	172	141	4.1	***	169	161	10.0	

[a]Standard error of means.
*$P<0.05$, **$P<0.01$, ***$P<0.001$.

and yearlings in Year 1 are presented in Table 3. For the cow and calf grazing area, there was no difference ($P>0.05$) in pre-grazing sward height between the Systems in Year 1 but post-grazing sward height was lower ($P<0.05$) for the INT than the EXT system. In Year 2 (data not presented), there was no difference ($P>0.05$) between the Systems in pre- and post-grazing sward height with mean values of 11.4 and 5.6 cm, and 11.4 and 5.8 cm for the INT and EXT systems, respectively. In Year 3, pre-grazing sward heights were lower ($P<0.05$) for the EXT than the INT system but there was no difference ($P>0.05$) between the systems in post-grazing heights. Differences in sward grazing mass ha^{-1} reflected differences in sward height in Year 1 but there was no difference ($P>0.05$) between the Systems in pre- and post-grazing mass in Year 3. Herbage DMD both pre- and post-grazing was similar ($P>0.05$) for the two systems. Herbage CP concentrations were lower ($P<0.01$) post-grazing in Year 1 and lower ($P<0.001$) both pre- and post-grazing in Year 3 for the EXT than the INT system. Apparent herbage daily intake of the cow plus calf did not differ (15.3 v. 16.1 kg DM day^{-1}) ($P>0.05$) between the Systems in Year 1. For the area grazed by the yearlings, there was no difference ($P>0.05$) between the Systems in sward pre- and post-grazing heights, grazing mass and DMD and CP concentrations.

The mean DMD of the first, deferred and second harvest silages were 716 (s.d. 39.2), 689 (s.d. 37.1) and 674 (s.d. 41.6) g kg^{-1}, respectively.

3.3. Animal performance

There was no difference ($P>0.05$) between the Systems in cow live weight, BCS or their changes (Table 4).

Table 4
Cow live weight, body condition score and their changes for the Intensive and Extensive grassland management systems

	Grassland Management System			
	Intensive	Extensive	S.E.M.[a]	Sig.
Live weight (kg)				
Housing	588	587	4.6	
Post-partum	561	563	4.4	
Turnout to grass	543	546	4.5	
Live weight change (kg)				
Winter	−44	−42	2.8	
Turnout to summer (June/July)	50	46	1.9	
Grazing season	82	82	2.4	
Annual[b]	37	41	2.7	
Body condition score (units)				
Housing	2.7	2.7	0.05	
Post-partum	2.6	2.7	0.04	
Turnout to grass	2.4	2.4	0.05	
Body condition score change (units)				
Winter	−0.31	−0.32	0.048	
Turnout to summer (June/July)	−0.02	−0.01	0.037	
Grazing season	0.22	0.16	0.045	
Annual[b]	−0.11	−0.16	0.052	

[a] Standard error of means.
[b] From turnout to pasture to following turnout to pasture.

Table 5
Pre-weaning calf live weight and live weight gain for the intensive and extensive grassland management systems

	Grassland management system			
	Intensive	Extensive	S.E.M. [a]	Sig.
Live weight (kg)				
Birth	43	43	0.6	
Turnout to grass	61	61	1.2	
Summer (June/July)	139	135	2.0	*
Weaning	267	264	3.0	
Live weight gain (kg)				
Birth to summer (June/July)	96	92	1.8	**
Turnout to summer (June/July)	76	73	1.8	*
Grazing season	205	202	3.0	
Birth to weaning	224	221	2.9	
Average daily gain (g)				
Turnout to summer (June/July)	1022	982	29.2	$P=0.06$
Grazing season	1062	1047	15.2	
Birth to weaning	1027	1009	13.4	$P=0.08$

[a] Standard error of means.

Calf live weight in summer was higher ($P<0.05$) for the INT than the EXT system but there was no difference ($P>0.05$) in live weight at weaning. Consequently, live weight gain of calves from birth to summer ($P<0.01$) and turnout to summer ($P<0.05$) was higher for calves in the INT than the EXT system but live weight gain during the grazing season and from birth to weaning did not differ ($P>0.05$) (Table 5).

Grassland management system had no effect ($P>0.05$) on post-weaning live weights, live weight gains, slaughter weight, carcass weight, kill-out proportion, estimated carcass gain, carcass conformation score, carcass fat score or relative weight of perinephric + retroperitoneal fat of heifer, steer or bull progeny (Table 6).

4. Discussion

There is a general need to incorporate findings from component research into beef suckler cow production systems research (Wright et al., 1996; Adams et al., 2000; Anderson et al., 2005). It is now accepted that in

Table 6
Growth, slaughter and carcass traits of heifer, steer and bull progeny for the intensive and extensive grassland management systems

Animal type	Heifers [b]		S.E.M. [a]	Sig.	Steers [c]		S.E.M. [a]	Sig.	Bulls [b]		S.E.M. [a]	Sig.
Grassland management system	Intensive	Extensive			Intensive	Extensive			Intensive	Extensive		
Live weight (kg)												
Birth	42	43	0.6		48	46	2.0		46	47	0.1	
Weaning	254	253	2.7		318	320	11.9		285	287	5.4	
Turnout to grass	314	314	3.4		385	384	15.1		–	–	–	
Housing	472	469	3.8		549	545	17.6		–	–	–	
Slaughter	518	513	4.1		657	658	22.4		571	582	8.6	
Live weight gain (kg)												
Birth to weaning	212	210	2.5		272	275	11.6		239	240	5.2	
Winter 1	60	61	2.3		67	63	10.5		287	294	8.1	
Grazing season 2	159	157	2.7		164	161	12.5		–	–	–	
Winter 2	46	44	1.6		109	114	12.1		–	–	–	
Birth to slaughter	476	470	3.9		614	612	21.5		525	535	8.5	
Average daily gain (g)												
Winter 1	386	391	14.8		441	401	73.3		1208	1238	35.4	
Grazing season 2	894	885	15.3		808	796	60.6		–	–	–	
Winter 2	886	838	38.1		864	901	95.2		–	–	–	
Birth to slaughter	783	773	6.4		856	853	29.8		1158	1179	19.0	
Carcass weight (kg)	282	281	2.5		368	370	12.7		333	335	5.2	
Carcass gain per day of age (g)	465	465	4.1		514	517	17.8		734	739	11.4	
Kill-out proportion (g/kg)	548	550	1.9		560	563	5.2		575	575	3.4	
Carcass conformation [d]	3.24	3.21	0.047		2.97	3.22	0.20		3.34	3.38	0.085	
Carcass fat score [e]	3.14	3.06	0.057		4.03	4.01	0.28		2.77	2.76	0.092	
Perinephric + retroperitoneal fat (kg)												
(g/kg carcass)	20.9	19.3	0.68		–	–	–		20.2	20.4	0.98	

[a] Standard error of means; [b]=6 years data; [c]=2 years data; [d,e] EU Beef Carcass Classification Scheme Scale:[d] 1 (poorest) to 5 (best); [e]1 (leanest) to 5 (fattest).

systems experiments it is often difficult to replicate treatment groups (Adams et al., 2000; Milne, 2006). Replication in studies involving complete Systems would generally require substantially higher resources. Using grazing experiments in Ireland, Conniffe (1976) found that between-animal-within-herd variation accounted for most of the variation between herds within grazing treatments. Consequently, using the individual animal as the experimental unit should not affect the conclusions drawn. Furthermore, considering the randomization of the experimental area initially and of the cows to the Systems annually and, the fact that this study was carried out over eight years, this increases the likelihood that the results obtained reflect the effects of the management Systems under investigation.

4.1. Grass, grass silage and estimated annual feed budget

The pasture heights and masses both pre- and post-grazing were indicative of the stocking rate and fertilizer nitrogen levels used in the systems. Reflecting the similar pre- and post-grazing sward height, herbage mass and DMD, the apparent herbage intake of the cow plus calf did not differ between Systems in Year 1. Studies with beef cows continuously grazing swards to either 4 to 5 or 7 to 8 cm (Wright et al., 1994) and 3.3 to 7.7 or 5.9 to 13.0 cm (Baumont et al., 2006) reported mean organic matter intakes per cow of 8.8 and 14.2, and 13.0 and 13.5 kg day^{-1}, respectively. In the study of Murphy et al. (in press) mean zero-grazed grass intakes for lactating LF and SLF cow genotypes were 11.0 and 11.6 kg DM day^{-1}. The estimates of 15.3 and 16.1 kg DM day^{-1} in the present study include consumption by the calf.

In terms of herbage chemical composition and nutritional value, the primary difference between the two Systems was herbage CP concentration reflecting the difference in fertiliser N application. This is in agreement with other systems-based studies where concurrent reductions in both fertiliser N and SR occurred (Keane and Allen, 1999; Audic et al., 2002).

Previous research has shown that compared to a grassland management system based on two harvests of grass silage, a system based on one single, deferred harvest of grass silage adversely affects the live weight gain of the progeny during the indoor winter period due to a lower nutritive value of the forage (Drennan and McGee, 2008). Consequently, the rationale behind the planned staggered, single-harvest silage in the EXT system was for the early-harvest to provide high nutritive value grass silage for the progeny and the deferred harvest to provide adequate nutritive value for the cow of similar digestibility to the second harvest in the INT system. Herbage digestibility for primary growths typically declines with advancing maturity or delayed harvest date by 3.9 to 5.7 g day^{-1} (Keady and O'Kiely, 1998; Keady et al., 2000; Kyne et al., 2001). However, the difference in DMD values between the early and deferred first harvests (716 g kg^{-1} vs. 689 g kg^{-1}) did not reflect the 17 d difference in mean harvest date. This can be partially attributed to the fact that varying proportions of silage areas were grazed in spring prior to closing for silage thus, enhancing the digestibility of the herbage harvested (O'Neill et al., 2001; Kyne et al., 2001). Nevertheless, this strategy was largely achieved as indicated by the relatively similar DMD of deferred (689 g kg^{-1}) and second (674 g kg^{-1}) harvest silages.

Using estimates of grass and/or grass silage DM intake under comparable conditions for cow (Drennan and McGee, 2004; McGee et al., 2005a; Murphy et al., in press), weanling (O'Neill et al., 2000; Kyne et al., 2001), steer (McGee et al., 2006; Clarke et al., 2008), heifer (Drennan et al., 1997) and bull (Drennan et al., 1994) animal categories, mean composition of the annual feed budget for both systems comprised approximately 0.61 for grazed grass, 0.31 for grass silage and 0.08 for supplementary concentrates. This compares with corresponding values of 0.66, 0.26 and 0.08 for spring-calving, grass-based dairy cow systems but on drier soils in Ireland (Dillon and Stakelum, 1999).

4.2. Cow live weight and body condition score

Similar to the present findings, Audic et al. (2002) found that decreasing SR by about 0.23 and N fertilisation rate by about 0.63 did not adversely affect the live weight gain of beef suckler cows on rotationally grazed systems. When proportional reductions in both SR and fertiliser N do not occur concurrently, cow live weight and body condition score gain can be adversely affected (Drennan and McGee, 2008).

For economic reasons beef suckler cow nutrition involves mobilisation of cow body reserves in winter and deposition during the subsequent grazing season when consuming the cheaper herbage (Petit et al., 1995) the extent, depending on grass supply. Cow live weight gain during the grazing season was substantially greater than the loss during the indoor period reflecting the predominance of young cows who are still growing (Drennan and McGee, 2004) in comparison to the cyclical annual live weight changes in a more mature cow herd (McGee et al., 2005a). For the same reasons annual BCS gain was reduced. Drennan and Berry

(2006) reported that the annual BCS change of spring-calving, first parity cows was substantially lower than for older parity groups (−0.78 v. +0.09 to −0.1).

4.3. Progeny performance

Calves on the INT system were significantly heavier by 4 kg in summer compared to calves on the EXT system. This small difference may be due to the greater land area taken up for the single silage harvesting and thus, a higher SR during the first part of the grazing season resulting in a decline in cow milk yield and consequently calf growth (Drennan and McGee, 2008). However, calf live weight gain during the first grazing season and pre-weaning did not differ between the two Systems. Audic et al. (2002) also found that decreasing SR by about 0.23 and nitrogen fertilisation rate by about 0.63 did not adversely affect the live weight gain of suckling calves on rotationally grazed systems. In accord with cow performance, where concurrent reductions in both SR and fertiliser N do not occur, calf weaning weight can also be adversely affected (Drennan and McGee, 2008). The pre-weaning live weight gain of the calves in the present Systems were in excess of 1.0 kg day^{-1} over the grazing season. These values are somewhat lower than previous reports of spring-calving rotationally grazed, temperate grassland systems (Drennan and McGee, 2004; Audic et al., 2002; Drennan and McGee, 2008). This can be attributed to differences in cow genotype and age between studies as the actual magnitude of calf weight gain is largely influenced by the milk yield of the dam (McGee et al., 2005b).

Due to the inverse relationship between live weight gain of weanling cattle on grass silage-based diets in winter and subsequent gain at pasture (McGee, 2005), the feeding strategy for the weanlings during the first winter was designed to avail of this compensatory growth. Supplementing high nutritive value grass silage with concentrates to achieve live weight gains in excess of 0.55 kg day^{-1} in 8/9 month old continental cross animals over the indoor winter period, while increasing winter gain, did not result in higher slaughter or carcass weight in due to subsequent compensatory growth over a long grazing season with adequate supplies of herbage (Kyne et al., 2001).

The comparable post-weaning growth, slaughter and carcass traits of the steer and heifer progeny on the INT and EXT systems reflected the similar DMD of the grazed herbage (and also the grass silage and concentrates, which were common). This is in accord with Keane and Allen (1999) comparing dairy calf-to-beef systems with varied SR and fertiliser N application rates. Similarly, Dieguez Cameroni et al. (2006) concluded that a grazing system for beef cattle with zero fertiliser N application resulted in similar individual animal performance as more intensive systems with higher fertiliser N and SR, when the SR was adjusted accordingly.

Animal live weight gain during the second grazing season was within the range reported for steers on temperate, lowland dairy calf-to-beef systems (Keane and Allen, 1998; McGee et al., 2005c). The daily live weight gain during the indoor finishing period was similar to previous findings for bull (Drennan and McGee, 2004) and steer (Drennan et al., 2005) progeny on similar production systems, but the performance of the heifer progeny was lower than the results (1187 g day^{-1}) obtained by Drennan et al. (1997). However, in terms of animal growth, caution is required in interpreting comparisons with other studies, particularly for individual components of production systems, because, independent of animal genetic merit and nutrient supply availability, there are interactions among previous nutrition and management (both indoors and grazing) and subsequent animal performance, mainly concerning compensatory growth potential (e.g. Drennan and Harte, 1979). Additionally, estimating carcass weight gain rather than live weight gain in experiments of this type is important (Keating and O'Kiely, 2000). In the present study, carcass weight per day of age was in good agreement with the findings of Drennan and McGee (2004) for heifers (481 g day^{-1}) and bulls (742 g day^{-1}) and with Drennan et al. (2005) for steers (507 g day^{-1}) produced on similar grass-based systems. Assuming equal numbers of male and female progeny produced cow^{-1} unit, for heifer plus steer production the progeny carcass output ha^{-1} was 458 and 370 kg for the INT and EXT systems, respectively. Corresponding values for heifer plus bull production were 549 and 446 kg. This compares with values of 756 and 538 kg ha^{-1} for conventional and extensive, respectively, dairy calf-to-beef systems (Keane and Allen, 1998). The output differences between suckler and dairy calf-to-beef systems largely reflect the maintenance cost of the beef suckler cow. The calculations above did not include carcass output from the cow when culled.

4.4. Nitrogen balance ha^{-1}

Surplus N within grassland-based production systems is susceptible to loss to the wider environment. In accord with previous studies (Lawes et al., 2000; Drennan and McGee, 2008) only small proportions of the N inputs were converted to animal product i.e. live weight gain. The purchased N inputs to the two Systems were limited to chemical fertiliser and concentrate supplement. Assuming a CP concentration in the purchased concentrate of 140 g kg^{-1}, this equated to an intake of 13 and 17 kg N per finished animal for steer and bull production, respectively. Combining the chemical fertiliser N applied, the total purchased N input was 228 and 117, and 245 and 119 kg ha^{-1} for INT and EXT systems of steer and bull production, respectively. Ignoring N sequestered in the soil and assuming a N content of live weight gain of 28 g kg^{-1} (Lawes et al., 2000) the corresponding N removal by the cow and progeny was 25 and 20, and 29 and 24 kg ha^{-1} equating to a N surplus of 204 and 97, and 216 and 95 kg ha^{-1} for the INT and EXT systems of steer and bull production, respectively. So in accord with previous findings, reducing fertiliser N use reduces the N surplus in beef systems (Lawes et al., 2000). Data collected for the present Systems showed that compared to the INT system the reduced SR and fertiliser N input of the EXT system significantly reduced nitrate levels in soil water (Richards et al., 2007). The N-use efficiency for the INT and EXT systems of steer and bull production were 0.11 and 0.17, and 0.12 and 0.20, respectively. Similarly, Dieguez Cameroni et al. (2006) reported an apparent N efficiency of 0.13, 0.15 and 0.26 during the grazing period for growing fattening bulls on high N-high SR, moderate N-high SR and zero N-low SR systems, respectively. Lowering the levels of N fertilisation used with a concurrent appropriate reduction in SR reduces N losses of ruminants with little or no change in their nutrition or in individual performance (Peyraud and Astigarraga, 1998).

4.5. Additional considerations

De-intensification of grassland management may increase grassland biodiversity (Isseltein et al., 2005). Furthermore, in terms of N input, the EXT System was compatible with the Nitrates Directive of the EU (Directive 91/676/EEC) which limited organic N to 170 kg ha^{-1}. Additionally, this System was compatible with the REPS operated in Ireland to date where the maximum permissible level of organic N was 170 kg ha^{-1} and total (organic plus inorganic) N was 260 kg ha^{-1}. At the stipulated annual organic N loads of 65, 24 and 57 kg for a beef suckler cow, animals 0–1 and 1–2 years old, respectively, the total organic N on the INT and EXT systems of steer and bull production was 192 and 155, and 205 and 166 kg ha^{-1} in that order. Addition of inorganic fertiliser N applied gave a corresponding total N input of 402 and 257, and 419 and 260 kg ha^{-1}. Under the new REPS scheme now operated in Ireland (Council Regulation (EC) No. 1698/2005–11th August 2007), the INT system also qualifies, provided participants farming above 170 kg organic N ha^{-1} have a valid Nitrates derogation.

5. Conclusion

It can be concluded that similar animal performance levels can be expected in an extensive grassland-based suckler calf-to-beef system compatible with the EU, Rural Environmental Protection Scheme as that attained in a more intensive System comprising of both a moderately high SR (~1.25 higher) and fertiliser N application (2.14 higher). Under the conditions of this study, fertiliser N application can be substituted with additional land without compromising individual animal performance.

Acknowledgements

The authors wish to acknowledge Mr. B. Davis for skilled technical assistance, the contributions of postgraduate research students Mr. S. Kyne (M.Agr.Sc.), Mr. B. O'Neill (M.Agr.Sc.) and Ms. B. Murphy (Ph.D.) and the farm staff at Grange Beef Research Centre for care and management of the animals in particular, Mr. P. Doyle (Deceased), Mr. P. McCann, Mr. P. Reilly, Mr. E. Mulligan and Mr. P. Kane. Also thanks to the staff of Grange Laboratories for grass and silage analyses.

References

Adams, D.C., Nielsen, M.K., Schacht, W.H., Clarke, R.T., 2000. Designing and conducting experiments for range beef cows. Proc. Amer. Soc. Anim. Sci. 1999.

Anderson, R.V., Rasby, R.J., Klopfenstein, T.J., Clarke, R.T., 2005. An evaluation of production and economic efficiency of two beef systems from calving to slaughter. J. Anim. Sci. 83, 694–704.

Audic, C., Hardy, A., Pelletier, P., 2002. Extensification of grazed pastures in French suckling cow systems. Grassl. Sci. Europe 7, 1008–1009.

Baumont, R., Traclet, M., Le Morvan, A., Egal, D., Jouven, M., D'Hour, P., 2006. Diet quality and intake during the grazing season in beef cows on permanent pasture. Grassl. Sci. Europe 11, 496–498.

Clarke, A.M., Black, A.D., Drennan, M.J., McGee, M., Berry, D.P., Kenny, D.A., 2008. Estimation of pasture and grass silage intake by three genotypes of beef cattle. Proc. Agric. Res. Forum 2008, Tullamore, Teagasc, 12th and 13th March, p. 90.

Commission of the European Communities, 1982. Commission of the European Communities (Beef Carcass Classification) Regulations. Council Regulations 1358/80, 1208/81, 1202/82. Commission Regulations 2930/81, 563/82, 1557/82. Commission of the European Communities, Brussels.

Conniffe, D., 1976. A comparison of between and within herd variance in grazing experiments. Ir. J. Agric. Res. 15, 39–46.

Crosson, P., O, 'Kiely, P., O, 'Mara, F.P., Wallace, M., 2006. The development of a mathematical model to investigate Irish beef production systems. Agric. Sys. 89, 349–370.

Dieguez Cameroni, F., Hornick, J., Cabaraux, J., Istasse, L., Dufrasne, I., 2006. Less intensified grazing management with growing fattening bulls. Anim. Res. 55, 105–120.

Dillon, P., Stakelum, G., 1999. Spring milk production. In: Murphy, J. (Ed.), A new agenda for dairying, pp. 3–7.

Dillon, P., Berry, D.P., Evans, R.D., Buckley, F., Horan, B., 2006. Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. Livest. Sci. 99, 141–158.

Drennan, M., 1993. Planned suckler beef production. Teagasc. Beef Series No. 4, p. 72.

Drennan, M.J., Harte, F.J., 1979. Compensatory growth in cattle. 2. Influence of growth rate in the calf stage (birth to 8 months) and during the first winter (8 to 13 months) on subsequent performance and carcass composition. Ir. J. Agric. Food Res. 18, 145–156.

Drennan, M.J., McGee, M., 2004. Effect of suckler cow genotype and nutrition level during the winter on voluntary intake and performance and on the growth and slaughter characteristics of their progeny. Ir. J. Agric. Food Res. 43, 185–199.

Drennan, M.J., Berry, D.P., 2006. Factors affecting body condition score, live weight and reproductive performance in spring-calving suckler cows. Ir. J. Agric. Food Res. 45, 25–38.

Drennan, M.J., McGee, M., 2008. Performance of spring-calving beef suckler cows and their progeny on four grassland management systems. Livest. Sci. doi:10.1016/j.livsci.2007.12.018 (2008).

Drennan, M.J., Moloney, A.P., O'Riordan, E.G., McGee, M., 1997. Effects of supplementary concentrates on performance of finishing heifers at pasture in autumn. Ir. J. Agric. Food Res. 36, 123.

Drennan, M.J., Moloney, A.P., Keane, M.G., 1994. Effects of protein and energy supplements on performance of young bulls offered grass silage. Ir. J. Agric. Food Res. 33, 1–10.

Drennan, M.J., McGee, M., Keane, M.G., 2005. Post-weaning performance and carcass characteristics of steer progeny from different suckler cow breed types. Ir. J. Agric. Food Res. 44, 195–204.

Drouillard, J.S., Kuhl, G.L., 1999. Effects of previous grazing nutrition and management on feedlot performance of cattle. J. Anim. Sci. 77 (Suppl. 2), 136–146.

Fitzgerald, D.A., Fitzgerald, D.L., 2004. Meteorological measurements. In: Keane, T., Collins, J.F. (Eds.), Climate, Weather and Irish Agriculture. Met Eireann, Dublin, Ireland, pp. 9–26.

Gardiner, M.J., 1962. Animal production research centre, Grange, Co. Meath (Soil Map), Soil Survey Bulletin No. 2. An Foras Taluntais, Dublin, Ireland.

Gately, T.F., 1994. Soil Analysis and Fertiliser, Lime, Animal Manure and Trace Element Recommendations. Johnstown Castle, Wexford, Ireland: Teagasc. 36 pages.

Isseltein, J., Jeangros, B., Pavlu, V., 2005. Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe — a review. Agron. Res. 3, 139–151.

Keady, T.W.J., O'Kiely, P., 1998. An evaluation of potassium and nitrogen fertilisation of grassland, and date of harvest, on fermentation, effluent production, dry matter recovery and predicted feeding value of silage. Grass Forage Sci. 53, 326–337.

Keady, T.W.J., Mayne, C.S., Fitzpatrick, D.A., 2000. Prediction of silage feeding value from the analysis of the herbage at ensiling and effects of nitrogen fertiliser, date of harvest and additive treatments on grass silage composition. J. Agric. Sci. Camb. 134, 353–368.

Keane, M.G., Allen, P., 1998. Effects of production system intensity on performance, carcass composition and meat quality of beef cattle. Livest. Prod. Sci. 56, 203–214.

Keane, M.G., Allen, P., 1999. Effects of pasture fertiliser N level on herbage composition, animal performance and on carcass and meat quality traits. Livest. Prod. Sci. 61, 233–244.

Keating, T., O'Kiely, P., 2000. Comparison of old permanent grassland, *Lolium perenne* and *Lolium multiflorum* swards grown for silage 4. effects of varying harvesting date. Ir. J. Agric. Food Res. 39, 55–71.

Kyne, S., Drennan, M.J., Caffrey, P.J., 2001. Influence of concentrate level during winter and date of turnout to pasture on the performance of cattle and the effect of grazing of silage ground on grass yield and quality. Ir. J. Agric. Food Res. 40, 23–32.

Lawes, J.A., Pain, B.F., Jarvis, S.C., Scholefield, D., 2000. Comparison of grassland management systems for beef cattle using self-contained farmlets: effects of contrasting nitrogen inputs and management strategies on nitrogen budgets, and herbage and animal production. Agric. Ecosystems. Envir. 80, 243–254.

Lewis, J.M., Klopfenstein, T.J., Stock, R.A., Nielsen, M.K., 1990. Evaluation of intensive vs extensive systems of beef production and the effect of level of beef cow milk production on postweaning performance. J. Anim. Sci. 68, 2517–2524.

Lowman, B.G., Scott, N.A., Somerville, S.H., 1976. Condition scoring of cattle. Bulletin, no. 6, (Revised edition). East of Scotland College of Agriculture, p. 31.

McGee, M., 2005. Recent developments in feeding beef cattle on grass silage-based diets. In: Park, R.S., Stronge, M.D. (Eds.), Silage production and utilisation, Proceedings of the XIVth International Silage Conference (a satellite workshop of the XXth International Grassland Congress), July 2005, Belfast, Northern Ireland. Wageningen Academic Publishers, The Netherlands, pp. 51–64.

McGee, M., Drennan, M.J., Caffrey, P.J., 2005a. Effect of suckler cow genotype on energy requirements and performance in winter and subsequently at pasture. Ir. J. Agric. Food Res. 44, 157–171.

McGee, M., Drennan, M.J., Caffrey, P.J., 2005b. Effect of suckler cow genotype on milk yield and pre-weaning calf performance. Ir. J. Agric. Food Res. 44, 185–194.

McGee, M., Keane, M.G., Neilan, R., Moloney, A.P., Caffrey, P.J., 2005c. Production and carcass traits of high dairy genetic merit Holstein, standard dairy genetic merit Friesian and Charolais × Holstein–Friesian male cattle. Ir. J. Agric. Food Res. 44, 215–231.

McGee, M., O'Kiely, P., O'Riordan, E.G., 2006. Intake, growth, carcass traits and plasma metabolites in finishing steers offered contrasting concentrate energy sources at two feeding levels. Proc. Agric. Res. Forum 2006, Tullamore, Teagasc, 15th and 16th March, p. 101.

Milne, J.A., 2006. Editorial. Grass Forage Sci. 61, 1.

Murphy, B.M., Drennan, M.J., O'Mara, F.P., McGee, M., in press. Performance and feed intake of five beef suckler cow genotypes and pre-weaning growth of their progeny. Ir. J. Agric. Food Res.

O'Kiely, P., Moloney, A.P., Killen, L., Shannon, A., 1997. A computer program to calculate the cost of providing ruminants with home-produced feedstuffs. Computers and Electronics in Agric. 19, 23–36.

O'Neill, B.J., Drennan, M.J., Caffrey, P.J., Thareau, A., 1999. Creep grazing for suckled calves. Ir. J. Agric. Food Res. 38, 269.

O'Neill, B., Drennan, M.J., Caffrey, P.J., 2000. Influence of winter feeding level and duration of the subsequent grazing season on animal performance. Proc. Agric. Res. Forum, Tullamore, Teagasc, 14 & 15 March 2000, pp. 77–78.

O'Neill, B.J., Drennan, M.J., Caffrey, P.J., 2001. Effects of extending the grazing season in beef production systems. Proc. Brit. Soc. Anim. Sci. 116 York, April.
O'Riordan, E.G., 1997. Effect of annual application rate and grass growth interval on annual herbage production. Proc. Agric. Res. Forum, Belfield, Dublin, 3rd and 4th April, pp. 133–134.
Petit, M., Garel, J.P., D'Hour, P., Agabriel, J., 1995. The use of forages by the beef cow herd. In: Journet, M., Grenet, E., Farce, M.-H., Theriez, M., Demarquilly, C. (Eds.), Recent developments in the Nutrition of Herbivores. Proceedings of the IVth International Symposium on the Nutrition of Herbivores. INRA, Editions, Paris, pp. 473–496.
Peyraud, J.L., Astigarraga, L., 1998. Review of the effect of nitrogen fertilization on the chemical composition, intake, digestion and nutritive value of fresh herbage: consequences on animal nutrition and N balance. Anim. Feed Sci. Tech. 72, 235–259.
Richards, K., Drennan, M., Lenehan, J.J., Connolly, J., Brophy, C., Carton, O.T., 2007. Nitrate leaching from Irish beef farming, a look at the impact of REPS. Proc. Agric. Res. Forum, Tullamore, Ireland, Teagasc 3.
Statistical Analysis Systems Institute, 2003. SAS/STAT. The SAS system for windows, Release 9.3.1. SAS Institute Inc., Cary, NC, USA.
Thenard, V., Dumont, R., Grosse, M., Trommenschlager, J.M., Fiorelli, J.L., Roux, M., 2006. Grass steer production system to improve carcass and meat quality. Livest. Sci. 105, 185–197.
Tilley, J.M.A., Terry, R.A., 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18, 104–111.
Wright, I.A., Jones, J.R., Maxwell, T.J., Russel, A.J.F., Hunter, E.A., 1994. The effect of genotype × environment interactions on biological efficiency in beef cows. Anim. Prod. 58, 197–207.
Wright, I.A., Maxwell, T.J., Russel, A.J.F., Hunter, E.A., Sibbald, A.R., Hetherington, R.A., Whyte, T.K., 1996. The effect of grazed sward height and stocking rate on animal performance and output from beef cow systems. Grass Forage Sci. 51, 199–208.